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Research Progress on Glutinous Rice Mortar

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***Abstract*—This article reviews the application history, production process, and reaction mechanism of glutinous rice mortar, analyzes the influence of different factors and additives on its mechanical properties, explores the research on modification by scholars in recent years to improve the properties of glutinous rice mortar, and provides prospects for future research on glutinous rice mortar based on practical applications.**

I. INTRODUCTION

In civil engineering, materials that can bond granular materials (such as sand and stones) or block materials (such as bricks and stones) into a whole are collectively referred to as cementing materials [1]. The generation and development of ancient Chinese architectural cementing materials are closely related to the development of Chinese architecture, among which the most representative cementing material is the world-renowned glutinous rice mortar. Glutinous rice mortar appeared in the southern and Northern Dynasties, developed in the Sui and Tang dynasties, and flourished in the Ming and Qing Dynasties [2]. During the Southern and Northern Dynasties, the use of glutinous rice mortar was limited and only used for noble tombs. In the Sui and Tang dynasties, with the development of architecture, people began to use glutinous rice mortar for Bridges, temples, ancient towers and other buildings. During the Ming and Qing Dynasties, rice production increased rapidly, and glutinous rice mortar was more widely used [3].

II. THE USE OF GLUTINOUS RICE MORTAR IN ANCIENT CHINESE ARCHITECTURE

Glutinous rice mortar was first applied to tomb construction. There was a brick tomb in Dengxian County of Henan Province in the Southern and Northern Dynasties, which used glutinous rice starch in its cementing material. Later, in the tombs of Song, Yuan, Ming and Qing Dynasties, glutinous rice mortar was also widely used to cast the tomb chamber, which was called "gray partition" structure [4]. In addition to tomb buildings, glutinous rice mortar is also used in building city walls and temple buildings. The pagoda of Taizhou Guoqing Temple was built in the reign of Emperor Kai of Sui and rebuilt in the 2nd year of Jianyan of Song Dynasty. Glutinous rice mortar was used as masonry mortar, which was extremely strong [5]. In the 1920s and 1980s, archaeologists found a large section of the Tang Dynasty city wall and a section of the Tang Dynasty city wall foundation in downtown Nanchang. After research, it was found that the site was built in the 14th year of Zhenguan (640 AD) of Emperor Taizong of the Tang Dynasty. The city wall was built with blue bricks and sewn with glutinous rice lime [6]. The ancient pagodas, temples and Bridges in Quanzhou built in the Tang and Song dynasties had good seismic performance and could withstand the 7.5-magnitude earthquake in 1604, which was closely related to the use of glutinous rice mortar as an adhesive [7]. Shanghai Jiading Fahua Pagoda, built from Yuan Dynasty to Da Dynasty, used glutinous rice mortar and white mortar to mark its foundation bricks [8]. Similarly, the city walls of Nanjing in the Ming Dynasty also used glutinous rice juice lime slurry to build the walls [9]. The glutinous rice mortar wall of Jingzhou in Ming Dynasty in Hubei province has a history of 500 years, and the construction of the city is very strong and easy to be attacked, and it is still "indestructible like concrete", so there is a saying of "striking Jingzhou with iron" [10].

In addition, because glutinous rice mortar has good waterproof and impermeable properties, it is also widely used in construction water conservancy. For example, the Shao Gong Dyke of the Mausoleum of the Ming Dynasty, the Yuhang Yuleian Stone Pond of the Qing Dynasty in Zhejiang Province, and the north and south sides of the Lugou Bridge in Beijing all used glutinous rice mortar as a masonry material, which is still indestructible after hundreds of years.

In general, glutinous rice mortar played an important role in ancient engineering. Its characteristics such as high strength, strong toughness and good impermeability made a qualitative leap in the cohesibility of building cementing materials, which is considered to be one of the highest achievements of ancient Chinese lime-based adhesives and played an important role in the history of Chinese architecture [4].

