Analysis and Appraisal of Fascine in Shahe Ancient Bridge Ruins, Xi'an, Shaanxi, China

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Abstract

The Chinese civilization has a long history, and the Chinese ancestors invented the "aquatic engineering technology" for flood control and water management as early as two thousand years ago: Fascine Body. The Fascine Body is a structure used to protect the bank and block the breach in the ancient Chinese flood control project. The excavation of the Shahe Ancient Bridge Ruins in Xi'an City, Shaanxi Province, China discovered the existence of a fascine body structure. Through C14 dating, fiber slice observation, infrared spectroscopy, X-ray diffraction, thermogravimetric analysis and SEM energy spectrum analysis of the fascine material, at the same time, conduct the microbial identification on it and the surrounding soil, analyze its dominant bacterial community, and control its microbial diseases in a targeted manner. The research on the fascine bank ruins solved the boundary problem of the width and length of the Shahe ancient bridge, evaluated the exact age of Shahe ancient bridge, provided the important materials for the research on ancient bridges, river embankments and other ruins, and also provided the important clues for the traffic and layout around Chang'an during the Qin and Han Dynasties of Chinese history.

1. Introduction

The Shahe Ancient Bridge Ruins are located in the Shahe River Channel, Qindu District, Xi'an City, Shaanxi Province, China. In 1989, the Shahe Ancient Bridge Ruins was named one of China's "Top Ten New Archaeological Discoveries". The layout of the Shahe Ancient Bridge Ruins is clear, and the preservation of wooden structure bridge piles is complete. The piles are the largest and oldest large-scale wooden structure bridge piles in the world. The research of the piles not only provides important physical materials for the research of the history of bridge construction, the history of bridge development, and the history of ancient metallurgy, but also has important value for the research of the changes in the history of transportation in the Qin and Han Dynasties and the development and evolution of bridges. The Shahe Ancient Bridge Ruins are located on the ancient river course. They are the main hub for crossing the Weihe River from the west of Chang'an City in Han and Tang Dynasties. They are also the important traffic bridge in and out of Chang'an City on the Silk Road. The bridge piles are constructed of rare nanmu and other woods. Various forms of tiles, bronze ornaments, floor tiles and other cultural relics unearthed near the ruins demonstrate the important status of the Shahe Ancient Bridge. The neatly arranged bridge piles and large cast iron structures on the riverbed provide reliable physical evidence for the restoration of ancient bridges in the Qin and Han dynasties in my country, and they are rare and precious relics for researching the development and evolution of bridge construction in China[1].

The fascine body is a structure used to protect the bank and block the rupture in the ancient Chinese flood control project[2, 3]. It is made of soft materials such as reeds, bamboo, willow branches, soil and gravel, and tied with ropes to form a cylindrical shape, to press the second fascine, the third fascine, and the fourth fascine on the outer surface of the first fascine to form a structure[4]. The use of fascine is a powerful technical guarantee for the ancients to construct in turbulent water. Therefore, it has been widely used in ancient Chinese water conservancy projects. This kind of technology has been used in many rivers such as the Yangtze River, the Yellow River and the Huai River, as well as in sea ponds and wharf

projects[5, 6]. Especially in the treatment of the Yellow River, emergency repair of levees, and blockage of ruptures, the fascine bodies are regarded as the most important engineering means[7, 8].

The existence of fascine bodies was also found in the Shahe bridge ruins, indicating that the Guanzhong area in Shaanxi Province had also used the fascine technology, pushing the credible history of fascine used in China to the Qin and Han dynasties. In this research, we used the identification and analysis of the sandy materials found in the Shahe ancient bridge ruins in Xi'an, Shaanxi, and analyzed the differences between the dominant microbial species and the bridge pier microbial species, so as to find the anti-fungal reinforcing agent for the sandy materials in a targeted manner. The long-term preservation of the Shahe ancient bridge ruins provides a certain scientific basis. At the same time, it correctly analyzes the status of the Qin and Han dynasties in the history of Chinese water conservancy, deeply understands the relationship between the bank and the ancient river bank, and judges the length and scope of the ancient Shahe bridge for the research of the Qin and Han dynasties, and it provides an important scientific basis for studying the traffic and layout around Chang'an City during the Qin and Han Dynasties.

