Journal of Rice Science

Research Article

ISSN: 2690-5183 | Volume 1

Sticky Rice in Traditional Chinese Mortar

Zhu H[1], Zhang B[1, 2*] and Hu Y[1]

[1]Department of Cultural Heritage and Museology, Zhejiang University, Hangzhou 310028, China

[2]Department of Chemistry, Zhejiang University, Hangzhou 310027, China

***Corresponding author:**

Bingjian Zhang,
Department of Chemistry, Zhejiang University,
Hangzhou 310027, China,
E-mail: zhangbiji@zju.edu.cn

Received: 20 Dec 2020
Accepted: 05 Jan 2021
Published: 12 Jan 2021

Keywords:

Chinese traditional composite mortar; Sticky rice mortar; Historic building

Citation:

Zhang B, Sticky Rice in Traditional Chinese Mortar. J Rice Sci. 2021; 1(4): 1-4.

1. Abstract

Chinese traditional organic–inorganic composite mortar is an outstanding feature of ancient Chinese technology. One such mortar, made using sticky rice, was widely used and has contributed to the long-term preservation of ancient architecture. Our laboratory has conducted in-depth research on the application, history, and mechanism of sticky rice mortar. We found that the strength and toughness of sticky rice mortar are related to a microstructure similar to the biomineralization formed during the mortar's solidification. The toughness and anti-seepage are related to an organic–inorganic synergy between nano-sized calcium carbonate and encapsulated sticky rice film. This research is of significance to the scientific utilization of traditional technology, especially the protection and restoration of ancient buildings.

2. Chinese Traditional Composite Mortar

After the long historical development of Chinese civilization, tens of thousands of ancient architectural artifacts have been left as cultural heritage. These include palaces, altars, mausoleums, walls, bridges, dams, and so forth. For the protection of these ancient architectural cultural heritage artifacts, traditional compound mortar is one of the hot issues.

China was one of the earliest countries to burn and use lime. The use of traditional Chinese mortar can be traced back to the late Neolithic period [1]. In 1979, archaeologists studying the ruins of Huxizhuang village in Shaanxi Province discovered limestone, burned and unburned lime blocks, and lime slags that dated to 5000 years before the present. There were lime stones, fired lime blocks, semi-finished lime blocks, lime slags, and "white ash surface" floors [2]. This is direct evidence of artificial burning of lime. The most primitive lime mortar was proof against water, moisture, and insects. It was also decorative but, over time, it could no longer meet the needs of daily life. Ancient Greeks had created ash mortar given their geographical advantage [3] but, since the Yangshao period (3000-5000BC), ancient Chinese used inorganic additive mortars with red clay and brick powder as additives [4]. By the time of the Eastern Han Dynasty (AD 25-220), traditional Chinese compound mortars characterized by the use of sticky rice had become a mature technical innovation [5].

Chinese traditional compound mortar thus refers to organic–inorganic compound mortars used in ancient China. Natural, organic additives included sticky rice soup, juice from vegetable leaves, egg whites, tung oil, fish oil, or animal blood. These did not usually change the appearance of the mortar; after mixing with lime pulp, they could not be distinguished by the naked eye [5]. Sticky rice mortar seems to be the earliest documented and archaeologically discovered of these compound mortars. It has strength, toughness, and anti-seepage performance. Its strength is comparable to modern cement, and it was used extensively in ancient China.

3. Application and Production of Sticky Rice Mortar in Ancient Chinese Architecture

The earliest use of sticky rice mortars recorded in ancient Chinese literature can be traced back to the Song Dynasty (AD 960–1279). The book Song Hui Yao Ji Gao (written during the Qing Dynasty) reports the use of sticky rice mortar during the construction of

the city walls of Hezhou in the 6th year of the Qiandao era of the Southern Song Dynasty. This book placed the event at AD 1170, saying "the inside and outside walls, the watch tower and the gate were built with five layers of brick lime mortar and daubed with sticky rice mortar, which were very majestic, durable and strong enough to be used for defense" [6]. According to documentary records, sticky rice and sticky yellow rice were commonly used in mortar production. Because of its good performance, sticky rice–lime mortar was used extensively in many important structures, including tombs, city walls, and water resource facilities.

