KFS Journal, Vol. 21(6), 2010: 479-485

Wood Properties of Japanese Cedar (*Cryptomeria japonica*) Planted as a Windbreak Forest of Mandarin Orange Field in Jeju Island

Beyung-Su Park[1], Kweon-Hwan Hwang[†1], and Sung-Ho Chong[1]

ABSTRACT

The anatomical characteristics, green moisture content, inorganic element concentration, and black heartwood percentage were compared between the Japanese cedar (*Cryptomeria japonica*) planted in a general mountain forest and in a windbreak forest for a mandarin orange field in Jeju island. The results obtained were as follows:

1. Black heartwood percentage was found to be much higher in the trees of windbreak forest than in those of general mountain forest.
2. Green moisture content of wood appeared to increase with the color change of heartwood from reddish brown to black.
3. Inorganic elements of K_2O and CaO in the ray cells of black heartwood were thought to be one of the important factors for black heartwood formation.
4. Wood specific gravity and strength properties were comparatively lower in the trees of Jeju island than in those of southern part of the Korean peninsula. These properties, however, were found to be not significantly different between the trees of windbreak forest and general mountain forest in Jeju island.

***Key words*:** Japanese cedar (*Cryptomeria japonica*), windbreak forest, wood properties, black heartwood, inorganic elements.

요 약

제주도 산지림 및 방풍림 삼나무 목재의 조직 특성, 생재함수율, 무기 함유물 농도 및 흑심재 발생률 조사를 통해 얻어진 결과는 다음과 같았다.

1. 흑심재의 발생률은 산지림의 나무에 비해 방풍림의 것에서 훨씬 더 높게 나타났다.
2. 생재함수율은 심재의 재색이 적갈색에서 흑색으로 변함에 따라 높아지는 것으로 드러났다.
3. 흑심재의 방사조직 내에 존재하는 무기 함유물인 K_2O 와 CaO 는 흑심재의 주요 형성 원인 가운데 하나인 것으로 여겨졌다.
4. 목재의 비중 및 기계적 성질은 제주도의 삼나무가 한반도 남부 지역의 삼나무에 비해 비교적 낮게 나타났지만 제주도 내의 방풍림과 산지림 나무 사이에서는 큰 차이를 보이지 않았다.

Received for publication: Jun 05, 2010 ; Reviewed: Aug 12, 2010 ; Accepted: Nov 17, 2010.
1) Dept. of Forest Products, Korea Forest Research Institute, Seoul 130-712, Korea.
†Corresponding author: Kweon-Hwang Hwang(E-mail: m54290@hotmail.com).

1. INTRODUCTION

Various wood species of temperate and warm temperate regions are distributed in Jeju island. Among them, Japanese cedar is considered to be one of the valuable wood species as a wood resources and was commonly planted as windbreaks for mandarin orange plantations in Jeju island.

As the orange industry in Jeju island has declined considerably, the Japanese cedar planted as windbreak trees has been left without appropriate care such as pruning, causing the formation of low-quality wood, black heartwood, etc. The heartwood of Japanese cedar is generally light-red or reddish brown but sometimes dark reddish brown, dark brown or black. It is well-known that both wood colors and wood quality of the black heartwood affect the application and price of wood.

The black heartwood was known to occur in the growing stage and even after cutting down (Abe et al., 1994). Various studies on the physical and anatomical properties of Japanese cedar have been conducted, with a few studies on the formation and properties of black heartwood.

In this study, the green moisture content and mechanical properties of wood, and percentage and cause of black heartwood formation were compared between the Japanese cedar (*Cryptomeria japonica*) planted in a general mountain forest and in a windbreak forest for a mandarin orange field in Jeju island.

2. Materials and methods

2-1 Material

Each 10 trees of Japanese cedar (*Cryptomeria japonica*) from a general mountain forest and a windbreak forest were provided by a Han-Nam pilot forest in Seoguipo city and National Forestry Cooperative Federation in Jeju city, respectively. The prepared logs were cut into discs of 50 mm thick at the breast height, and the remaining parts were sawn for testing basic wood qualities. Table 1 shows the basic information of prepared Japanese cedar logs.

