

# Microfibril Angle Characteristics of Korean Pine Trees from Depending on Provinces<sup>1</sup>

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## ABSTRACT

This study investigated the characteristics of microfibril angle(MFA) in order to see if there was any difference in pine tree lumber quality among the three mountain areas surrounding the Taebaek Mountains in Korea - Yeongdong (Goseong-gun), Yeongseo (Hongcheon-gun) and Yeongnam (Bonghwa-gun). Pine trees of each mountain area were divided into earlywood and latewood in relation to heartwood part (1959 ~ 1961, 3 annual rings) and sapwood part (2002 ~ 2004, 3 annual rings), and measured at tangential section. The microfibril angle showed significant differences between mountain areas. In general, Goseong Mountain was found to have 37.35°, followed by Hongcheon Mountain 32.42° and Bonghwa Mountain 25.75°, in order. The sapwood part had larger angle than heartwood part; and earlywood, than latewood. Variation within a single annual ring tended to be smaller from earlywood toward latewood.

**Keywords:** Korean pine, microfibril angle (MFA), quality characteristics, secondary wall, tangential section

## 1. INTRODUCTION

Pine trees are spread the most extensively in Korea as a fundamental tree species for the forest ecosystem, accounting for about 26%, the widest, of the total national forest area (KRFI, 2016). Morphologically, pine trees generally have a straight stem and, for their excellent lumber quality, have long been utilized as furniture material or building timbers for ancient palaces, temples, etc. According to the investigation on changes in wood species utilized in Korean architectural structures, pine trees are found to have been utilized in most of the structures (Park *et al.*, 2007).

Many traditional wooden architectural craftsmen and concerned persons who deal with Korean pine tree lumbers say that pine trees have different quality depending upon areas. In a survey on any difference in pine tree quality according to areas, about 70% of the respondents answered there were differences (Han *et al.*, 2015). The cell wall of cells comprising lumber has a laminated structure which can be separated to primary wall and secondary wall. The secondary wall consists of S<sub>1</sub>, S<sub>2</sub> and S<sub>3</sub> layers. Each layer has different microfibril orientation. The microfibril orientation of the thickest layer of secondary wall, S<sub>2</sub>, has a huge impact on the physical and mechanical properties of

<sup>1</sup> Date Received February 3, 2020, Date Accepted June 26, 2020

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lumber (KFRI, 2014). Microfibril angle (MFA) refers to the angle between cell axis and microfibril orientation of secondary-wall  $S_2$  layer. The MFA is one of the important factors evaluating lumber quality (Bergander *et al.*, 2000). Therefore, many related studies have been reported. Oh (1997) reported that compression strength decreased with the increase in the cell height and MFA of uniseriate ray. Eun *et al.* (2008) studied 3 needleleaf tree species (*Pinus densiflora* S. et Z., *Pinus koraiensis* S. et Z., *Pinus rigida* Mill.) and found that microfibril was larger around the pith part and decreased toward the bark until 15 ~ 20 annual rings before it stabilized. Rlee *et al.* (2005) reported that the microfibril angle was larger in the earlywood part than latewood part while generally showing no significant difference between the south and north sides of the pith. Park *et al.* (2006), in their study on the variation of material properties of pine tree of superior families, found the microfibril angle range of 9.0 ~ 28.6°, wide differences between families. The studies of pine trees characteristics by region include the physical and mechanical properties of Korean red pine wood from different growth sites and correlations between them (Han *et al.*, 2016), seasonal change of cambium activity of pine trees at different growth sites (Park *et al.*, 2015), establishing local master ring-width chronologies (Oh *et al.*, 2017). In addition, studies on the identification of tree species have compared of cellular anatomical, physical and mechanical properties between Dahurian larch and Japanese larch (Han *et al.*, 2017), effects of density, temperature, size, grain angle of wood materials on non-destructive moisture meters (Pang and Jeong, 2019), performance enhancement of automatic wood classification of Korean softwood by ensembles of convolutional neural networks (Kwon *et al.*, 2019).

The previous research of this present study is the study on the anatomical characteristics of Korean pine trees according to area. The paper found differences

in tracheid lengths and diameters according to Yeongdong (Goseong), Yeongseo (Hongcheon) and Yeongnam (Bonghwa) regions (Kim *et al.*, 2018A). Moreover, a study on their physical characteristics reported that pine trees from different areas had different shrinkage, and the lateral shrinkage and tracheid length had a proportional relationship (Kim *et al.*, 2018B).

