Investigation of Elemental Distribution for Wooden Historic Architecture by Handheld XRF Analyzer: In the Case of the Confucian Temple of the Kodokan of Mito Domain

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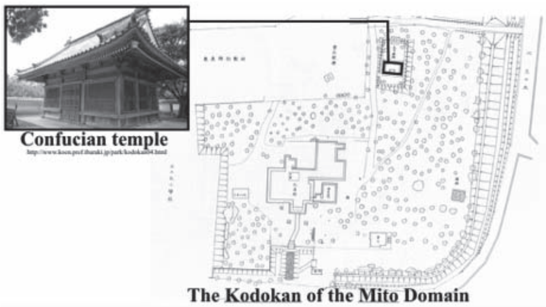

Fig.1. Plan of the Kodokan of the Mito Domain

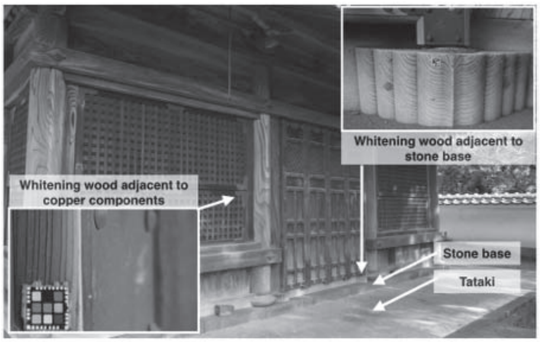

Fig.2. The 2 types of whitening phenomenon in sections of No. 7~9

ABSTRACT

Whitish discoloration of wood in the case of wooden historic architecture might be caused by different factors with various characteristics of elemental distribution. The handheld XRF analyzer were utilized to investigate the whitening phenomenon of wood which was observed in areas adjacent to the stone base and copper components of the Confucian Temple of Kodokan of the Mito Domain, non destructively. The result of XRF analysis indicated that the whitening phenomenon in wood structures lower than 70 cm height occurred in areas predominantly affected by elements of Ca, Fe, Cl, S while all distributed separately, which implied a possibility of interference from water activities among Tataki, stone base and wood structures. In contrast, whitening phenomenon of wood adjacent to copper components occurred in areas predominantly affected by element of Cu.

1. INTRODUCTION

As one of the main factors to induce degradation of wood, white-rot fungi, UV and visible irradiation often cause bleaching discoloration of normal wood[1-6].

However, 2 types of different whitening phenomenon observed in wooden cultural properties have raised concern recently. Satou proposed a hypothesis about the formation of the whitish discoloration observed in the wood in contact with base-stones in the case of traditional wooden buildings. She ascribed this phenomenon to inorganic components (e.g., Ca, S, etc.) in stone, which might be transported by condensation water between wood and stone[7-9]. Zhou focused on the whitening phenomenon of wood adjacent to metal components of traditional architectures. In her research, degradation of wood and presentation of metal oxalate (e.g., CuC2O4, ZnC2O4, etc.) were detected in whitening wood[10]. Accordingly, different types of whitening wood might present different characteristics of elemental distribution, which provides a possibility to build correct recognition for various types of whitening phenomenon occurred in wood via non-destructive elemental analysis and reduce damage from sampling procedures.

The whitening phenomenon of wood was observed in areas adjacent to the stone base and copper components of the Confucian Temple (孔子廟, reconstructed in 1970 mainly by zelkova wood (ケヤキ)) of Kodokan of the Mito Domain (水戸弘道館, Mito City, Ibaraki Prefecture, Fig.1, Fig.2).

In this research, elemental investigation by handheld XRF analyzer was utilized to figure out the elemental differences of whitening phenomenon occurred in different wood structures, which were expected to enhance the understanding and assist the conservators to take suitable treatments toward whitening phenomenon of wood in the future.

2. METHOD

The elemental investigation was undertaken with a portable XRF device (Bruker AXS, S1 TURBO) under a 45s analysis time for each investigation point, and distributions of detected intensities of elements were illustrated in the form of contour plot graphs. For convenience, the sections were numbered from 1 to 12 according to structures, which was naturally separated into 12 sections by the position of its pillars (Fig.4).

