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ESTIMATION OF DAMAGE TO BLACK PINE WOOD (*PINUS THUNBERGII* PARL.) CAUSED BY *MATSUCOCCUS THUNBERGIANAE* MILLER AND PARK

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Abstract

A study was conducted to evaluate differences of sound and damaged wood (*Pinus thunbergii* Parl. by *Matstucoccus thunbergianae* Miller and Park) in order to determine whether damaged trees could be utilized as a general black pine material. The quantity of 1% NaOH extraction was almost the same between damaged and sound woods. There was no difference in cell size and cell wall thickness between damaged and sound woods. Cell count per annual ring in damaged trees was less than that of sound trees. There was a little difference in longitudinal resin canal count per area between damaged and sound trees, but longitudinal resin canal count per annual ring in damaged wood was almost two times higher than that in sound trees. The shrinkage ratio in damaged wood was higher than that in sound wood. The width of annual ring in damaged wood was denser than that of sound wood, but the ratio of late wood had no difference between damaged and sound woods. There was only a little difference in the three types of mechanical properties (bending, compression and shearing methods) between damaged and sound woods.

Introduction

Forests in the southern area of Korea consist largely of black pine (*Pinus thunbergii* Parl.), also known as Japanese black pine. Although it is a versatile and resilient tree, it is also susceptible to disease. The black pine is a big coniferous tree grows to 40 m under good conditions but is typically much smaller, particularly when grows on beach dunes, a common habitat for this tree. Black pine tree growth differs according to the effects of climate change (Dario *et al*. 2010). This tree is remarkably resistant to harsh conditions such as cold winter winds, salt spray, drought, and low nutrient soils. The secondary xylem of the conifers is commonly called softwood. Softwoods are simpler and more homogeneous in structure than hardwoods (Butterfield and Meylan 1980). These soft woods are very useful for the production of wood for construction and pulp (Vanina *et al*. 2011). Particularly**,** clear wood and tight grain patterns and its superior mechanical properties were prized (James *et al*. 2003). However, wood and wood-based materials are damaged by insects, fungi, marine borers, or bacteria (Achim *et al*. 2001). Damaged woods are classified as low quality materials. There are normally no differences in sap and heart woods in conifer for timber quality. In some cases, different colour of sap and heart has a low commercial value (Kim *et al*. 2009).

The black pine bast scale *Matsucoccus thunbergianae* Miller and Park is considered a serious pest of the black pine in Korea (Lim *et al.* 2012). Damage to black pine forest caused by *M. thunbergianae* has appeared on the western and southern coasts of Korea and was noticeably visible in Goheung

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County, Junnam Province, from 1963 until a recent date. This scale insect has one generation a year, with adults emerging from the black pine bark to mate and lay eggs from early March to early May (Kim and Oh 1992). Damage caused by *M. thunbergianae* also has significant economic consequences (Mendel and Rosenberg 1988). In heavy infestations, whole forests can be virtually destroyed. It also attacks Japanese red pine however, mortality in this species is negligible (Park *et al*. 1994). Since its discovery in 1983, survey results have shown that the zone of infection has been expanding at a rate of approximately 5 km each year (Park 1991).

The leaves of black pine tree branches damaged by *M. thunbergianae* begin to turn brown from the lower part of the crown (Lim *et al*. 2013). Although the bast scale mainly injures the parenchyma cells of the phloem, it also affects the xylem, causing the formation of trabecula, spiral thickenings and spiral ribs, and intercellular spaces. Secondary infections by fungi occur in secondary xylem and can finally lead to death (Lim and Soh 1994). To date, there have been many studies on resistance to the pine needle gall midge in Japanese black pine and the spread of black pine blast scale (Susumu 1998, Kondo *et al*. 2000, Lim *et al*. 2012). However, the damage is still ongoing, and the areas of damaged forest are increasing; consequently, economic losses will also continue to increase. The damaged wood will take the effect of chemical, anatomical, physical, and mechanical differences. Therefore, in order to reduce the economic damage and environmental damage arising from forest destruction, trees surviving from the attack by *M. thunbergianae* should be utilized.

In this study, a comparative analysis was conducted to evaluate chemical, anatomical, physical, and mechanical differences between sound wood of *P. thunbergii* and that infected by *M. thunbergianae* in order to determine whether damaged trees could be utilized as a general black pine material.

