J. Korean Wood Sci. Technol. 42(5): 516~522, 2014 http://dx.doi.org/DOI : 10.5658/WOOD.2014.42.5.516

Characterization of Burned Architectural Woods by Fire Using SEM-EDXS and Computerized Tomography[1]

Hyun-Mi Lee[2] · Won-Joung Hwang[2,†] · Dong-Heub Lee[2] · Dong-Won Son[2]

ABSTRACT

Old architectural wood materials damaged by a fire were evaluated on the basis of wood species and scanning electron microscopy (SEM) observation of wood tissues in combination with energy dispersive X-ray spectroscopy (EDXS) analysis. Results of SEM observation showed that tracheid wall thickness of burned parts was very thin compared with undamaged and sound wood, and tylosoid in the resin canals disappeared after the exposure to fire. SEM-EDXS analysis indicated that carbon and oxygen peaks occurred in the original energy band, and the carbon peak was higher than that of the oxygen in the burned part. A computerized tomography was also undertaken to investigate the carbonization layer formed by fire and possible internal defects.

Keywords : architecture wood material, SEM-EDXS, computed tomography, wood tissues, carbonized wood

1. INTRODUCTION

To preserve old wood architecture and the traditional architecture style correct safety inspection and preservation measures in the existing architecture are required (Gang and Bak 1993; Bak *et al.* 1993). In order to achieve this investigation and study of the existing old wood architecture should proceed in a systematic way and examine all the available data and techniques concerning traditional wood architecture (Kim *et al.* 2003). Therefore scientific structure interpretation is required in compiling and assessing all the available data for the previous architecture. Therefore the development of a portable CT system for detection of wood deterioration has been developed for application to ancient wood buildings (Lee and Kim 2004). Another method employed involved the observation on the changing pattern of wood tissue from SEM observation (Lee 2008).

There is available the exact knowledge about the structure of traditional wood architecture such as the estimation of resistance period for reliability repairing and reconstruction and the scientific diagnosis for the establishment of a standard for decay and safety of traditional architecture (Kim *et al.* 2003; Fujii *et al.* 2010).

In this study computed tomography was employed to measure wood defect, deterioration and decay for 17 Sungnyemun's materials with tissue observation

---

[1] Date Received April 14, 2013, Date Accepted August 14, 2014

[2] Department of Forest Products, Korea Forest Research Institute, Seoul 130-712, Korea

[†] Corresponding author : Won-Joung Hwang (e-mail: wonjoung@forest.go.kr)

Table 1. The list and details of the carbonize probation material

No	Specimens	Size (mm)	Damaged shape
1	lintel	95 × 220 × 3360	carbonized, decayed
2	fan-rib rafter 2	Ø170, 3755	partly carbonized

Fig. 1. Computed tomography.

and component analysis to find the cause of failure. Scanning electron microscopy (SEM)- energy dispersive X-ray spectroscopy (SEM-EDXS) and computed tomography (CT) method was proved that it will be used for a part of property analysis of a deteriorated, or burned woods by fire.

2. MATERIALS and METHODS

2.1. Disclosure Materials

The nation’s first national treasure, Sungnyemun, which was badly damaged by fire on February 10th 2008, had 10% and 90% physical damage on the first floor and second floor of a gate tower, respectively.

This study used 2 materials, which were provided by MyongJi University Industry-Academic Collaboration Foundation (affiliated institutes, Korea Architecture Culture institutes).

2.2.1. Computed Tomography

To identify defects and deterioration inside wood and to produce a decay map ultrasonic measurement computerized tomography was employed (Fig. 1). The computerized tomography device, Toshiba Corporation’s X-peed TSX model, which is located in the Korea Forest Research Institute, was used. X-rays were filmed at 5 second interval at 120 Kv, 110 mA. To judge the degree of deterioration of materials two dimensional images were obtained by taking photographs at 5 mm intervals along the length direction. Based on these data, material images including carbonization, static, knot and hardware, were compared with ultrasonic measurement results.