Early in the Eastern Han Dynasty, sticky rice mortar was used in building tombs-for example, the brick tomb in Xvzhou, Jiangsu Province. From ancient documents and archaeological examples, we can see that when a tomb structure did not use masonry, sticky rice mortar would be used as the main construction material. For this, sticky rice would be mixed with water and then boiled to achieve the effect of extremely mushy rice grains in an extremely thick rice soup. When the sticky rice soup was just beginning to thicken, an appropriate amount of lime would be added to the boiling mixture. There were two different applications for this sticky rice mortar. The first method was to cover the tomb with a layer of gravel sand and a layer of sticky rice mortar. The coffin would also be covered with tabia mortar. After being hardening, the structure would be as hard as stone. A second method of production was to add prepared tabia mortar to the boiling sticky rice soup, stirring evenly until it became a mass, then ramming it.

As mentioned above, the application of sticky rice mortar in urban constructions can be traced back to the Song Dynasty. Archaeological results show its use in the Tang Dynasty (AD 618–907): we have detected starch composition in mortar samples from the walls of Tang-Dynasty Xi'an, in Shaanxi Province. According to ancient literature and archaeological examples, there were two situations calling for the use of sticky rice mortar in urban construction. The first situation involved using masonry as a frame and sticky rice mortar as a cementing material. In this method, achieving iron-like hardness, builders needed to pour the sticky rice soup over every 0.3m of the rising construction. The second situation involved using sticky rice mortar as the main material and tamping the mortar until it was solidified. When tamping, the raw material was rammed to 1/4 of its original volume. After air drying, such a rammed building could withstand steel bombs. Buildings located at the seashore used large amounts of lime; oyster lime, with its similar properties, could economically be used instead of sandy soil for making glutinous ash.

Owing to its waterproof property, sticky rice mortar was also used in water facilities. The application of sticky rice mortar in water resource facilities can be traced back to the Yuan Dynasty. Archaeological findings exist in stone bridge constructions of the Song Dynasty, such as the Benshan Bridge of Southern Song–Dynasty Changzhou, Jiangsu [7]. The bank of Shaogong, the city wall at the royal tomb of the Ming Dynasty [8], the bank of the Qiantang river [9], and the bank of the Lugou bridge[10] were all built using sticky rice mortar and remain in good shape today. Ancient literature and archaeological examples show that the use of sticky rice mortar in water conservancy projects would mix 5kg of glutinous rice juice with 60kg of lime. Once mixed evenly, it was filled into brick seams and beaten evenly in order to achieve durability.

4. Scientific Research on Sticky Rice Mortar

In recent years, the Cultural Relics Protection Materials Laboratory of Zhejiang University has conducted a comprehensive study to identify sticky rice mortar, its mechanism of action, and the production process. Representatives such as Zhang Bingjian, Zhang Kun [11], Wei Guofeng [12], Yang Fuwei, Li Jiajia [13] and others have published a total of 16 articles in journals such as *Construction and Building Materials, the Journal of Archaeological Method and Theory, and Archaeometry*.

In the work of this laboratory, using chemical analytical methods, we analyzed 378 samples of ancient mortars sourced from 159 buildings, ships, and architectural relics. These sites were found across 22 provinces, autonomous regions, and municipalities of China. The specific test results were published in the article "Why Ancient Chinese People Like to Use Organic–Inorganic Composite Mortars?" [13]. Our analyses revealed that 112 mortar samples, representing 52 constructions and architectural relics, contained starch. The constructions included tombs, temple buildings, walls, and towers. Ancient mortars containing starch were mainly distributed in the Yangtze and Yellow River basins. The test results of most samples were violet, indicating that the samples contained amylopectin. We speculated that the additive was sticky rice [13].

Replicating the sticky rice mortar formula and preparing an imitation of sticky rice mortar, we found that the addition of sticky rice mortar can significantly improve the performance of lime mortar, giving it greater stability, mechanical strength, and compatibility. For example, adding 3% sticky rice to lime increased its compressive strength by 30 times and its surface hardness by 2.5 times, and its resistance to water immersion was greater than 68d [7]. Further investigation showed that sticky rice played at least two important roles, as follows:

- Polysaccharides like sticky rice can affect the biomineralization process of carbonate and change the size, shape and structure of carbonate crystals [10]. Yanglin [14], Zhang Xiuying [15], and Ding Weijia [16] et al., respectively, found that glucan, cyclodextrins, and modified starch change the shape and host lattice of calcium carbonate. We investigated the effects of sticky rice on the carbonation process of lime [17], finding that nano-size calcite was produced and its structure was more compact after the introduction of sticky rice. This kind of

compacting structure must be the basis of the remarkable properties of sticky rice–lime mortar, such as high pressive strength and surface toughness.

