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Investigation of Radial Distributions of Tangential Strains and of Moisture Contents within a Log Cross Section by Circumferential Slices[*1]

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ABSTRACT

This study was carried out to provide the so-called circumferential slicing method for investigating radial distributions of the tangential strains and of moisture contents within the log cross section (LC) of *Kalopanax pictus* during indoor drying it. While the heartwood showed an almost uniform moisture content distribution in the range of about 50～55% in case of the green wood, it has gradually decreased toward the outer side, showing about 19% of moisture content difference from the innermost slice. Although the moisture gradient along the radial direction has gradually become gentle as drying progresses, the sapwood of the outer side represented the moisture contents below the fiber saturation point after 24 hours of drying while the heartwood in the inner part showed the moisture contents higher than the fiber saturation point. The pith side was laid under the tensile stress after 24 hours of drying, and then gradually decreasing toward the bark side, and showed the distribution being switched again to the tensile stress on the bark side. As the drying has progressed, this trend got more intensified, and finally showed the U-shaped distribution model after 48 hours of drying. The circumferential slice test is considered to be suitable in quantitatively determining the tangential strains and moisture content within a LC.

Keywords : circumferential slicing, tangential strains, moisture contents, log cross section

1. INTRODUCTION

During the drying process of log cross section **(LC)** that significantly depends on the evaporation of vapor from end surfaces the moisture gradient along the thickness is quite gentle in comparison to the lumber with the same thickness. The LC was very frequently defected by check and V-shaped crack during the drying, because the growth stresses, hygrothermal recovery stresses, surface stresses, and differential shrinkage stresses are independently or superimposely involved (Kubler, 1973a, 1973b, 1975, 1977; Lee *et al.*, 1998, 2000; Wilhelmy and Kubler, 1973). The border checkings occur frequently by building up the drying stresses in the transition wood either between heartwood and sapwood or between juvenile

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wood and mature wood (Kang *et al*., 2001), additionally due to the radial variations of the physical properties such as differences in the green moisture contents and the permeability between heartwood and sapwood and differences in shrinkages between juvenile wood around pith and mature wood around outer region coexist within a LC (Shupe *et al*. 1995a, 1995b). Therefore, in order to effectively prevent formation of heart checking, border checking, and V-shaped cracking during drying of the LC, it is not sufficient to partially detect and interpret the moisture contents and tangential stresses closely related to formation of them. It can be considered quite useful in optimizing the drying schedules and deciding the effective pretreatments by determining the moisture contents and the tangential stresses comprehensively and quantitatively, and then by examining their distributions along the radial direction within a LC.

As for techniques of determining the drying stresses for lumbers sawn parallelly to a log axis, some methods such as the slicing test, prong test, strip test, and flying test have been studied and widely used (Brandao *et al*., 1996; Jung *et al*., 2000). However, these methods hold some incongruent aspects in detecting the drying stresses of a LC. In other words, not only it is difficult to detect clearly the tangential drying stresses built on the end surface along the circumferential direction, but also there is a considerable error between the measurement value and actual value when preparing the test specimens from a part of the LC since most of the LCs are in eccentricity. Also, the probe of stresses and moisture contents in the transition wood between the heartwood and sapwood or the juvenile wood and mature wood have some incomplete elements. According to some previous studies (Kang *et al*., 2004; Choi and Lee, 2004; Lee, Li and Choi, 2003; Lee *et al*., 2004), the circumferential slicing test has been regarded as a quite useful measure in assessing the moisture content and the tangential strain within an LC. Showing the circumferential slicing test more clearly and concretely is expected to contribute to investigating in detail the drying mechanism of LC or boxed heartwood timber.

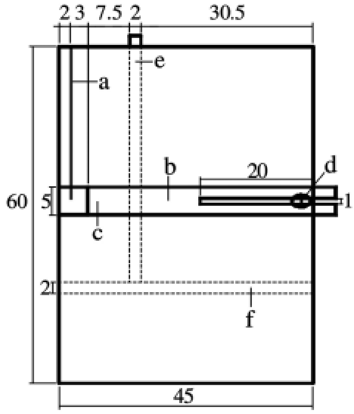
This study was carried out to provide the so-called circumferential slicing test for investigating radial distributions of the tangential strains within the LC by measuring the peripheral length change of each circumferential slice just before/after excoriating while the circumferential slicing one by one from the periphery side toward the pith, and then investigating moisture contents of each slice.