2.2.2. Tissue Observation and Component Analysis

To measure and compare material tissue and chemical modification small 3 sections (a cross section, a radial section, a tangential section) were taken from 3 parts (carbonization, transfer moiety, healthy part) of the following specimens; a part of decayed lintel, tie-beam, rafter 2, a fan-rib rafter 1, a fan-rib rafter 2. Carbonization and transfer moiety parts were digested in distilled water. They were dried and frozen by using a resistance-type freeze dryer. To obtain a clean observation face/surface for each section (a cross section, a radial section, a tangential section) the frozen specimens were cut at 20 μm thickness by a freezing microtome. After thawing and drying cut specimens at room temperature, they were dried in the dry oven at a temperature of 60°C. Healthy and decay parts were dealt with soft-

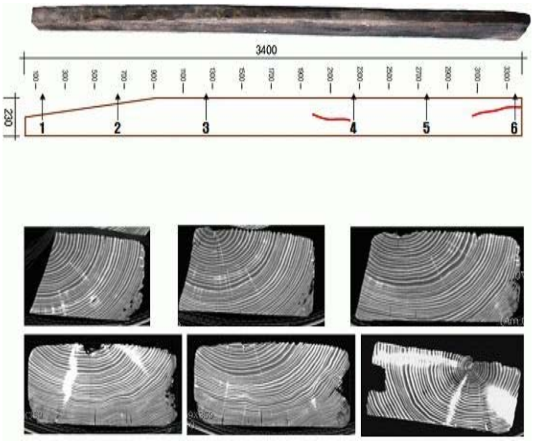


Fig. 2. Lintel's schematic and CT images.

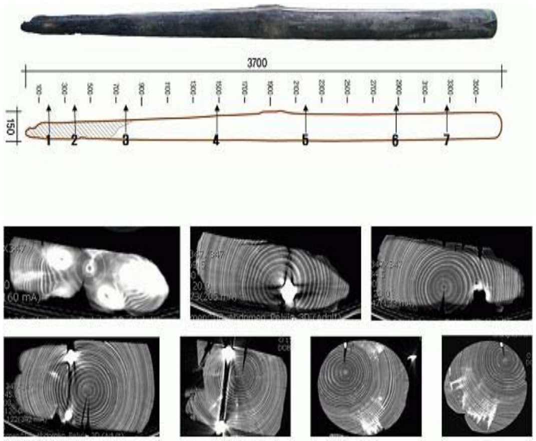


Fig. 3. A fan-rib rafter 2's schematic and CT images.

ening treatment and sectioned by microtome and then dried in the oven. Dried sectioned samples were attached by conductivity adhesive to the stage and gold coated by a sputter coater (SCD 005) under high vacuum.

Samples were observed by Philips, XL30 ESEM TMP connected to energy dispersive X-ray spectroscopy (EDXS) and component analysis was employed.

3. RESULTS and DISCUSSION

3.1. Computed Tomography

Prediction investigation into residual performance of damaged materials by fire has been previously undertaken by computerized tomography (Davis and Wells 1992; Lee 2010). CT images indicated that the white area reflected high density and a deep color or black area represented low density or a space. Among the materials used, a lintel material, which had the least damage by fire in the outside cells and secondary damage (like a nail, static, loss) except carbonization, was found to exhibit a little internal decay but was shown not to form a carbonization layer. On the other hand for fan-rib rafters carbonization was the most serious and the secondary damage caused by a nail was also discovered. In addition, CT images showed that the carbonization layer formed was about 2-4 mm. in depth. In the ironware, (like a nail), because of high density compared with wood, diffuse reflection had taken a place as seen in the fan-rib rafters' CT image in the Figs. 2 and 3. For static or decay density was lower than wood and was represented by black color. In wood density of knots was higher than for woody parts and appeared as a bright white color but unlike a nail, light scattering did not occur. Furthermore, the carbonization layer which was relatively lower than tissue produced a medium color between tissue and a space.

3.2. Probation Material Anatomic Characteristics and Micro-structure Observation

3.2.1. Identification of Wood species

A cell component of *Pinus* sp. hard pine's species as being a conifer consists of epithelial cells surrounding tracheids, longitudinal, transverse resin canals, ray parenchyma cells and ray tracheids.