2. Materials And Methods

2.1 Microscopic Slice Observation

Cut a small piece of sample and embed it with epoxy resin after trimming. After the resin was cured, used an ultra-thin microtome (EM UC7, Leica company, Germany) with a thickness of 1-2 μm . Fix the slice on the stage, used an optical microscope (XWY-VI, Zhuhai Hualun Paper Technology Co., Ltd., China) to observed the microstructure of the sample under 40 $\times$.

2.2 Infrared Absorption Spectroscopy (FT-IR) Analysis

The sample is rolled with an agate mortar to make a powder of about 2 mg, and the infrared spectrum is analyzed by KBr tableting method (Fourier transform infrared spectrometer, Nicolet is 10, Thermo Fisher company, USA). The spectral range is 4000-400 cm^{-1} , the resolution is 4 cm^{-1} , and the number of scans of the sample and background is 64 times. According to the characteristic absorption peaks of each functional group on the infrared spectrum of the sample, the molecular structure of the sample can be inferred.

2.3 X-ray Diffraction (XRD) Analysis

After the surface of the sample is polished and smoothed, an X-ray diffractometer (D8, Bruker company, Germany) is used to research the crystallinity index change of the Shahe sample relative to the modern sample. Conditions during the test: scan time is 21-30 s, scan range is 5-70 $^{\circ}$, scan rate is 0.02/s, X-ray tube is Cu target, radiant tube voltage is 40 kV, radiant tube current is 40 mA.

2.4 Thermogravimetric (TG) Analysis

Weigh 5 mg of the sample and use a synchronous thermal analyzer (TG209F1, NETZSCH company, Germany) to analyze the thermogravimetric curve of the Shahe sample to determine its preservation status. Conditions during the test: the protective gas is nitrogen, the temperature range is 35-900 °C, and the heating rate is 10 °C/min.

2.5 Scanning Electron Microscope and EDX Spectrum Analysis

The sample is glued on the sample stage horizontally and vertically using conductive glue, sprayed with gold, and SEM and energy spectrum observation and analysis is performed (SU3500, Hitachi company, Japan).

2.6 Microbial analysis and identification

Environment will influence the distribution of microorganisms, we could through the analysis of advantage microbial different confirmed that the difference between the bridge pier and fascine materials. The samples of bridge pier and fascine materials were placed in PDA medium cultured 48 hours (Aobox Biotechnology Co. LTD, Beijing, China), respectively, after being microorganisms grow out, use inoculation loops to pick a single colony, placed in a sterile PDA, repeat this step, When only one kind of microorganism grows in the plate, the mycelium and spores are sprayed with gold on conductive adhesive and photographed by scanning electron microscopy (SEM, SU-3500, Hitachi, Japan). The fungi were sent to Shanghai Parsono Biotechnology Co., LTD. (Shanghai, China) for species identification.

2.7 Data Analysis

SPSS 19.0 software (SPSS Inc, Chicago, IL, USA) was used for statistical analysis. Values are expressed as means±standard deviation (SD) of at least three independent experiments. Statistical comparisons were made using one-way analysis of variance, and multiple comparisons between groups were performed using Tukey's test, with $p < 0.05$ considered statistically significant and $p < 0.01$ highly significant.