2. MASTERIALS and METHODS

2.1. Circumferential Slicing Test

2.1.1. Circumferential Sawing Jig

We have used the woodworking band saw and a specially devised jig in order to cut continuously the circumferential slices with a fixed thickness from a LC (Fig. 1). The jig was prepared by adhering the surfaces of 2 plywoods with the size of 12 mm in thickness, 45 cm in width, and 60 cm in length, and by inserting the radius control lever (Fig. 1, b). The radius control lever can adjust the distance between the band sawing kerf-line (Fig. 1, a) and center point of the LC, into groove located on the upper side of the 2-plywoods panel. The radius control lever made of a transparent acrylic resin with a thickness of 10 mm is installed with a sharp nail (Fig. 1, c) that can fix the center point of the LC; and on its opposite side, a U-shaped groove was made so that the radius control lever can be guided. The radius control lever is designed to fix the wing nut (Fig. 1, d)



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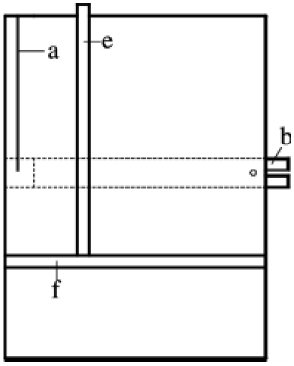

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a ; Sawn line
b ; Adjust-jig
c ; Center of a log cross section fastened on a nail
d ; Wing nut for fixing the adjust-jig
e ; Strip for meter gauge
f ; Stopper

Fig. 1. Overviews of the jig for circumferential slicing (unit; cm).

firmly when that function is needed. In case of this jig, the radius that is possible for the circumferential sawing of the LC was in the range of minimum 33 mm to maximum 173 mm. The strip for meter gauge (Fig. 1, e) and stopper (Fig. 1, f) are installed on the underside of the jig to be contacted with the table of band saw. The strip for meter gauge is inserted into the guide groove of the meter gauge on the band saw table, and so performs the function of inducing a certain movement in the forward and backward direction of the jig. Also, the stopper (Fig. 1, f) plays the role that the jig does not move any further into the tooth blade as it is caught by the stopper and the front part of band saw table, when the center point of the LC (Fig 1, c) reaches to the point that is matched with the tooth point line of the band saw.

2.1.2. Circumferential Slicing

The jig was put on the table after inserting the guide strip on the underside of the jig to the miter gauge groove of the band saw machine (Fig. 2, a). After determining the rotational center of the LC to be sliced, a fixing nail of the radius control lever was driven into the point (Fig. 2, b). After inserting the radius control lever to the groove of it while having the LC fixed, the distance from the kerf was adjusted by band sawing (Fig. 1, a) so that a circle with the largest diameter (excluding the bark) can be processed. And then, the radius control lever with a wing nut was fastened (Fig. 2, c). After band sawing is initiated, the jig was pushed forward until the stopper of it gets to the front side of the band saw table and can not advance any further. At this time, the LC is only sawn in a straight line by the saw blade (Fig. 2, d). From then on, the circumferential sawing is performed while rotating the LC slowly in the clockwise direction (Fig. 2, e). After completing the first circumferential sawing process, and so removing the bark from body of the LC, the jig was moved backward and a reference line was drawn on the upper end surface of the LC from the center to the external periphery of the LC (Fig. 2, f). This line was used in matching two reference lines when measuring the peripheral length of the circumferential slice so that this