From fifty standing trees, wood tissues were extracted using an increment borer of 5 mm in diameter for green moisture content determination. The butt ends of one hundred and fifty trees were also examined for black heartwood percentage in the trees of general mountain forest and windbreak forest, respectively.

Table 1. Basic information of Japanese cedar (*Cryptomeria japonica*) from the general mountain forest and windbreak forest in Jeju island

Section	DBH (mm)	Annual ring width (mm)		Annual rings (year)		Heartwood percentage (%)
		HW	SW	HW	SW	
GMF	303.2	4.8	3.1	22.0	14.3	68.8
WBW	283.8	5.5	2.9	18.1	13.8	70.0

GMF: logs from general mountain forest, WBF: logs from windbreak forest, DBH: diameter at breast height, HW: heartwood, SW: sapwood

2-2 Test Methods

2-1-1 Black heartwood percentage

To measure the black heartwood percentage in the basal cross section of the trees, the harvested logs were left untouched for one month and the heartwood was classified into reddish and black based on the colors in basal cross sections.

The color intensity L^* of the black heartwood was further separated into light (30 ~ 39), medium (20 ~ 29), and heavy (19 or less). The L^* of the reddish heartwood was 40 or more. A portable color-difference meter (MINOLTA, CR-10) was used for measuring the color difference.

2-1-2 Green moisture content

The core samples extracted by an increment borer were used to measure green moisture contents. The measurement of green moisture contents was conducted by the oven-dry method of KS F2199 (KSA, 2001).

2-1-3 Identification of inorganic elements

10×10×10 mm cubes were used in the slide preparations for the anatomical observation by an optical microscope and a scanning electron microscope, SEM (HITACHI S-350).

Titration method of EDTA (ethylene-diamine-tetra-acetic acid) was adopted for the identification of inorganic elements in scanning electron microscopy.

2-1-4 Mechanical properties

Quater-sawn timbers from each sample tree were dried in a drying oven at 75 degrees Celsius for a week. Test samples of compression, bending, and shear strength were then prepared from the sound part. A universal testing machine (Instron 4206, 150kN load cell) was used for evaluating the mechanical properties in accordance with KS F 2206~2209. After the bending tests, specimens for moisture content (KS F 2199) and specific gravity (KS F 2199) were taken at the nearest sound part from the point of failure.

3. RESULTS AND DISCUSSION

3-1 Black heartwood percentage

Generally the heartwood color of Japanese cedar is light-red or reddish brown. However, the heartwood from the windbreak forest was found to be dark reddish-brown, dark brown, blackish brown or black, as shown in Figure 1. Therefore, the trees from the windbreak forest appeared darker than those from the general mountain forest. Table 2 shows the percentage of black heartwood. The red heartwood accounted for 85% in the trees from general mountain forest, compared to black heartwood 82% in the trees from windbreak forest.

This higher percentage of black heartwood in the trees from the windbreak forest may be highly related to the growth environment, injury or fertilization that affect on the wood properties.

Fig.1. Cross sectional surface of Japanese cedar (*Cryptomeria japonica*) planted in the windbreak forest of a mandarin orange field in Jeju island.

Table 2. Heartwood percentage of Japanese cedar (*Cryptomeria japonica*) from general mountain forest and windbreak forest in Jeju island based on color

Section	Red heartwood (Red, Reddish)	Black heartwood (From reddish brown to black)		
		Light	Medium	Heavy
GMF	84.7	13.3	2.0	-
WBF	18.0	20.0	51.3	10.7

See legends in Table 1.

3-2 Green moisture content

The variation of moisture content in heartwood of Japanese cedar was known to be large. The dark brown heartwood was often considered to have an adverse effect on the aesthetic value and wood drying properties due to its high green moisture content (Abe et al., 1994).

Table 3 shows that the darker the heartwood, the higher the moisture content. However, the heartwood color and green moisture content was found to be not significantly correlated.