Investigation points were determined according to the coordinate systems established from 5cm to 270cm height above bottom (where wood structures in contact with stone base) for sections of No. 5~11 in which copper components were applied to decorate the Nageshi(長押, a horizontal piece of timber to connect pillars), frames of windows and doors, and from 5cm to 70cm height above bottom for sections with almost no metal components (No. 1, 2, 3, 12). Investigation points of wooden structures in all sections were tested generally at 25cm intervals in the x-axis direction, 5cm intervals for areas lower than 70cm height and 10cm intervals for areas higher than 70cm height in the y-axis direction. In Nageshi, wooden parts adjacent to upper or lower edges and 5 cm above or below copper components were tested, and in vertical or horizontal frames of windows and doors, wooden parts between metallic components were tested at 5 cm intervals. 3683 points were tested in total.

The stone base, the Tataki which supported the stone base (三和土, earthen floor made from mixtures of lime, water, bittern, etc.), and a point of interior wood of the Confucian Temple were also investigated.

3. RESULTS AND DISCUSSION

Through XRF analysis of the stone base and the Tataki, predominant Ca and Fe element followed by small amounts of Si, K, Cl, Mn, Ti and etc. were identified. In interior wood, predominant Ca and K element followed by small amounts of Si, Cl, Mn, Fe and etc. were identified (Fig.3.).

Ca, Fe, Cl, S, Mn, Cu in wood structures were focused on and the distribution were summarized in the Fig.4. The lower limit of the color scale for each element was set based on the interior reference point to confirm the increase and decrease of elemental content in comparison with which. The upper limit was set based on the general elemental contents of wood structures. Areas exceeding the lower limit and upper limit of the color scale were represented by white and grey color respectively.

Contour plot graphs of Ca element reflected significant concentration below 70cm height. Not only in wood structures, which were directly in contact with the stone base, the significant concentration of Ca was continuously detected until height around 50cm in sections of No. 2, 7. Compared with contour plot graphs and photographs of each section, Ca highly concentrated areas were largely consistent with areas with whitening phenomenon.

Beside iron nail affected areas (showed as grey areas in contour plots), Fe was mainly detected in Ca concentrated areas, while most significantly detected around pillar-bases.

Both Cl and S were also detected in Ca concentrated areas. Cl was generally distributed in areas lower than 15cm height. On the other hand, except the concentration around 260~270cm height in sections of No. 7~9 which showed no connection with whitening of wood, S was mainly distributed in areas around 30~50cm height while not the areas directly in contact with the stone base in most sections.

Lower content of Mn was generally observed in stone base contacted areas. However, its concentration in some specific locations existed in sections of No. 1, 3 and 8, which seems located in whitening areas.

The characteristic distribution of Ca, Fe, S, Cl in same areas might imply a separation process induced by water activities among wood structures, stone base and Tataki for differences of solutes in affinity with stationary and mobile phase[11)], namely wood and water. It is possible that water activities induced transportation of elements and resulted in the increase of Ca and Fe contents, which might be provided by stone base and the Tataki, in wood structures. Although Cl and S were barely detected in the stone base, Tataki and interior wood, Cl and S were possibly transported to wood via the movement of water from the surrounding environment. Water activities among Tataki, stone base and wood structures might be closely connected with water content in foundation, which was primarily affected by ground water level and rainfall infiltration. By combining with specific monitoring investigations of water movement, more exact information about this interactive relationship were expected to be revealed in future researches.

Significant concentration of Cu was only detected in wood adjacent to copper components. Contour plot graphs of each section showed a similar inverse relationship between distance from cooper components and Cu contents, especially in vertical frames of doors and windows. Additionally, Cl was also detected in wood next to copper components, although not as significant as Cu (showed as blue in contour plot graphs). Relatively high moisture contents in wood in the vicinity of metal components are likely to happen because metals can act as a cooling medium, which might lead to transportation of elements in these areas[12)].

High moisture contents and water activities in wood might also increase the risk of bio-deterioration. Mn and Cu were important participants in lignin degradation process of the white rot fungi[13)]. Since the significant detection of Mn and Cu in whitening areas in this investigation, microbe activities should not be neglected in this case.

4. CONCLUSION

Investigation by handheld XRF analyzer for wood structures of the Confucian Temple indicated that XRF analysis could be an effective method to figure out the elemental characteristics of wood structures with different degradation phenomenon.

Results of XRF analysis reflected that the whitening phenomenon in wood structures lower than 70 cm height occurred in areas predominantly affected by elements of Ca, Fe, Cl, S, the whitening phenomenon of wood adjacent to copper components occurred in areas predominantly affected by element of Cu. However, since the limitation of XRF analysis, further studies of variation of moisture in wood and water content in foundation, microbe activities are therefore necessary to confirm the exact connections among whitening phenomenon of wood, the transportation of elements and microbe activities.