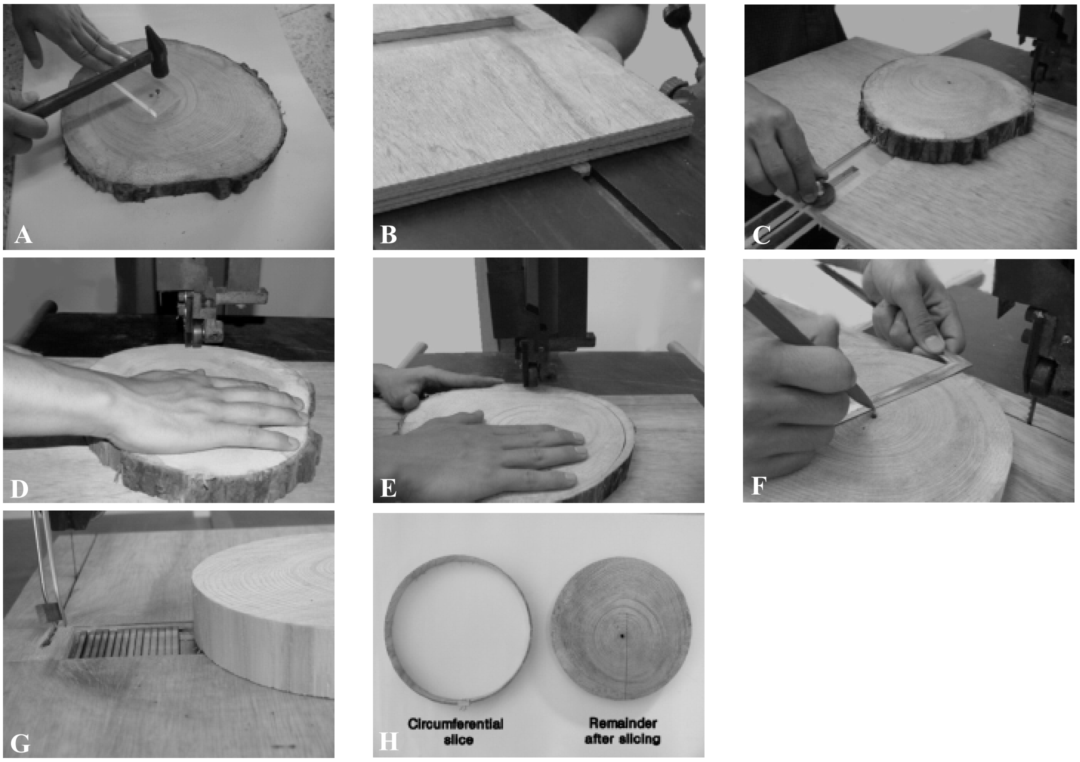

Fig. 2. A process for a circumferential slicing from a log cross section.

line could be remained at the start and end parts of circumferential slice although processing with the band saw. In order to process the circumferential slice with a thickness of about 3 mm, the radius control lever was adjusted and moved to the direction of band saw blade as much as the thickness of circumferential slice. And then, the radius control lever was fixed with a wing nut and the circumferential slice was processed by repeating linear sawing and circumferential sawing (Fig. 2, d～Fig. 2, e). Here in order to process the circumferential slicing continuously with a thickness of 3 mm, insert the 4 mm- thick acrylic strip, that causes a kerfing loss during slicing, into the groove of the radius control lever and remove one each whenever the circumferential slicing is completed once. In this case, we could obtain a uniform thickness of slices far more conveniently (Fig 2, g).

2.1.3. Measurement of Circumferential Length

The circumferential length of a LC or a circumferential slice was measured by using a PI (π) tape. The PI tape used in this study is made of the #1095 clock spring steel from the Collins Phillips Tool in USA and its precision was ±0.03 mm. The method of reading the scale is identical to that of vernier calipers and the circumferential length was obtained by multiplying PI (π) to the measured value since the value measured with the PI tape represents the diame-

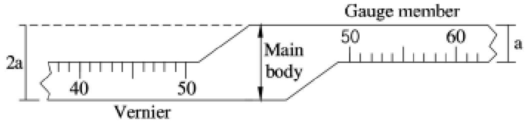

Fig. 3. A PI (π) tape (A width of main body is twice as large as that of the gauge member.).

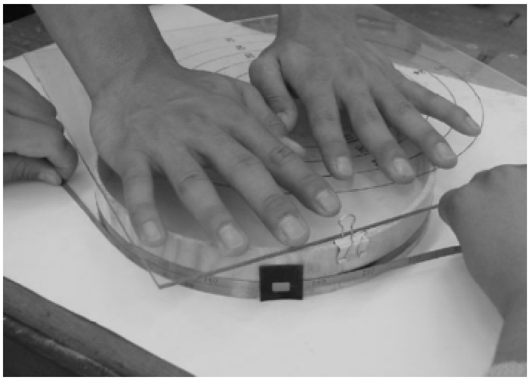

Fig. 4. The measurement of a diameter of a circumferential slice.

ter of the LC or circumferential slice.

One end of this PI tape is in a shape of a stairway so that both ends of the tape are not crossed from each other when crossing over both ends of the tape for the measurement of a diameter (Fig. 3). Also when measuring a diameter, we have used the polyethylene film by inserting it into the PI tape so that it always passes through the identical tangential surface of a LC or circumferential slice (Fig. 4). Just after completing the circumferential slicing, this part was fixed with tweezers after matching the reference line of sawing section at both end kerfs of the circumferential slice. The diameter of the circumferential slice was measured after putting the circumferential slice fixed with tweezers on a flat worktable, covering an end surface of circumferential slice with a transparent acrylic board and pushing it down lightly.

