# ABSTRACTS (PH D THESIS)

## Study on conservation of archaeological waterlogged wood in Vietnam

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Archaeological waterlogged wood (WW) is one significant part of the archaeological resource because it provides evidence for the primary raw material used for structures, artifacts, and fuel throughout most of human existence. Therefore, conservation of cultural heritage is fundamental for conveying culture, traditions, ways of thinking and behaving to future generations. The preservation has an impressive impact on society from a political, sociological and anthropological point of view. The conservation treatments aim to prolong the life of cultural properties, without impairing the information and value they contain.

There are several archaeological sites have been discovered in Vietnam such as the ancient shipwrecks under the seabed in the south of Vietnam, wooden artifacts under the ground in the Thang Long heritage site - Hanoi, Bach Dang stake yard - Quang Ninh, and so on. Among them, the Thang Long Imperial Citadel site is one of the most important heritage sites, and it was named on the World Heritage list by UNESCO's World Heritage Committee in 2010. During the archaeological investigation, a significant proportion of wooden artifacts was unearthed from the Thang Long archaeological site. Some of them remain buried *in-situ* while others were salvaged from the site. These cultural properties are continually threatened by environmental impacts since the long-term protections are not implemented. Given the current condition of heritage, it is recommended that the immediate conservation treatment should be taken into account for preserving these artifacts. The conservation of cultural relics at Thang Long Imperial Citadel site, therefore, is one of the important plans put forth by the Government of Vietnam.

Conservation of archaeological WW is often a difficult subject in Vietnam. This is because general preservation methods cannot be applied for Vietnamese tropical WW. Therefore, this study aimed to establish appropriate preservation technology for the WW obtained from the Thang Long Imperial Citadel site, Hanoi, Vietnam.

Chapter 1 introduced the research background, objective and outline of the study. Additionally, the chapter also introduced conservation treatment methods currently applied to WW.

Chapter 2 summarizes the species identification and physicochemical properties of 15 waterlogged hardwood samples obtained from Thang Long archaeological site. The anatomical features showed that those samples were belonging to 10 different genera. The measurements on physical and chemical characteristics of WW showed different levels of wood degradation. Chemical analysis also confirmed the degree of wood degradation. Interestingly, the deterioration of *Erythrophleum fordii* Oliv. wood was very limited even after several hundred years of burial.

In Chapter 3, the natural durability of the *E. fordii* wood against white rot fungi was performed to elucidate the excellent state of preservation of this timber in the soil, and for determining appropriate procedures to conserve this timber. The results revealed high structural rigidity of *E. fordii* timber. The *E. fordii* wood fiber consisted of heavily lignified thick-walled fibers with the fiber lumina almost completely closed. 2D HSQC NMR evaluation revealed the *E. fordii* wood to have a heavily condensed lignin structure that reflected by the durability classes [1].

General preservation treatment methods using PEG4000, trehalose, and keratin was tested (Chapter 4). The results showed that the dimensional stability of WW was significantly improved after the treatments. The anti-shrink efficiency (ASE) values of the WW treated with keratin ranged between 72.5% and 96.2% depending on the species and degree of wood degradation. These values varied from 82.4% to 96.9% for the WW treated with PEG4000 or trehalose. Microscopic observations showed that the chemically treated woods maintained their original cell structures, forms, and shapes. It was also revealed that the reinforcement of cell walls by the feather keratin treatment was different from those observed for the PEG4000 or trehalose treatments. It was observed that PEG4000 and trehalose primarily filled the wood

voids, while keratin predominantly absorbed on the cell walls and middle lamella. Based on the improved dimensional stability of wood, shortened impregnation time, removability of chemical, and aesthetic results obtained from the treatment, keratin showed a good performance in average as a preservation materials [2].

In order to establish the suitable treatment conditions for Vietnamese WW, steady-state diffusion coefficients of PEG4000, trehalose, and feather keratin through eight WW species were carried out (Chapter 5). The diffusion coefficients were strongly affected by wood species, the anisotropic structures of wood, conservation agents. Based on diffusion coefficient, expected impregnation time for dip-diffusion treatments can be estimated. A new method utilizing the *in-situ* crosslinking reaction of the hydrophilic polymer to enhance recoverability of WW from unexpected drying was developed (Chapter 6). The results showed that treatment with cross-linked PAANa resulted in excellent shape recovery of WW after multiple drying-rewetting cycles, while the recovery was not complete in the untreated samples [3]. The cross-linking PAANa treatment could be used to provide resistance and recovery after unexpected drying, and may be used either as the primary conservation method or as a pretreatment in conjunction with other established conservation methods.

In summary, the species identification and physicochemical properties of 15 WW samples were examined. It is revealed that the *E. fordii* (called as Lim wood) commonly excavated from the site is extremely resistant to degradation. The condensed type lignin is abundant, and the wood is made from the thick wall wood fibers with fibers lumina were completely closed. General preservation treatment methods using PEG, trehalose, and feather keratin was applied for conservation of small WW samples. Among chemical investigations, keratin exhibited high performance in average as a preservation material. It was clarified that the diffusion coefficient of preservatives depends on wood species, and pointed out the necessity of deciding treatment conditions for each tree species. Finally, a new method of protecting excavated wood from unexpected drying by utilizing the *in-situ* crosslinking reaction of the hydrophilic polymer was developed. The results of this study can be applied practically for the conservation of WW in Vietnam. However, inherent limitations of WW materials, several species have not been explicitly explored within this study. Moreover, since the anisotropic structure of wood and the degree of deterioration varies widely (even though wood samples are cut from the same beams), future study is required to examine additional tests for different WW species and samples with different degrees of wood degradation.

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