Materials and Methods

Black pine that had grown in Goheung County, Junnam Province was used for this study. The damaged or sound woods were classified by infection of *M. thunbergianae* based on the appearance and diameter size. The damaged and sound woods were also classified by the vermin density (Table 1). The former is a tree where the appearance of the tree is bent and branches are deflected below, but the latter is a tree that appears straight, and the branches are not deflected. The damaged and sound woods were cut by the heights of upper, middle, and lower parts and the total number of sample trees obtained by damaged and sound stands were 18. Stem discs (2 cm thick) were obtained from all the sample trees classified by the three diameter class (large, middle, and small at breast height, 1.2 m).

Table 1. Investigation of vermin density.

Classification		Large diameter 35 ± 2 cm			Middle diameter 25 ± 2 cm			Small diameter 15 ± 2 cm		
		1	2	3	1	2	3	1	2	3
Sound wood	Upper	0	0	0	0	0	0	0	0	0
	Middle	0	0	4	0	0	0	0	0	6
	Lower	0	0	6	0	0	0	0	0	0
Damaged wood	Upper	20	26	16	9	4	18	24	7	16
	Middle	29	25	26	33	25	29	22	20	4
	Lower	22	34	36	14	26	6	3	8	30

Five branches were used for the investigation of vermin density for the upper, middle and lower parts in crown of damaged and sound woods.

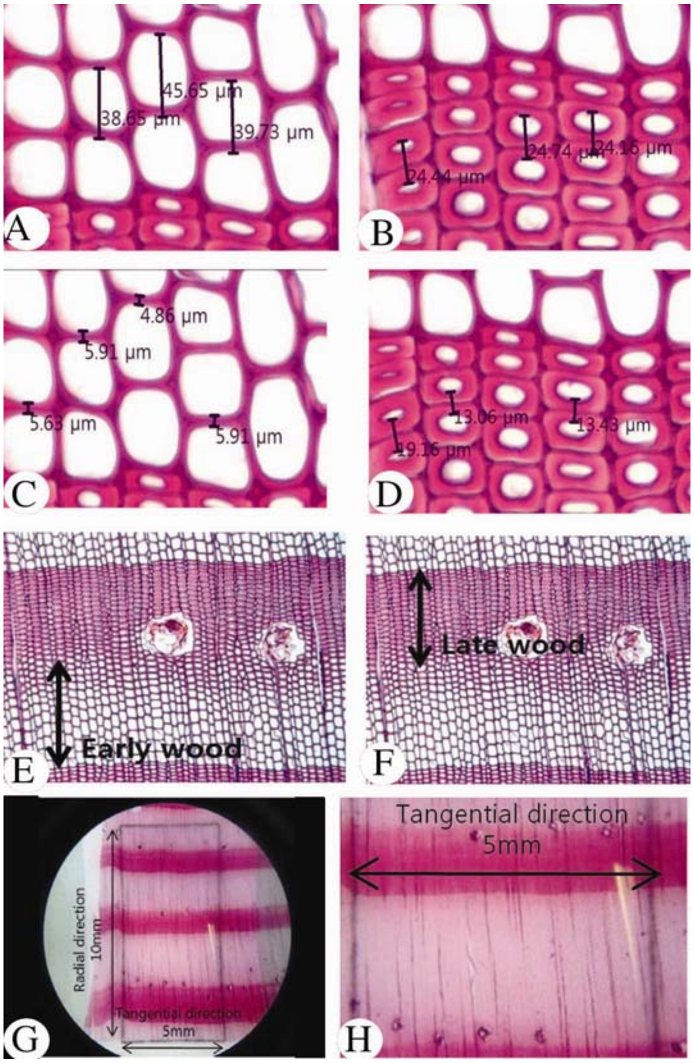

Fig. 1. Measurement of anatomical properties. A. Cell size (early wood), B. Cell size (late wood), C. Cell wall thickness (early wood), D. Cell wall thickness (late wood), E. No. of cells (early wood), F. No. of cells (late wood), G. No. of longitudinal resin canals (area), H. No. of longitudinal resin canals (annual ring).