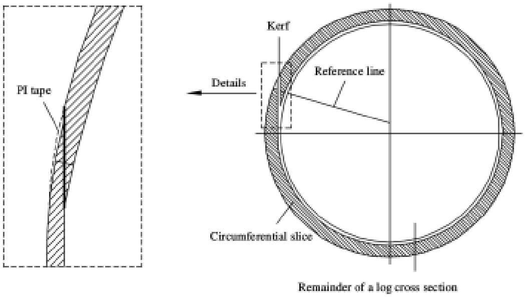

Fig. 5. A loss and surplus of circumference of a slice, respectively, due to band sawing kerf (right) and openings between the PI (π) tape surface and tangential surface of a slice (left).

The length of a loss by the kerf of the band saw blade was regarded as offsetting since the PI tape is not completely attached to the tangential surface from the part that both ends of the circumferential slice meet with each other as shown on the Fig. 5. After examining the medium density fiberboard, that the actual tangential stress is considered to be in a free stress, tens of times, the difference in the circumferential length before and after processing the circumferential slice was insignificant with no more than 0.03 mm.

2.1.4. Evaluating the Tangential Strain and Moisture Content from a Circumferential Slice

We have calculated the tangential strain of each circumferential slice with the equation (1) by measuring the circumferential length of a LC prior to processing the circumferential slice (Co) and the circumferential length of the circumferential slice just after the circumferential slicing (Ca). If this value is a negative (-) value, we have interpreted it to be under the compressive stresses and if it is a positive (+) value, we regarded it to be under the tensile stresses.

Tangential Strain (mm / mm) =

$$\frac{C_o\ (\mathrm{mm})\ -\ C_a\ (\mathrm{mm})}{C_o\ (\mathrm{mm})} \cdots\cdots\cdots \mathrm{Eq}\ (1)$$

On the other hand, we have weighed each slice immediately after measuring the circumferential length of circumferential slices and calculated the moisture contents of the slices by measuring the weight after oven-dried it at a temperature of 103°C until they arrive at a constant quantity.

2.1.5. Radial Distributions of Tangential Strains and of Moisture Contents

We have prepared 30 pieces of *Kalopanax pictus* LC with 28 cm of average diameter and 3 cm of thickness. We have investigated radial distributions of the tangential strains and moisture contents within a green LC by selecting one random LC just after cross-cutting them. The rest of LCs were air-dried at a room temperature and the radial distributions of the tangential strains and moisture contents during indoor drying were measured by selecting one sound LC in every 12 hours. The average temperature and average relative humidity during the indoor drying test was performed were 26 °C and 78% respectively. The indoor drying was performed for a total of 60 hours until the check could be observed visually on the end surfaces of the LCs.

3. RESULTS and DISCUSSIONS

3.1. Radial Distributions of Moisture Contents

Fig. 6 shows the radial distributions of moisture contents for each LC during the drying process at a room temperature.

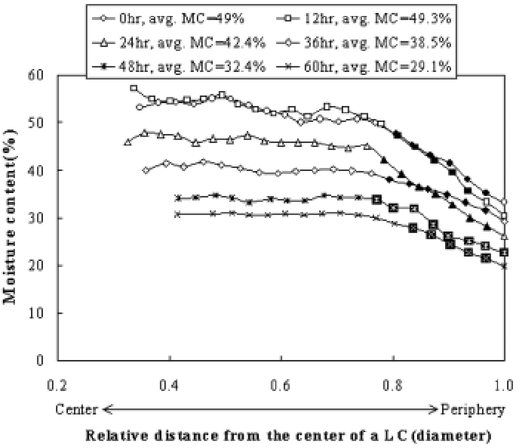

Fig. 6. The radial distribution of moisture contents within a log cross section (LC) of *Kalopanax pictus* during indoor drying (The closed marks represent the slices mixed with sapwood and heartwood).

In case of the green wood, the heartwood part has shown an almost uniform moisture contents of around 50% to 55%, but the moisture contents have gradually decreased as they get closer to the outer part after reaching to the transition area of heartwood/sapwood. And it has shown 33.4% from the outermost slice, resulting in a 19% difference of green MC between the innermost slice and outermost slice. While it has shown a similar moisture content distribution up until 60 hours after starting to dry, the moisture gradient toward the radial direction was getting gentle, showing the moisture content difference of 11.1% between the innermost slice and outermost slice. However while the sapwood on the outer side has represented the moisture content less than fiber saturation point after 24 hours of drying, the heartwood on the inner side has still shown the average moisture content of 46.7%. If this distribution continues for a long period of time, the sapwood may be laid under a tensile stress and it will have a high possibility of generating a check in the transition wood of heartwood and sapwood.