This present study, building on the studies on the anatomical and physical characteristics of pine trees according to their areas of growth, seeks to investigate pine-tree microfibril angle to see if there is any difference according to their places of growth and analyze the relationship with the anatomical and physical characteristics in order to identify lumber quality characteristics depending upon areas.

## 2. MATERIALS and METHODS

### 2.1. Materials

Pine trees from Yeongdong (Goseong), Yeongseo (Hongcheon) and Yeongnam (Bonghw) retained in the Forestry Association's East Sea Distribution Center were transferred in 2015 for this study experiment. This is the same disk as previous studies of this study, Kim *et al.* (2018A) and Kim *et al.* (2018B). At the point of transfer, they were in a disk form with the thickness of about 20 cm (Fig. 1). Table 1 exhibits their tree rings, chest diameter, average annual ring width, latewood proportion and tree trimming year.

### 2.2. Methods

#### 2.2.1. Microfibril angle measurement

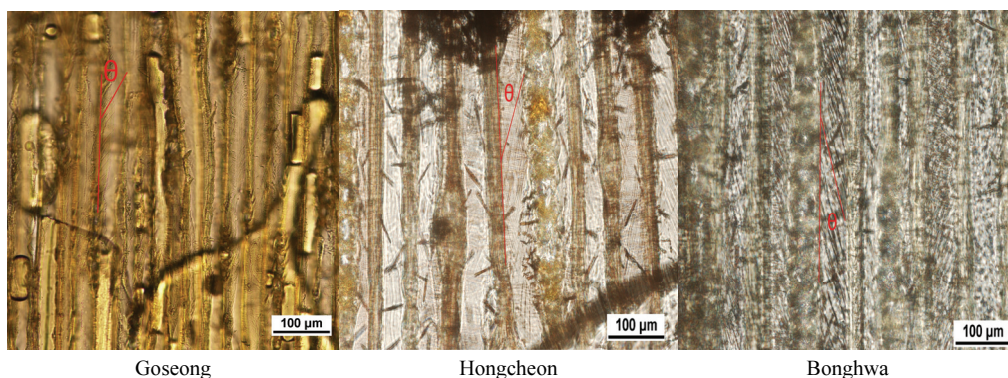
Specimens were made with the disks from the three places in the size of 1.5 × 1.5 × 1.5 cm including the heartwood part (1959 ~ 1961, 3 annual rings) and sapwood part (2002 ~ 2004, 3 annual rings). The

**Table 1.** Information on experimental samples

Province	No. of Tree ring	Diameter (cm)	Average annual ring width (cm)	Latewood ratio (%)	Tree trimming year
Goseong	85	48	3.1	22.87	2013
Hongcheon	82	42	2.6	20.19	2012
Bonghwa	76	45.5	3.1	18.57	2014



**Fig. 1.** Disks from each province.



**Fig. 2.** Microfibril angle( $\theta = \circ$ ) on heartwood of each province.

specimens were softened and divided into earlywood and latewood at each annual ring to make 3 tangential section pieces each in the thickness of 20 ~ 24  $\mu\text{m}$  using Microtome. The sample pieces were soaked into Schultze, dehydrated using alcohol series (10, 30, 60, 80, 100%), and placed on the slide glass to process using 3 ~ 4% iodine-potassium iodide. Then, 50% ni-

tric acid was dropped to form needle crystal and make permanent preparation using permount (Park *et al.*, 1993). They were observed with multimedia image microscope (Ni KON JP/E cl I paa 801), then, 45 microfibril angles were filmed and measured on each slide using NIS (NIS-E lements BR 4.50.00 64-bit) program (Fig. 2).

2.2.2. Microfibril angle variation within single annual ring

Three sample pieces were made each in earlywood and latewood within 1 annual ring of heartwood and sapwood from three mountain areas, and the microfibril angle variation in a single annual ring was investigated.

3. RESULTS and DISCUSSION

3.1. Characteristics of microfibril angle

Table 2 shows the heartwood part and sapwood part of pine trees from the three areas and microfibril angle of their earlywood and latewood. The average of area-specific microfibril-angle heartwood part and sapwood part and their earlywood and latewood was 37.35°, the highest, for those from Goseong Mountain, followed by Hongcheon Mountain with 32.42°, and Bonghwa Mountain, 25.75°, the smallest (Table 2). In terms of heartwood part and sapwood part, all the three mountain areas had larger microfibril angle in sapwood part than heartwood part. With respect to earlywood and latewood, the three places showed larger microfibril angle in earlywood than latewood. Eun *et al.* (2008) reported in their study on microstructure variation in the stem of main Korean needleleaf woods that microfibril angle was the largest at the pith of