Quantitative analysis was based on the dry weight of sample according to ASTM D 1109-84 (2013). The sample used secondary xylem of damaged and sound wood and 1% solution of sodium hydroxide (NaOH) was used. Oven dried wood flour of 2 g was put in a 200 ml Erlenmeyer flask for chemical analysis of extractives. And after, a test for 1% NaOH solubility of wood was analyzed. This test covers the determination of the solubility of wood in a hot dilute alkali solution. Hot alkali extracts low molecular weight carbohydrates consisting mainly of hemicellulose and degraded cellulose in wood. This solubility of wood is an indication of the degree of fungal decay, or degradation by heat, light, oxidation, and so forth. One application is in determining the degree of fungus decay that has taken place in a given wood sample. Weight percentage of matter soluble in 1% NaOH, on the moisture-free basic, was calculated by the following equations :

Matter soluble in NaOH, % = $[(W_1 - W_2)/W_1] \times 100$ (1)

where: W_1 = Weight of moisture-free wood in specimen prior to testing, and W_2 = Weight of dried specimen after treatment with the NaOH solution.

Permanent preparation was made by a general method for anatomical property observation. Cell size and cell wall thickness were measured by using stereoscopic and optical microscope's image analysis equipment (IMT, I-solution Lite) with permanent preparation. The difference of cell size and cell wall thickness of damaged and sound woods was investigated at cross section (×100-fold), and the size was expressed by µm. The averaged value which was measured 5 times was used within the boundary of 300 µm between early wood and late wood because the cell size and cell wall thickness were different from the location of early wood and late wood.

The cell count was measured in one row per annual ring at the cross section of damaged and sound woods on the optical microscope with permanent preparation. Longitudinal resin canal count was measured by (1) longitudinal resin canal per annual ring and (2) longitudinal resin canal per area (tangential direction 5 mm × radial direction 10 mm) of damaged and sound woods at the cross section (× 20-fold) by stereoscopic microscope.

Measurement of physical properties: According to the KS F 2203 in KS, shrinkage test (Average shrinkage, air-dried shrinkage and oven dry shrinkage) was conducted in constant temperature and humidity room (temperature 20 ± 2^{o}C, humidity 65 ± 3%). Density, annual ring and ratio of late wood were measured using the specimens of strength test according to KS F 2198 and KS F 2202.

Measurement of mechanical properties: Bending test was performed on the samples using a universal testing machine (UTM) (TSU-2, Taeshin Accuracy Machine, Korea) with a center point loading method (concentrated load at mid-span and supported at the ends). The size of the sample was 20 × 20 × 320 mm and the span was 280 mm and the crosshead speed was set at 2.5 mm/min. Both static modulus of elasticity (MOE_s) and modulus of rupture (MOR) values were calculated from load-deflection curves of the tests.

A compressive and shear strength tests were carried out according to the procedure of a Korean standard (KS F2206 2011, KS F2209 2011) using a hydraulic testing machine (EHF-ED10-20L, Shimazu, Japan). The loading speed was set at 1 mm/min. The load-deformation data were analyzed to determine the compressive modulus of elasticity, the compressive modulus of rupture and shear modulus of rupture.

Results and Discussion

This test was conducted to evaluate chemical differences of sound and damaged wood. The amounts of 1% NaOH extract of damaged and sound wood at different diameters are shown in Table 2. There was not a significant difference in quantitative analysis between the sound and damaged woods in all conditions. Kim *et al.* (1995) reported the results of the different trends that extracts by the 1% NaOH showed a small amount in damaged wood. The reason is that their research used dead trees that resulted from the secondary infection by fungi. This study used trees surviving the damage, and there was not a difference in the damaged and sound woods.

Average values of cell size, cell wall thickness, cell count and longitudinal resin canal count for black pine (*Pinus thunbergii*) by *M. thunbergianae* were analyzed (Table 3). Damaged and sound woods were firstly classified with respect to diameter and early wood, and late wood were secondly classified.

The cell sizes of damaged and sound wood were similar to large, middle and small diameter in early wood. The cell wall thickness in damaged and sound woods was similar to large, middle and small diameter in early wood. In cell size and cell wall thickness, there was a prominent difference between early wood and late wood, but the difference was not found between damaged and sound wood.

Table 2. The amount of extractives with 1% NaOH.

Classification	Alkali extractives, %		
	Large diameter	Middle diameter	Small diameter
Sound wood	13.73 (0.43)	13.86 a1) (0.05)	13.95 (0.08)
Damaged wood	13.43 (0.94)	12.54 b (0.01)	14.28 (0.19)

[1] Means with the same letter are not significantly different at a p value of 0.05% according to Duncan's new multiple range test; values given in parenthesis are standard deviation.

Table 3. Anatomical parameters of sound and damaged black pine wood.