3. Results And Discussion

3.1 Structure of Fascine Body

In water conservancy projects, "fascine" is used as a kind of hydraulic construction, it is used for firewood, bamboo and wood and other soft materials, mixed with earth and stone, and rolled as shown in Figure 2A, several fascine bodies are connected with ropes and piles in revetment, blockage, closure and other projects. The pictures found in the Shahe bridge ruins are consistent with the traditional craftsmanship. The silt block is wrapped in a mat-like weave and is related to a man-made river bank into the embankment. The silt layer is called "fascine bank", that is, a bank built with fascine body. We mark the edges of each small block in Figure 2B and C in Figure 2D and E respectively, and we preliminarily determine that the "fascine bank" range is the river bank at that time, and the northern boundary of the

bridge body is the newly discovered northernmost row of bridge piles. We can basically determine the length and scope of the No. 1 Shahe Ancient Bridge. According to the newly discovered silt layer accumulation and the range of bridge piles, it can be preliminarily determined that the plane where the silt layer is located is the river bank, and the northern boundary of the bridge body is bounded by the newly discovered northernmost row of bridge piles. Excavation was carried out on the south side of the protection greenhouses and continued to explore southward, but no new bridge piles were found. The above results confirm that the width of Shahe ancient bridge is 16 meters, and the northern end is 22 meters away from the protection hall. In 1989, when the Shahe Ancient Bridge was excavated for the first time, the C14 dating method was used to determine the age of the No. 1 Bridge about 2350-1910 years ago. In this research, we have dated two sets of braided fabric samples wrapped in a silt layer, the age is about 2210-2058 and 2230-2072, which are slightly later than the bridge piles, but the difference is not very large. The C¹⁴ dating results represent the growth age of the sample, not the construction age (Table 1). In the construction of bridge piles, it takes a long time for the trees to be planted to mature and then felled for the construction of the bridge piles, and there is often a big gap between the growth age and use age, it takes a long time for trees to grow until they are grown and then felled for use in constructing bridge piles. There is often a big gap between the age of growth and the age of use. and the soft materials used in the braid are mostly plants with a shorter growth cycle, and their growth age is close to the age of use, and the dating results of the bridge pile and the braid generally differ between 100-200 years, which is consistent with the tree's time required for growth. According to the dating results of fascine material, it can be determined that the construction age of the Shahe Ancient Bridge is the transitional period of Qin and Han Dynasties.

Table 1. C¹⁴ dating.

Number	Sample	C ¹⁴ dating	Calibration age	
			1σ (68.2%)	2σ (95.4%)
1	Wood	2210±30	260-206BC(33%) 320-275BC(27.9%) 359-347BC(7.3%)	371-199BC (95.4%)
2	Wood	2180±30	354-291BC(68.2%) 232-193BC(23.5%)	361-168BC (95.4%)
3	Braided fabric	2130±30	202-108BC(68.2%)	210-52BC (85.1%) 350-308BC (10.3%)
4	Braided fabric	2080±30	116-51BC(52%) 157-134(16.2%)	190-38BC (94.5%) 9-3BC (0.9%)
5	Wood	2170±30	352-297BC(40.2%) 211-176BC(24.3%) 228-221BC(3.7%)	360-155BC (92.9%) 134-116BC (2.5%)
6	Wood	2300±30	401-366BC(68.2%)	406-356BC (79.4%) 287-234BC (16%)

3.2 Microscope Slice Observation

The surface of the Shahe ancient bridge sample is dark yellow-brown, the section is charcoal black, and there is a small amount of soil particles attached. The shape is a long strip with a thickness of about 0.5 mm, the middle part is slightly recessed inward, and both sides are slightly higher. The texture is weak and fragile (Figure 3A). The control sample is modern fresh bamboo branches (Figure 3B). As shown in Figure 3C, in the longitudinal section microstructure of the Shahe ancient bridge sample, no wood anatomical structures such as wood rays, ducts, etc. are observed. It is a typical vascular bundle structure with parallel solid beams on the periphery, irregular in shape and uneven thickness, and it may come from thick-walled fibers. As shown in Figure 3D, there are some well-preserved parenchyma cells in the vascular bundle in the cross-section of the Shahe ancient bridge sample, but the fiber bundles are connected into one piece and there are breaks, and the middle layer cannot be distinguished. The above characteristics are consistent with the anatomical structure characteristics of bamboo, and it can be determined that the plant samples unearthed at the Shahe Ancient Bridge ruins are bamboo.