Table 3. Variation of green moisture content in Japanese cedar (*Cryptomeria japonica*) from general mountain forest and windbreak forest in Jeju island

Section		Heartwood (%)		
		Light	Medium	Heavy
GMF	HW	129.6 ± 51.2	145.4 ± 25.5	196.3 ± 36.6
	SW	223.2 ± 57.4	231.5 ± 38.7	235.1 ± 42.0
WBF	HW	112.2 ± 23.7	124.7 ± 34.1	143.8 ± 22.2
	SW	217.2 ± 47.9	163.0 ± 72.6	170.1 ± 61.3

See legends in Table 1.

3-3 Identification of inorganic elements

To explore the black heartwood causing substances, cell inclusions in the radial section were examined. Lots of thread-like inorganic elements were identified in the ray cells of black heartwood, but only small amounts of them were found in the red heartwood. These inorganic elements were therefore thought to play a key role in the formation of black heartwood (Oda et al., 1994).

Table 4. Concentration of inorganic elements in Japanese cedar (*Cryptomeria japonica*) from general mountain forest and windbreak forest in Jeju island

Section		Color intensity (L^*)	K_2O (%)	CaO (%)	MgO (%)
GMF	SW	79	0.10	0.09	0.08
	HW	39	0.41	0.09	0.09
WBF	SW	69	0.27	0.10	0.10
	HW	37	0.51	0.21	0.10
	BHW	19	0.77	0.20	0.76

BHW: black heartwood; See other legends in Table 1.

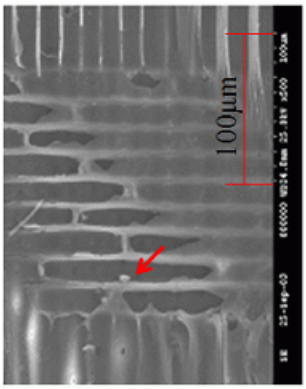

Fig. 2. Sapwood ray in the tree with red heartwood.

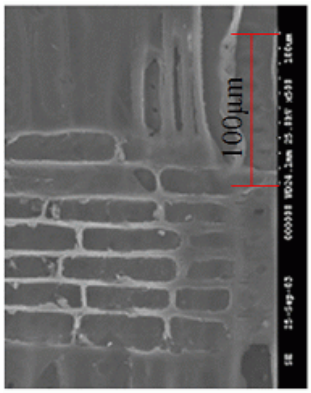

Fig. 3. Sapwood ray in the tree with black heartwood.

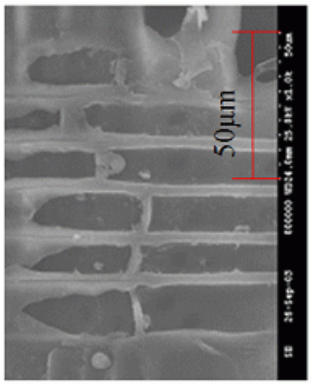

Fig. 4. Heartwood ray in the tree with red heartwood.

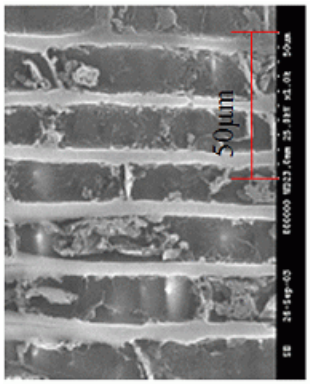

Fig. 5. Heartwood ray in the tree with black heartwood.

For the analysis of these materials, EDTA titration method was used. As shown in Table 4, the concentration of K_2O was the highest in the black heartwood. The higher amount of K_2O may be an

important factor for black heartwood formation because K_2O amount is highly related to color intensity.

As shown in Figures 2 to 5, heartwood contains more K_2O than sapwood, and black heartwood from a windbreak forest also has more K_2O than red heartwood from mountain forest. This phenomenon seems to be caused by the effect of fertilizer for increasing mandarin production. Abe and Oda (1994) reported that black heartwood formation in the Japanese cedar was not caused by ammonia and oxygen but by calcium hydrogen carbonate.