Classification		Cell size, μm		Cell wall thickness, μm		No. of cells		No. of longitudinal resin canals	
		EW	LW	EW	LW	EW	LW	Area	Annual ring
Sound wood	L	44.25	21.86	3.15	6.60	50.56 a1)	48.89 a	20.33	7.18 a
		(3.78)	(1.05)	(0.29)	(1.05)	(13.33)	(13.17)	(3.35)	(2.54)
	M	46.25	21.69	3.04	7.32	36.33 b	36.00 b	21.22	6.83 a
		(2.15)	(0.64)	(0.30)	(0.64)	(12.09)	(13.61)	(6.76)	(2.56)
	S	41.45	20.16	3.23	6.28	30.00 b	30.09 b	22.56	8.63 a
		(2.48)	(0.73)	(0.45)	(0.73)	(16.33)	(9.74)	(7.04)	(2.33)
Damaged wood	L	43.56	21.16	3.10	6.51	24.09 c	27.18 bc	22.44	3.74 b
		(3.98)	(0.81)	(0.37)	(0.81)	(22.54)	(21.12)	(6.15)	(3.22)
	M	42.77	21.79	3.15	6.79	15.73 d	23.97 c	21.22	2.65 b
		(0.36)	(0.62)	(0.36)	(0.62)	(10.52)	(14.80)	(5.07)	(2.36)
	S	43.28	20.42	3.15	6.68	17.32 d	18.68 c	21.33	3.88 b
		(3.39)	(0.73)	(0.35)	(0.73)	(8.75)	(7.62)	(7.75)	(2.69)

[1] Means with the same letter are not significantly different at a p value of 0.05% according to Duncan's new multiple range test; EW = Early wood; LW = Late wood; L = Large diameter; M = Middle diameter; S = Small diameter; values given in parenthesis are standard deviation.

Cell counts of early-and late wood in sound wood were almost two times greater than that in damaged wood based on the measurement result of cell counts of annual rings. Sound wood had a tendency for the large diameter wood to have more cell counts, the small diameter wood to have less cell counts. But the cell count of damaged wood was not different for each diameter. The sound wood had a greater cell count compared to the damaged wood. The reason is that width of annual ring in damaged woods was denser than in sound trees and the cell count was measured in one row per annual ring at the cross section of damaged and sound woods. Therefore cell count per annual ring is different, but it is simply determined to be due to differences in annual ring widths.

There was not a difference in the damaged and sound woods for the number of longitudinal resin canal per certain area, but the number of damaged wood was much smaller than that of sound wood for the number of longitudinal resin canal per annual ring. It is considered that the number and location of formation and development of longitudinal resin canal do not depend on the annual ring width, but the size of an area. Wilcox (1970) reported that anatomical changes in wood diverse cell and cell walls attacked by fungi and bacteria. But anatomical difference was not significantly different between the sound and damaged wood in this study.

Average values of oven dry, air-dried and average shrinkage for damaged black pine wood by *M. thunbergianae* were analyzed (Table 4). The differences in shrinkage were less. The shrinkage of damaged wood was higher than those of sound wood in all conditions. Based on the results of this analysis, the difference in shrinkage between sound and damaged wood was found.

Table 4. Shrinkage of black pine wood according to the damage effect.

Classification	Oven dry shrinkage, (%)				Air-dried shrinkage, (%)				Average shrinkage, (%)			
	T	p	R	p	T	p	R	p	T	p	R	p
Sound	7.57 a[1] (1.06)	0.00	4.22 a (0.94)	0.00	3.67 a (0.55)	0.00	2.04 a (0.65)	0.00	0.23 a (0.03)	0.00	0.13 a (0.04)	0.00
Damaged	8.30 b (1.00)		4.66 b (1.00)		4.24 b (0.52)		2.24 b (0.63)		0.26 b (0.03)		0.14 b (0.04)	

[1] Means with the same letter on vertical line are not significantly different at a p value of 0.05% according to Duncan's new multiple range test; T = Tangential direction; R = Radial direction; p = p-value; values of standard deviation are given in parenthesis.

Table 5. Physical properties of black pine wood according to the damage effect.

Classification	Annual ring (mm)			Ratio of late wood, (%)			Air-dried density (g/cm^3)		
	Sound	Damaged	p	Sound	Damaged	p	Sound	Damaged	p
L	5.13 (1.06)	2.81 (1.17)	0.000**	31.39 (8.53)	32.97 (8.18)	0.328	0.57 (0.04)	0.58 (0.06)	0.288
M	3.11 (0.64)	2.42 (0.94)	0.001**	31.89 (5.85)	32.67 (7.21)	0.612	0.60 (0.04)	0.60 (0.07)	0.923
S	2.97 (0.67)	2.05 (0.78)	0.000**	28.99 (7.57)	32.71 (8.32)	0.065	0.60 (0.06)	0.62 (0.04)	0.052

** Indicates significant difference at $p < 0.01$; L = Large diameter; M = Middle diameter; S = Small diameter; values of standard deviation are given in parenthesis.