3.3 Infrared Spectroscopy and X-ray Diffraction Analysis

As shown in Figure 4A, the absorption peak at 1732 cm⁻¹ is derived from the C=O stretching vibration on the acetyl group, which is the characteristic absorption peak of hemicellulose which is different from other components. The peak was not detected in the infrared spectrum of the Shahe ancient bridge sample. Moreover, the cellulose C-H bending vibration peak at 897 cm⁻¹ was not detected in the infrared spectrum of the Shahe ancient bridge sample. The above results show that compared with fresh bamboo, the cellulose and hemicellulose of the Shahe ancient bridge sample are both significantly degraded.

XRD was used to determine the crystallinity of fresh bamboo and Shahe ancient bridge samples (Figure 4B), using segal's calculation method, namely:

$$CrI = \frac{I_{200} - I_{am}}{I_{200}} \times 100\%$$

$$I_{200}2\theta = 22^\circ \quad I_{am}2\theta = 18^\circ$$

In the formula: CrI is the relative crystallinity; I₂₀₀ is the maximum intensity of the diffraction surface; I_{am} represents the intensity of the non-crystalline background diffraction when the 2θ angle is close to 18°.

In the diffraction intensity curve of the Shahe ancient bridge sample, the strong diffraction peak at 16.1° disappeared, which indicates that the unit cell structure of the cellulose crystal area in the Shahe ancient bridge sample has changed during the long-term underground burial process. The calculation shows that the relative crystallinity of fresh bamboo is 65%, while the relative crystallinity of the Shahe ancient bridge sample is 29%, indicating that the degradation of cellulose mainly occurs in the crystallization area during the long-term underground burial of the Shahe ancient bridge sample.

3.4 Thermogravimetric Analysis

It can be seen from Figure 5A that the pyrolysis process of the Shahe ancient bridge sample can be divided into 4 stages. The first stage is from room temperature to about 200 °C, at this stage, only water is separated out, and the weight loss is small, there is a small weight loss peak at 109 °C, which is the drying stage; the second stage is 200-220 °C without obvious weight loss, mainly a small amount of depolymerization, restructuring and glass transition occurred inside the sample, which is the pre-pyrolysis stage; the third stage is about 220-410 °C, which is the main reaction stage, this stage is mainly due to the mass loss caused by the pyrolysis of cellulose, hemicellulose and lignin, the mass change in this stage accounts for about 84% of the total process. The fourth stage is the residue pyrolysis stage, the temperature range is 450-900 °C, in this stage, the TG curve declines slowly, mainly due to lignin cracking, entering the slow weight loss stage.

As shown in Figure 5B, the DTG curve of fresh bamboo has a shoulder peak at 316°C. Since hemicellulose starts to decompose in a large amount below 350 °C, cellulose mainly decomposes at 315-400 °C, and the pyrolysis peak of lignin only appears after 400 °C, so this shoulder peak mainly corresponds to the decomposition of hemicellulose. The shoulder peak does not appear in the Shahe ancient bridge sample, indicating that the hemicellulose in the Shahe ancient bridge sample is poorly preserved.

3.5 SEM analysis

Bamboo wood is used as a flood control material and is deposited along with the sand and gravel in the river bed. After long-term deposition, the surface takes the form of bamboo, but the inside has been carbonized. It can be seen from Figure 6 (A) and (B) that the surface and cross-sectional morphology of the bamboo carbonized layer have been completely carbonized into a hard and dense layered structure. The thickness of the carbonized layer with a certain regularity is 2-4 μm, and it is speculated that the layered structure is caused by the growth rings of bamboo. Fiber carbonization has a very good effect on preventing microbial degradation. Compared with other woods, bamboo contains a higher content of starch, sugar, protein and relatively less extractives such as resin, wax, and tannin, so it is more susceptible to microbial erosion, the degradation occurs, and the preservation state is worse. The collected samples found traces of fine fibers in the gaps between the carbonized layers, as shown in Figure 6 (C) and (D). Presumably, due to the partial carbonization of the surrounding fibers, the preservation of the fine fibers is greatly promoted.