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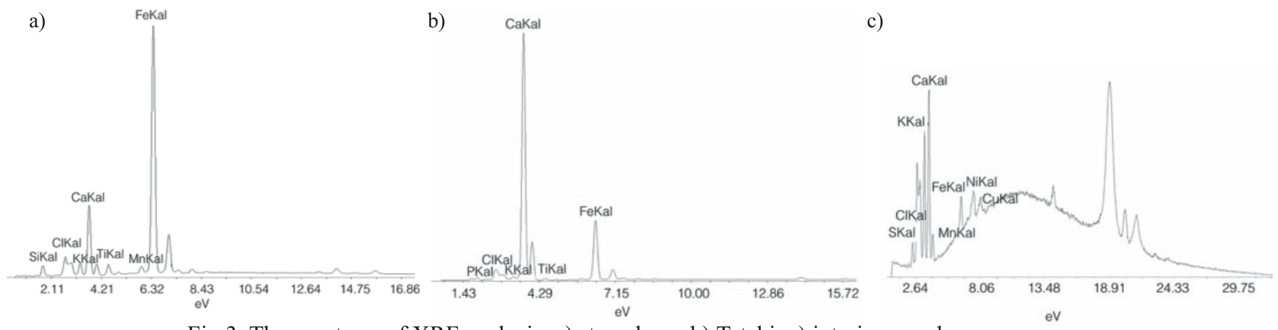