Lee *et al* (1998 and 2000) and Kang *et al*

(2001) have reported that it is desirable to slow down the drying rate of sapwood in order for heartwood and sapwood to come to the fiber saturation point at the same time. However, a caution shall be followed in that the heartwood could reach the fiber saturation point first in the case that the slowing down is excessive. Especially for the species with quite a low percentage of sapwood, they insisted that it would be safer to removing the sapwood part by a circumferential sawing prior to drying.

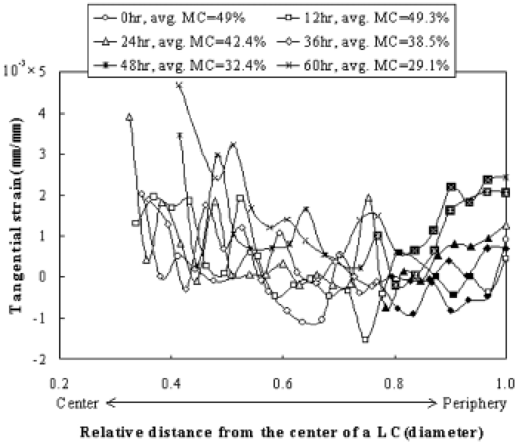

Fig. 7. The radial distributions of tangential strains within a log cross section (LC) of *Kalopanax pictus* during indoor drying (The closed marks represent the slices mixed with sapwood and heartwood).

3.2. Radial Distributions of Tangential Strains

The radial distribution of tangential strains within an LC during the drying is described on the Fig. 7.

In case of the green wood, it has shown a slight tensile stress from the outermost slice near to the bark after being switched to the compressive stress around its 0.67 diameter away from the pith after showing a considerable value of tensile stress from the innermost slice around the pith. This showed the distribution model of the growth stresses presented by Wilhelmy and Kubler (1973), except for those that the bark side shows a tensile stress. The tensile stress in the bark side might have been caused by slight moisture evaporation which was made through the tangential surface of the log cross section skinned during the yard storage.

The pith side was under the tensile stress although there were some fluctuations after 24 hours of drying and it showed the distribution that was again switched to the tensile stress from the bark side after being gradually decreased toward the bark. This trend has been more intensified as the drying process continued and it has shown an U-shaped distribution model after 48 hours of drying time. The tensile stress in the bark side, as shown in the moisture content distribution model (Fig. 6), could be interpreted as in this way - while the sapwood on the bark side was trying to get shrunk, but shrinking was suppressed by the inner side of the heartwood that was still above the fiber saturation point. Especially, a special caution shall be made in that the LC can be defected by the V-shaped crack when the differential shrinkage stresses under a tensile stress occurred after the middle stage of drying due to the difference in the shrinkage of tangential direction and radial direction are superimposed (Kubler, 1975). On the other hand, the tensile stress appeared high in the pith part could not be explained only by the moisture content distribution model on the Fig. 6. This result is assumed that it has a close relationship with either the difference in shrinkage between the juvenile wood and mature wood or the inherent radial distribution of the tangential shrinkage *Kalopanax pictus* except for the moisture gradient in between adjacent parts. Therefore, these points are the advantages of the circumferential slice test that allows determining the tangential strains quantitatively after reflecting all variables.

4. CONCLUSIONS

The results that have investigated the radial distributions of tangential drying stresses and of moisture contents within an LC by the circumferential slice test during the indoor drying of *Kalopanax pictus* are followed as below.

While the heartwood showed an almost uniform moisture content distribution in the range of about 50～55% in case of the green wood, the moisture content has gradually decreased toward the outer side, showing about 19% of moisture content difference from the innermost slice. Although the moisture gradient along the radial direction has gradually become gentle as drying progresses, the sapwood of the outer side represented the moisture contents of hygroscopic range of wood after 24 hours of drying while the heartwood in the inner part showed the moisture contents higher than the hygroscopic range.

The pith side was laid under the tensile stress after 24 hours of drying, and then gradually decreasing toward the bark side, and showed the distribution being switched again to the tensile stress on the bark side. As the drying has progressed, this trend got more intensified, and finally showed the U-shaped distribution model after 48 hours of drying.

The circumferential slice test is considered to be suitable in quantitatively determining the tangential strains and moisture content within a LC.

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