3-4 Mechanical properties

Japanese cedar has been induced from Japan and planted in the southern part of the Korean peninsula and Jeju island. Shim et al. (1981) reported its wood specific gravity to be 0.38 and 0.44, and its bending, compressive, and shear strengths were 65.5 and 60.0 MPa, 24.1 and 36.7 MPa, and 8.2 and 10.2 MPa, respectively.

Table 5. Mechanical properties of Japanese cedar (*Cryptomeria japonica*) from general mountain forest and windbreak forest in Jeju island

Section		Moisture content (%)	Specific gravity	Bending strength (MPa)	Compressive strength (MPa)	Shear strength (MPa)	Tensile strength (MPa)
GMF	HW	16.4	0.33	42.9±6.5	28.8±4.8	7.2±0.8	53.7±12.7
	SW	17.1	0.31	40.1±3.3	24.3±2.3	7.0±0.7	48.3±9.3
WBF	HW	16.0	0.33	39.1±7.6	24.9±5.7	6.3±1.1	38.6±5.0
	SW	17.5	0.35	40.2±7.0	19.0±2.3	7.0±1.2	42.0±6.7

See legends in Table 1.

In this study, the wood specific gravity of the Japanese cedar ranged from 0.31 to 0.35, with bending, compressive, and shear strengths of 39.1 to 49.2 MPa, 29.0 to 28.8 MPa, and 6.3 to 7.2 MPa, respectively. Thus, the wood specific gravity and strength properties of Japanese cedar in Jeju island were lower than the results reported by Shim et al. (1981).

This was thought to be due to the higher moisture content and lower specific gravity, resulting in lower strength. Wood specific gravity and strength properties, however, were found not to be significantly different between trees of windbreak forest and general mountain forest in Jeju island.

4. CONCLUSIONS

Japanese cedar (*Cryptomeria japonica*) is a major tree in Jeju island. But its knotty stem and low wood quality are demerits for the use of wooden building construction and furniture industry. For the better utilization, the black heartwood which observed frequently in the windbreak forest should be studied further.

The percentage and cause of black heartwood formation, green moisture content and strength properties of wood were compared between the Japanese cedar planted in a general mountain forest and in a windbreak forest for a mandarin orange field in Jeju island.

The black heartwood percentage was found to be much higher in the trees of windbreak forest than in those of general mountain forest. Inorganic elements, K_2O and CaO, in the ray cells were

thought to be an important factor for the formation of black heartwood. The wood specific gravity and strength properties were comparatively lower in the trees of Jeju island than in those of southern part of the Korean peninsula.

5. REFERENCES

Abe Z., Oda K. and J. Matsumara. 1994. The color change of sugi (*Cryptomeria japonica*) heartwood from reddish brown to black (I). Mokuzai Gakkaishi 40(10):1119-1125.

Abe Z. and K. Oda. 1994. The color change of sugi (*Cryptomeria japonica*) heartwood from reddish brown to black (II). Mokuzai gakkaishi 40(10):1126-1130.

Korean Standard Association. 2001. KS F 2198. Determination of density and specific gravity of wood.

Korean Standard Association. 2001. KS F 2199. Determination of moisture content of wood.

Korean Standard Association. 2001. KS F 2202. Determination of average width of annual rings for wood.

Korean Standard Association. 2004. KS F 2206. Method of compression test for wood.

Korean Standard Association. 2004. KS F 2207. Method of tension test for wood.

Korean Standard Association. 2004. KS F 2208. Method of bending test for wood.

Korean Standard Association. 2004. KS F 2209. Method of shear test for wood.

Oda K., J. Matsumara & Z. Abe. 1994. Black-heartwood formation and ash contents in the stem of sugi (*Cryptomeria japonica*). Sci. Bull. Fac. Agr., Kyushu Univ. 48(3-4) :171-176.

Shim K., Lee K. Y., So W. T., Ahn K. M., Kang S. K. and J. M. Jo. 1981. On wood properties of imported species grown in Korea (II). Bull. Forest Research Institute 28:7-32.