Fig.3. The spectrum of XRF analysis, a) stone base, b) Tataki, c) interior wood

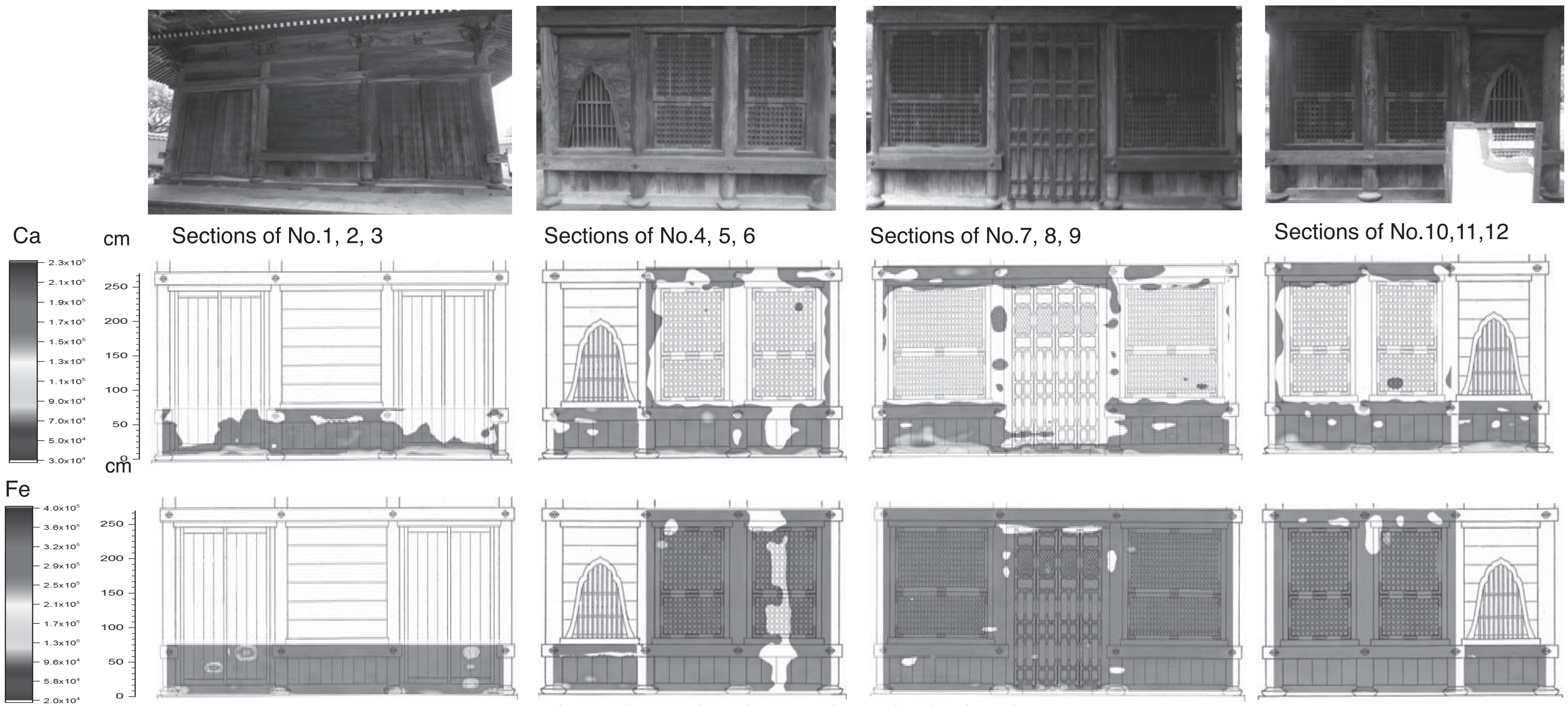

Fig.4-1. Photographs and contour plot graphs of each section

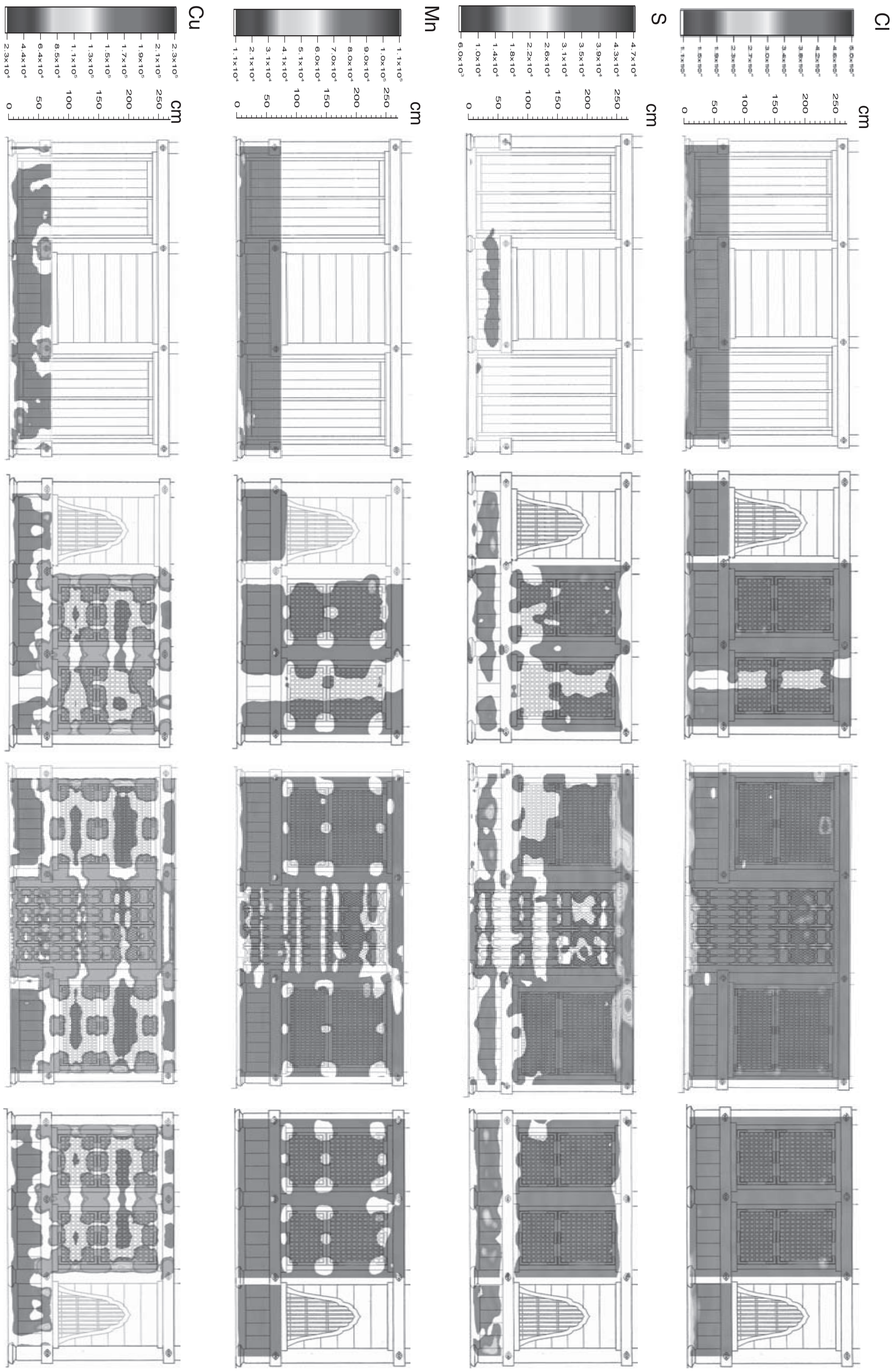

Fig.4-2. Photographs and contour plot graphs of each section