pine tree and declined until 15 ~ 20 annual rings along the annual ring increase towards the bark before stabilizing; and microfibril angle also decreased as a tree grew from juvenile wood to mature wood. Lee *et al.* (2015) studied the characteristics of yellow-hearted pine and reported that microfibril angle at the pith part (21 annual rings) was 35 ~ 40°; mid part (81 annual rings), 25 ~ 30°; and bark part (141 annual rings), 20 ~ 35°; and the angle grew smaller towards the bark part. This present study found microfibril angles growing wider towards the bark (sapwood part) from pith (heartwood part) in all of the three places, showing difference from the findings by Eun *et al.* (2008), Lee (2016) and Lee *et al.* (2015). Additional investigation seems necessary in this regard. As preceding studies such as Kim *et al.* (1998), Lee *et al.* (2015), KFRI (2014), and Eun *et al.* (2008), this present study also reported that latewood microfibril angle was smaller than earlywood angle, indicating the same results in this study as well.

Table 2 is also about Duncan test using IBM SPSS Statistics 24 to examine if there was any difference in microfibril angle of earlywood and latewood as well as heartwood part and sapwood part of pine trees from the three areas. In the heartwood part, the earlywood of Goseong Mountain had 36.56°; Hongcheon Mountain, 33.31°; and Bonghwa Mountain, 24.61°; and the

Table 2. Microfibril angle of each province

MFA(°)	Goseong		Hongcheon		Bonghwa	
	Earlywood	Latewood	Earlywood	Latewood	Earlywood	Latewood
Heartwood	A* 36.56 ±0.42	a 32.59 ±0.72	B 33.31 ±1.23	b 26.25 ±2.57	C 24.61 ±1.82	c 21.14 ±2.00
Sapwood	A 41.45 ±2.53	a 38.78 ±2.32	A 37.98 ±1.42	b 32.13 ±1.43	B 30.93 ±1.18	c 26.27 ±0.36
Average	I 37.35 ±10.16		II 32.42 ±9.665		III 25.75 ±7.24	

\* The same letters indicate no significant difference by Duncan's multiple test at 0.05 level. Earlywood = Capital letter, Latewood = Small letter, Average = Roman numerals.

latewood of Goseong Mountain had 32.59°; Hongcheon Mountain, 26.25°; and Bonghwa Mountain, 21.14°. In the sapwood part, the earlywood of Goseong Mountain had 41.45°; Hongcheon Mountain, 37.98°; and Bonghwa Mountain, 30.93°; and the latewood of Goseong Mountain was 38.78°; Hongcheon Mountain, 32.13°; and Bonghwa Mountain, 26.27°, indicating Goseong Mountain was the largest, followed by Hongcheon Mountain and Bonghwa Mountain in order. Statistical processing was implemented to see if there was any difference between them. As a result, significant differences were observed among the three areas in general, excepting the earlywood of sapwood part, which showed no significant difference between Goseong Mountain and Hongcheon Mountain.

In the previous study on the anatomical characteristics of the three mountain areas, the tracheid length was measured by separating the heartwood part (1955 ~ 1964) and sapwood part (2002 ~ 2011). The study reported that the measurements were found the largest in trees from Bonghwa Mountain, followed by Hongcheon Mountain and Goseong Mountain in order (Kim *et al.*, 2018A). In terms of the relationship between the tracheid lengths above and microfibril angles of this present study; the longer the tracheid lengths, the narrower the microfibril angles were found. Kim *et al.* (1998), KFRI (2014), Rlee *et al.* (2005), Hiller (1964), Mark (1967), Preston (1952), Wellwood (1962), Wadanabe *et al.* (1964) and others reported a negative correlation between tracheid length and microfibril angle as microfibril angle grew narrower, tracheid length was longer and the angle was wider as tracheid length was shorter. In the preceding study on the physical characteristics of trees from the three mountain areas, shrinkage from green to air dry and shrinkage from green to oven-dry were measured in the tangential direction. The shrinkage from green to air dry of Goseong Mountain was 2.86 %; Hongcheon Mountain, 3.94 %; and Bonghwa Mountain, 4.39 %.