Table 2. Identified wood species of Sungnyemun material's

No.	Subsidiary	Quantity	Wood species	
			Specific name	Common name
1	lintel	1	*Pinus* sp.	Pine
2	Tie-beam	1	*Pinus* sp.	Pine
3	rafter 2	1	*Pinus* sp.	Pine
4	fan-rib rafter 1	1	*Pinus* sp.	Pine

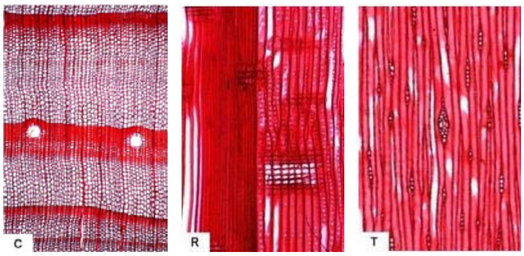


Fig. 4. A fan-rib rafter 1's 3sections structure. C: cross section, R: radial section, T: tangential section.

Tracheid arrangements in the transverse phase (Fig. 4. C) was orderly and longitudinal resin canals were present and epithelial cells surrounding resin canals were observed. In the radial section, a radial structure was made of ray tracheids and ray parenchyma cells. Ray tracheids were distributed in the upper and lower sides and dentate thickening was found in the ray tracheid's internal wall. Whether dentate thickening existed or not is an important systematic characteristic to distinguish *Pinus* and *Pinus koraiensis*. Cross filed putting's structure was window like and was distributed one at a part (Fig. 4. R). In the tangential section (Fig. 4. T), radial structure was uniseriate, 1-15 cells, most 10 cells and longitudinal resin canal was distributed (Jung *et al.* 2002).

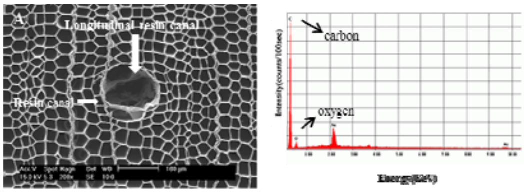
From the above characteristics it was assumed to be pinaceae, *Pinus*, pine (hard pine). In South Korea, 2 species (*Pinus densiflora* S. et Z. and *Pinus thunbergii* Parl) are distributed. *Pinus densiflora* is more widely distributed than *Pinus thunbergii* which occurs for the most part at the coast. Considering these characteristics, it was assumed to be pinaceae. All 4 samples used in this study had these characteristics.

Among Sungnyemun's materials, 4 materials were observed and analyzed. The results, as seen Table 2, showed that all materials belonged to the pinaceae.

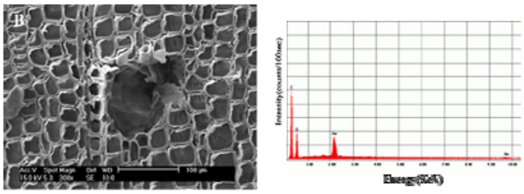
3.2.2. Carbonized Material Microstructure Observation and Chemical Modification Measurement

Pinus hard pine cells consist of tracheids, longitudinal transverse resin canals, epithelial cells ray parenchyma cells and ray tracheids. In general with regard to the transverse phase, epithelial cells which surround tracheid arrangement, wall thickness, early wood · late wood's implementation, longitudinal resin, were observed. In the radial section characteristics of tracheid pit shape, arrangement, and ray parenchyma cells and ray tracheids were found and in the tangential section, radial structure including width, height and transverse features were observed.

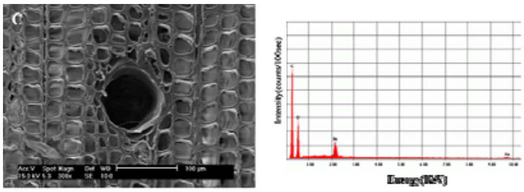
Figs. 5-8 show exemplary results of each material observed by SEM. Each material appeared similar in almost all of the same phases. In terms of the transverse phase, tracheid wall thickness in the burned part was much thinner than in the transfer moiety and the healthy part. The reason is that in the process of carbonization, it was assumed that among wood's main components, cellulose, hemicelluloses