- There is cooperation between sticky rice and calcite [17, 18], that is, they wrap and pad each other, as can be seen from in SEM. These fine structures make sticky rice mortar strong and flexible. Similar organic-inorganic structure appears frequently in products of biomineralization including bones, teeth and mollusk shells [19]. Bones and teeth are hybrid materials of collagen and hydroxyapatite [20]; mollusk shells are hybrid materials of amylase, protein, and calcium carbonate [21].

Our laboratory has improved and optimized the sticky rice mortar formula so that the product may find better applications in the protection of modern cultural relics. Sticky rice–lime mortar has already been used in the restoration of some ancient masonry constructions. For example, it was used to repair the Shouchang Bridge of the Southern Song Dynasty and the stone tablets of the Fantian Temple in Five Dynasties–period (AD 916) Zhejiang. It was also used to repair the city walls of Three Kingdoms–period (AD 222–280) Shengzhou, Zhejiang, and the Guoan Temple Tower of Northern Song–dynasty (AD 960–1127) Wenzhou, Zhejiang. After more than five years of follow-up observation, the application remains effective.

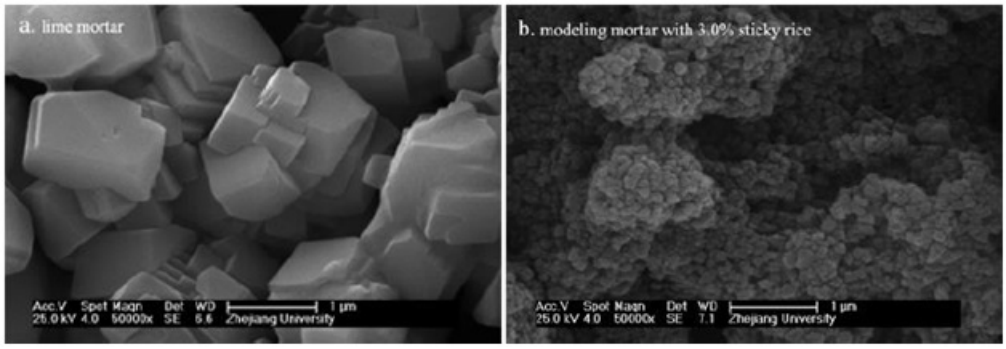

Figure 1: a Microscopic morphology of lime slurry samples; b Microscopic morphology of mortar samples containing 3% sticky rice[1]

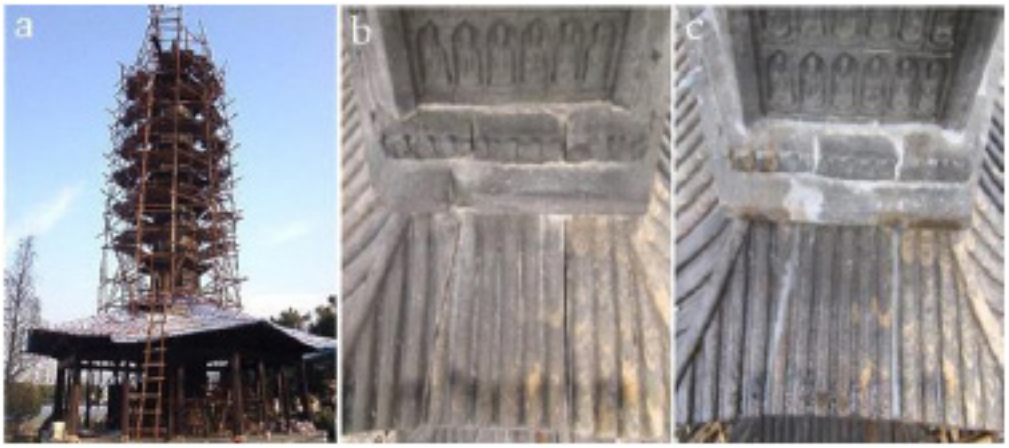

Figure 2: a Guoan Temple Tower restoration site; b and c Fourth eaves of pagoda before and restoration [1]

5. Conclusion

From historical documents and archaeological evidence, it is known that traditional Chinese organic–inorganic composite mortars are represented by this sticky rice mortar that, appearing at least 1800 years ago, is an outstanding technology of ancient China. Due to its durability, strength, bonding, toughness, and impermeability, sticky rice mortar was used widely in ancient Chinese buildings. Its strength and toughness are related to the biomineralization microstructure formed during the solidification of the mortar; its toughness and impermeability are related to the organic–inorganic synergy between generated nano-scale calcium carbonate and encapsulated sticky rice film. At a moment when the cultural heritage of ancient buildings is in urgent need of protection, research on sticky rice mortar can help with restorations and protection.