The shrinkage from green to oven-dry of Goseong Mountain was 6.32 %; Hongcheon Mountain, 6.58 %; and Bonghwa Mountain, 9.85 %, indicating that both conditions had the largest measurement in trees from Bonghwa Mountain, followed by Hongcheon Mountain and Goseong Mountain (Kim *et al.*, 2018B). In terms of the relationship between the shrinkage above and microfibril angle of this present study; the larger the shrinkage from green to air dry and shrinkage from green to oven-dry, the narrower the microfibril angle was found. Barber *et al.* (1964) and Kim *et al.* (1998) reported that, as microfibril angle increased, longitudinal shrinkage rose; and, as the former decreased, lateral shrinkage increased. Therefore, of the physical characteristics found by Kim *et al.* (2018B), differences between mountain areas seem to have been caused by tracheid length (Kim *et al.*, 2018A) and microfibril angle of this present study. Such differences seem to be due to each mountain area's topography, soil, climate, etc. Study related to this aspect will need to be implemented in the future as well.

### 3.2. Microfibril angle variation within single annual ring

Fig. 3 exhibits microfibril angle variations within a single annual ring of the heartwood part and sapwood part of pine trees from Goseong Mountain, Hongcheon Mountain and Bonghwa Mountain. All the three mountain areas showed smaller angle variations from earlywood to latewood. Lee *et al.* (2015), in their study on the quality characteristics of yellow-hearted pine, found that, in a single annual ring, microfibril angles were larger in earlywood than latewood. The researchers also measured earlywood and latewood microfibril angles in 21 and 51 annual rings and found that earlywood was 28.26°; and latewood, 25.75°, demonstrating angles narrowing from earlywood to latewood. Chun *et al.* (1983), in the study on microfibril angle of lumbar cell wall, reported that the

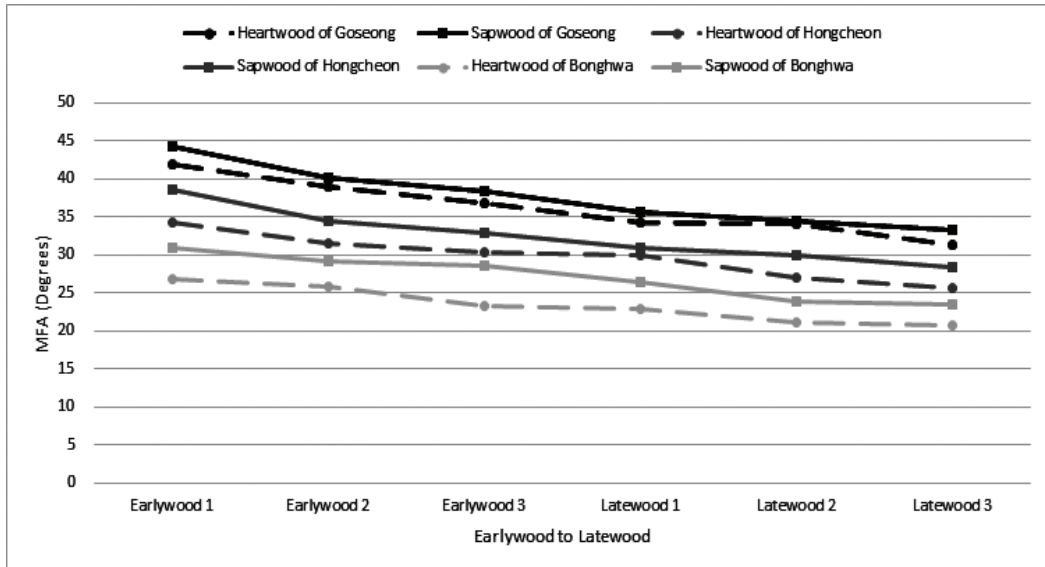


Fig. 3. Variation of microfibril angle within 1 annual ring of each province.

microfibril angles of normal nut-tree lumbar stem averaged 17.6°; earlywood part, 19.8°; and latewood part, 15.3°, finding larger angles in earlywood than latewood, consistently with this present study.

#### 4. CONCLUSION

In this present study, microfibril angle characteristics were examined in order to see if there was any difference in pine tree quality depending upon their growth areas - Yeongdong (Goseong), Yeongseo (Hongcheon) and Yeongnam (Bonghwa) surrounding the Taebaek Mountains. The microfibril angles showed difference according to areas. In terms of the heartwood and sapwood parts and their earlywood and latewood, Goseong Mountain was measured to have 37.35°; Hongcheon Mountain, 32.42°; and Bonghwa Mountain, 25.75° in general. In the comparison between heartwood and sapwood part, the sapwood part showed larger measurement than heartwood part. Between earlywood and latewood, the earlywood had

bigger angles than latewood. Variation in a single annual ring was found narrower from earlywood to latewood. Microfibril angles with regional difference were found to have an impact on a physical property (shrinkage) together with the anatomical characteristic (tracheid length).

#### ACKNOWLEDGMENT

This research was supported by Chungbuk National University (2018-2019).

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