Carbonization part



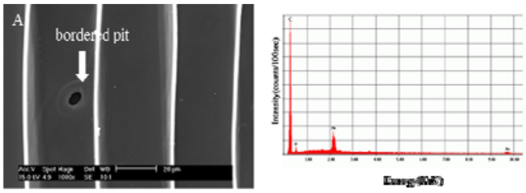
Transfer moiety



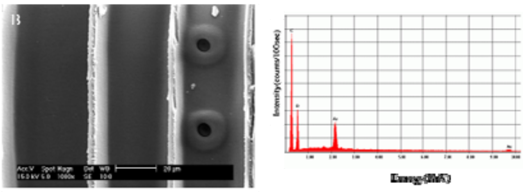
Healthy part

Fig. 5. SEM images of fan-rib rafter 2's each part cross section and SEM-EDXS's results (A: Carbonization part, B: Transfer part, C: Healthy part).

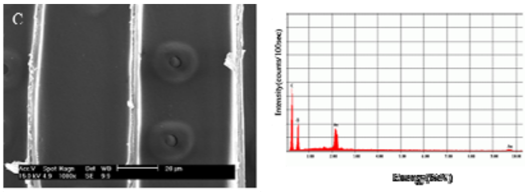
- It had longitudinal resin canal cross section showing a growth ring boundary (Cross section showing a growth ring boundary).



Carbonization part



Transfer moiety



Healthy part

Fig. 6. SEM images of Fan-rib rafter 1's each part radial section and SEM-EDXS's results (late wood tracheid) (A: Carbonization part, B: Transfer part, C: Healthy part).

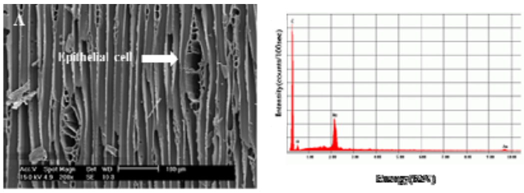
- Late wood tracheid and bordered pit's radial section was significantly found.

and lignin were decomposed and evaporated, then contracted by a high temperature. However, although destruction and loss of tracheid wall occurred in the carbonized part of some materials, it was considered that it occurred during the process of making samples rather than in the process of carbonization.

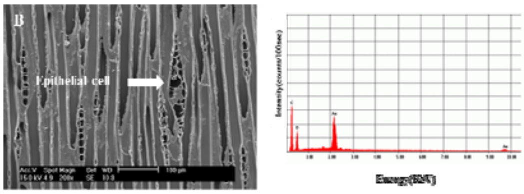
In the Figs. 6, 7 as for radial sections and tangential sections, unique and wood structure change was not found, but pit walls of tracheids, epithelial cell and bordered pits in the carbonized part were lost much more than in the transfer moiety and healthy part. It was assumed that very thin pit walls were destroyed by a high temperature in the process of carbonization. However, there was little anatomical difference of wood in the transfer moiety and healthy part.

In the Fig. 7, conifer cell components epithelial cells surrounding tracheids, longitudinal · transverse resin canals and ray tracheids were observed. Additionally fusiform rays including transverse resin canals and uniseriate rays were observed.

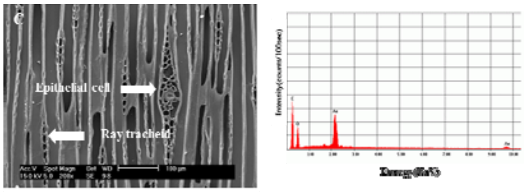
On the other hand Fig. 8 showing the decay part results from SEM that hyphae occur in the radial section, cracks and static in the cell wall had occurred. However the cell wall of radial structures in the tangential section exhibited considerable



Carbonization part

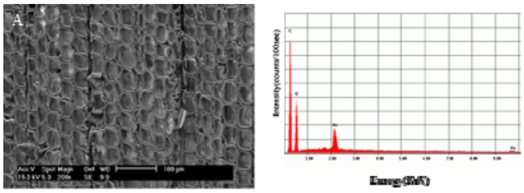


Transfer moiety

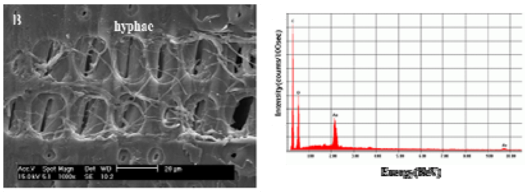


Healthy part

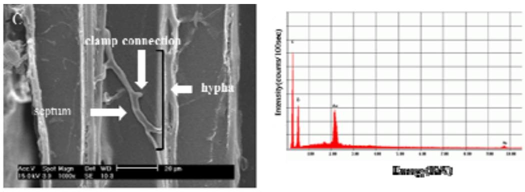
Fig. 7. SEM images of each part tangential section of tie beam and SEM-EDXS's results (A: Carbonization part, B: Transfer part, C: Healthy part).