6. Acknowledgement

National Key R&D Program of China（2020YFC1522402）are greatly acknowledged for their financial support.

References:

1. Zhang BJ, Fang SQ, Li JJ, et al. Chinese traditional composite mortar (in Chinese) [M]. Beijing: China Building Materials Industry Press, 2020: 17, 20-26, 173, 219, 277, 329-37.
2. Zhang YL. A dictionary of Chang'an of the Han Dynasty[M]. Xi'an: Shaanxi People's Publishing House. 1993.
3. Grist ER, Paine KA, Heath A, Norman J, Pinder H. Compressive strength development of binary and ternary lime-pozzolan mortars[J]. MATERIALS & DESIGN. 2013; 52: 514-23.
4. Li ZX. The world's oldest concrete[M]. Archaeology. 1988; 8: 751-6.
5. Li JJ. A Study on the Understanding of Chinese Traditional Compound Grays[D]. Hangzhou: Zhejiang University, 2019.
6. Xu S. Song Hui Yao Ji Gao (Qing Dynasty). Beijing: Zhonghua Book Company. 1957.
7. Yang FW, Zhang BJ, Pan CC ,Zeng YY. Traditional mortar represented by sticky rice lime mortar--One of the great inventions in ancient China[J]. Science in China Series-Technological Sciences. 2009; 52: 1641-7.
8. Wang ZC. Ancient city below water - Sizhou city (in Chinese). Encyclopedic Knowl. 2005; 11: 54-6.
9. Yu HY, Chen D. Protection and development of tourism resources for ancient seawall of Qiantang River (in Chinese). Zhejiang Hydrotechn. 2004; 4: 9-10.
10. Wang YM. The Developing History of Cement in China (in Chinese). Beijing: China Architecture & Building Press. 2005. 4-5.
11. Zhang K, Fang SQ, et al. Contribution of enzymatic method for analyzing sucrose and starch in traditional chinese lime -and earth -based mortars[J]. QUIMICA NOVA. 2020; 43: 884-90.
12. Wei GF, Zhang H, Wang H, Fang S, Zhang B, Yang F. An experimental study on application of sticky rice-lime mortar in conservation of the stone tower in the Xiangji Temple[J].Construction and Building Materials. 2012; 28: 624-32.
13. Li JJ, Zhang BJ. Why Ancient Chinese People Like to Use Organic-Inorganic Composite Mortars? Application History and Reasons of Organic-Inorganic Mortars in Ancient Chinese Buildings[J]. Journal of Archaeological Method and Theory. 2019; 26: 502-36.
14. Yang L, Ding WJ, An YG, et al. Control synthesis of Aragonite Calcium Carbonate with Glucan as the template. Chem J Chin Univ. 2004; 8: 1403-1406.
15. Zhang XY, Liao ZJ, Yang L, Hu ZG, Jiang K, Guo YM. Interaction between β-Cyclodextrin and Crystallization of Calcium Carbonate (in Chinese). Acta Chim Sinica. 2003; 1: 69-73.
16. Ding WJ, An YG, Yang L, Liao ZJ, Zhang XY, Jiang k. Study on IR of interaction of three Modified-Starchs and Crystallization of Calcium Carbonate (in Chinese). Spectrosc Spect Anal. 2005; 25: 701-4.
17. Zeng YY, Zhang BJ, Liang XL. A case study and mechanism investigation of typical mortars used on ancient architecture in China. Thermochim Acta. 2008; 473: 1-6.
18. Liu Q, Zhang BJ. Bio inspired preparation of a protective Biomineralized material on the surfaces of historic stones. Acta Chim Sinica. 2006; 64: 1601-5.
19. Wang LD, Sun WZ, Liang T X, et al. Research status of Biomimetic materials (in Chinese). J Mater Eng, 1996, 2: 3-5.
20. Xie FL. Cross-linkage of hydroxyapatite/gelatin nanocomposite using EGDE (in Chinese). Sci Tech Gel. 2007; 27: 24-8.
21. Li XH, Hou WT. The conch structure and Biomimetic research on ceramics (in Chinese). Bull Chin Ceram Soc. 2003; 2: 53-5.