3.6 EDX spectrum analysis

Figures 7A and 7B show the energy spectrum analysis results of the carbonized layer of the bamboo sample and the bamboo fiber, respectively. It can be seen that the main components of the carbonized layer are C and O, and their component contents are 65.72% and 33.24% respectively, and there are very small amounts of Mg, Al, Si, Ca, Mn, Fe and other trace elements. Compared with the fiber layer, the element types are basically similar. Its main components are C and O, and the content is 64.63% and 28.18% respectively. The increase in the content of Ca and Fe elements is speculated to be caused by the pollution of the sand on the surface.

3.7 Microbiological analysis

The Internal Transcribed Spacer Identification results show that the dominant microbial populations are different between the fascine material and bridge pier fungi isolated, as shown in Figure 8. The microbial population of bridge pier mainly includes *Trichoderma longibrachiatum*, *Trichoderma harzianum* and *Aspergillus flavus*. SEM and colony morphology are consistent with ITS analysis results. Fascine materials microorganism are mainly *Aspergillus versicolor*, *Talaromyces amestolkiae*, *Lecanicillium aphanocladii*. and the results were consistent with colony observation and SEM. The results above showed that the microorganism populations are different for both the fascine material and bridge pier, reminding us of the independence of the environment in fascine material and bridge pier.

Conclusions

Analyzing the fascine materials of the Shahe ancient bridge, it is found that the samples of the Shahe ancient bridge have typical characteristics of vascular bundles and specially arranged fibers and parenchyma, which are identified as bamboo; through infrared spectroscopy, X-ray diffraction analysis, and thermogravimetric analysis, SEM energy spectrum display analysis showed that the cellulose and hemicellulose of the Shahe ancient bridge sample were degraded seriously, and the cellulose degradation mainly occurred in the crystallization area. Microbiological analysis proved the environment difference between the fascine material and bridge pier, could effectively select the targeted anti-mold reinforcement materials. The excavation of the "fascine bank" ruins determined the bridge width and length boundary of the Shahe Bridge, which provided the important clues for the research of the traffic and layout around Chang'an City during the Qin and Han Dynasties, and also provided a scientific basis for the systematic research of the Shahe Ancient Bridge.

Declarations

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Author Contributions

The manuscript was prepared through contributions of all authors. BM planned the study together with JC and NL, conducted all data analysis, and wrote most of the manuscript. AC, JW, YL, DL, and JL contributed to the collection of samples in the article. All authors have given approval to the final version of the manuscript.

Conflict of interest

The authors declare that they have no competing financial interests.

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Figures

Figure 1

The Shahe ancient bridge ruins and its fascine bank ruins. (A) Shahe Ancient Bridge site 19-20 years of exploration map; (B) Site protection shed and surrounding geomorphic environment; (C) Fascine bank ruins; (D) Shahe ancient bridge ruins; (E) Unearthed woven material of fascine body.

Figure 2

Identification of the fascine bank ruins. (A) and (B) are the fascine bank ruins; (C) and (D) are the boundaries of each fascine bank unit marked by the fascine bank ruins; (E) is the basic structure and application diagram of the ancient fascine body unit.

Figure 3

The fiber structure of the Shahe ancient bridge fascine body sample. (A) Shahe ancient bridge sample image; (B) Fresh bamboo sample image; (C) Shahe ancient bridge sample longitudinal section microstructure; (D) Shahe ancient bridge sample transverse section microstructure.

Figure 4

(A) Infrared spectrum of Shahe ancient bridge sample and fresh bamboo; (B) Diffraction intensity curve of Shahe ancient bridge sample and fresh bamboo.

Figure 5

(A) TG/DTG curve of Shahe ancient bridge sample; (B) TG/DTG curve of fresh bamboo.

Figure 6

The surface and cross-sectional micro-morphology of the carbonized layer and fiber layer in the unearthed fascine material.

Figure 7

Carbonized layer and fiber surface energy spectrum analysis diagram of bamboo sample.

Figure 8

Isolation and identification of dominant microorganisms of fascine material and bridge pier.