Cross section



Radial section



Tangential section

Fig. 8. SEM images of lintel's decay part and SEM-EDXS results.

deterioration. The hyphae possess characteristics of basidiomycete (rotting fungi) such as clamp connection and septum and the wood structure seemed healthy without decay.

By using SEM, material's structure and EDXS were observed and measured together. The result was that Carbon and Oxygen's specific X-ray was peak in the peculiar energy band (C: 0.282KeV, O: 0.523KeV) (Figs. 5-8).

Wood is cellulose, lignin, hemicellulose, and also comprise a major component of the cell wall. However, when wood is burned wood charcoal, most of the major components of the volatile components of the carbon and oxygen are left with only components. X-ray analysis of the results in this study than in the burn wood charcoal part appears high in carbon and oxygen composition was confirmed. Less carbon than oxygen, the amount of burned wood when it is shown the influence of oxygen or oxygen to accelerate the thermal decomposition of wood components are frequently thought to be due to the consumption.

4. CONCLUSION

This study was undertaken to investigate the carbonized layer and internal defects formed from fire of wood architecture by using CT and to observe material structure with the SEM. Furthermore components of the structures were measured by X-ray spectroscopy (EDXS). SEM-EDXS and computed tomography method was proved that it will be used for a part of property analysis of a deteriorated wood by fire or burned wood.

Among Sungnyemun's materials, 2 materials were examined for their internal state by CT as a scientific method. The results showed that wood structure with decay not developing remained in a healthy state and that there was little difference from carbonization part and transfer moiety. On the other hand pit walls of tracheids and bordered pits from the transfer moiety was destroyed much more than in the healthy part in the burned part of radial section and tangential section.

REFERENCES

Bak, S.J., Gang, A.G., Kim, Y.J. 1993. Species identification and microscope structure of ancient wood excavated from the remains (I) -Species of coffin woods excavated from ancient tombs. Journal of the Korean Society of Conservation Science for Cultural Properties 2(2): 3～14.

Davis, J., Wells. P. 1992. Computed tomography measurements on wood. Industrial Metrology 2(2-4): 195～218.

Fujii, Y., Fujiwara, Y., Kigawa, R., Suda, T., Suzuki, Y. 2010. Characteristics and diagnosing technology of biodegradation in wooden historical buildings. A case study on Amida-do in Higashi Hongan-Ji Temple in Kyoto. World Conference on Timber Engineering. p. 8.

Gang, A.G., Bak, S.J. 1993. Species identification and microscope structure of ancient wood excavated from the remains (Ⅱ) -Degradation of ancient woods. Journal of the Korean Society of Conservation Science for Cultural Properties 2(2): 15～24.

Jung, K.H., Park, S.J., Kang, A.K. 2002. Species identification of wooden materials attached to iron nails of Ancient Tombs excavated from Nung-san ri. Journal of The Korean Wood Science and Technology, 30(4): 17～22.

Kim, G.C., Bae, M.S., Lee, J.J. 2003. Difference of deterioration according to exposed condition of column in wooden traditional building. Journal of The Korean Wood Science and Technology, 31(2): 58～68.

Lee, H.H. 2008. A study on conservation treatment for excavated carbonization wooden object: Comparative experiment on the PEG method and sugar alcohol method. The Korea Society of Conservation Science for Cultural Properties 24: 57～66.

Lee, J.J., Kim, K.M. 2004. Development of portable CT system for detection of wood deterioration. The Architectural Institute of Korea 24(1): 391～394.

Lee, S.J. 2010. Quantitative detection of the internal defect in wooden members of ancient building throughout nondestructive evaluation with X-ray and ultrasound. Ph.D. Thesis. Seoul National University, Korea. pp. 20～40.