Table 5 shows the average annual ring width, ratio of late wood, and air-dried density measured in strength test specimens from sound and damaged woods. The average annual ring width of sound wood was greater than that of damaged wood.

There was also a significant difference in average annual ring width of sound and damaged wood in all diameters. The width of annual ring in damaged woods was denser than in sound trees. The annual ring width of damaged wood was statistically different from that of sound wood. Sone (1986) reported that *M. thunbergianae* reduces the annual elongation of black pine trees by forming a gall on the basal part of current-year needles and eventually causes a substantial loss of vigor.

Neither the ratio of late wood nor the air-dried density was affected in sound and damaged wood by *M. thunbergianae*. There was no significant difference between effects in sound and damaged woods.

Table 6 shows the average values of bending modulus of rupture (MOR$_b$), dynamic modulus of elasticity (MOE$_d$), static modulus of elasticity (MOE$_s$), compressive modulus of rupture (MOR$_c$), compressive modulus of elasticity (MOE$_c$), and the shear strength of damaged and sound woods.

Table 6. Mechanical properties of sound and damaged black pine wood.

Classification	Bending								
	MOR$_b$, MPa			MOE$_d$, GPa			MOE$_s$, GPa		
	Sound	Damaged	p	Sound	Damaged	p	Sound	Damaged	p
L	74.27 (11.32)	80.31 (10.25)	0.007**	8.15 (1.49)	9.43 (1.68)	0.000**	7.31 1.54	7.95 1.70	0.056

Classification	Compressive						Shear strength, MPa		
	MOR$_c$, MPa			MOE$_c$, GPa					
	Sound	Damaged	p	Sound	Damaged	p	Sound	Damaged	p
L	32.45 (3.86)	34.41 (3.98)	0.015	4.16 (0.75)	4.19 (0.74)	0.849	10.60 1.71	11.48 1.27	0.005**
M	37.49 (4.22)	41.14 (6.33)	0.007**	5.04 (1.12)	5.31 (1.07)	0.315	9.68 1.86	10.28 2.05	0.172
S	37.05 (8.44)	39.16 (5.33)	0.227	4.63 (1.35)	4.83 (1.02)	0.510	10.72 1.72	11.84 1.36	0.005**

** Indicates significant difference at $p < 0.01$; MOR$_b$ = Bending modulus of rupture; MOE$_d$ = Dynamic modulus of elasticity; MOE$_s$ = Static modulus of elasticity; MOR$_c$ = Compressive modulus of rupture; MOE$_c$ = compressive modulus of elasticity; L = Large diameter; M = Middle diameter; S = Small diameter; values of standard deviation are given in parenthesis.

The differences in bending strength performance values were small. The bending strength performance values of damaged wood were higher than those of sound wood due to the difference in annual ring width. Kennedy (1995) demonstrated that an increase in annual ring width reduced the strength and density of wood, whereas, in contrast, Kim *et al.* (1995) found that bending strength was lower in damaged wood. However, their findings applied to trees that died due to secondary fungal infections. In the present study, there was no difference between trees surviving the damage caused by *M. thunbergianae* and sound trees. Therefore, surviving trees can be used for lumber.

Also, the values of compressive strength performances and shear strength of damaged wood were higher than those of sound wood due to the difference in annual ring width. The values of compressive strength performances and shear strength of damage wood were higher than those for sound wood.

This paper describes the various properties used to determine whether damaged black pine trees can be used as a general purpose. The quantity of 1% NaOH extraction was almost the same between damaged and sound woods. There was no difference in cell size and cell wall thickness between damaged and sound woods. The width of annual ring in damaged wood was denser than that in sound wood. There was only a little difference in the three types of mechanical properties (bending, compression and shearing methods) between damaged and sound woods. Most results showed no statistically significant differences due to secondary infections by fungi occurrence in the wood itself. *M. thunbergianae* reduces the annual elongation of the black pine tree, which increases strength slightly. Trees surviving the damage caused by *M. thunbergianae* can be used as a general purpose black pine material.

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