Fig. 1. Guoqing Temple Pagoda

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Fig. 2. Jiading Fahua Tower

Fig. 3. The Ming city wall

Fig. 4. Jingzhou Ancient City

In recent years, scholars at home and abroad have carried out a lot of work on the research field of glutinous rice mortar, and achieved some valuable conclusions and achievements. In order to comprehensively understand the research situation of glutinous rice mortar, this paper reviews and analyzes the production process of glutinous rice mortar, the reaction mechanism of glutinous rice mortar, the properties and influencing factors of glutinous rice mortar, and the future research direction of this field is deeply considered.

III. GLUTINOUS RICE MORTAR PRODUCTION PROCESS

As early as the Ming Dynasty Song Yingxing edited "Tiangong Kaiwu" on the composition of glutinous rice mortar, production methods and properties have been recorded in detail "used to Xiangtomb and water storage tank, then ash, into the river sand, loess two, with glutinous rice japonica, sheep peach vine juice and even, light build strong, never damaged, called Sanhetu [11]". In popular terms, it is to mix one part of gray soil, two parts of river sand and loess, with glutinous rice flour and goat peach vine juice to mix evenly, you get a three-soil, with this soil to build durable buildings, never destroyed. Shen Kuo, a scientist in the Northern Song Dynasty, wrote in his book Mengxi Pen Talk [13] that "Helian City is as close as a stone" after landing on the "Tongwan City" built with "Trinity Earth" in Bactrian [12], showing the firmness of "Trinity Earth".

The specific production process is as follows:

1) Preparation of Glutinous Rice Paste

When configuring glutinous rice mortar, the first thing should be the preparation of glutinous rice pulp. High-quality glutinous rice should be selected as raw materials, and the glutinous rice pulp should be boiled according to a fixed proportion. In the process of cooking, the water content and temperature of the glutinous rice pulp should be always paid attention to [14]. 75% to 77% of the composition of glutinous rice is starch, and the starch of glutinous rice is mainly amylopectin and a small amount of amylose [15]. Studies have shown that the complete gelatinization of starch requires sufficient water. When the water content is greater than 63%, the crystalline structure of starch will dissociate due to the expansion of starch particles. With the continuous heating, the fluidity of starch particles increases, and the crystallization zone can also be melted, showing common viscoelastic behavior [16]. Therefore, controlling the water content and temperature of glutinous rice pulp is the key to fully gelatinize glutinous rice starch and form organic/inorganic composite structure with lime mortar [17].

2) Add Lime

When the glutinous rice mortar is boiled and parked for half an hour, lime can be added in a 1:1 ratio [18]. Lime is calcined by natural raw materials such as limestone and dolomitic limestone with $CaCO_3$as the main component. When lime is added, the hydration reaction of lime in contact with water can be used to release a lot of heat, and the cooling rate of glutinous rice pulp can be delayed by controlling the hydration reaction rate of lime. In addition, a large amount of water is consumed in the lime hydration process, so part of the water in the glutinous rice paste will be absorbed, thus achieving the effect of optimizing the organic/inorganic composite structure of the glutinous rice mortar [17].

IV. PROPERTIES AND INFLUENCING FACTORS OF GLUTINOUS MORTAR

A. Mechanical Properties of Glutinous Mortar

1) Surface hardness

The surface hardness of glutinous rice mortar refers to the deformation ability of the material surface under the action of external forces, and Rockwell hardness and other indicators are usually used to evaluate the surface hardness of glutinous rice mortar. The results show that the

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surface hardness of glutinous rice mortar is affected by many factors, including the ratio of glutinous rice mortar, curing time and so on. Generally speaking, with the increase of glutinous rice content in glutinous rice mortar, the surface hardness will be increased. At the same time, in the early curing stage, the surface hardness value of glutinous rice mortar is relatively low. With the increase of curing time, the surface hardness also increases, and continues to increase after 90 days of age, but the growth rate is slow [19].

2) Compressive strength

The compressive strength of glutinous rice mortar is an important mechanical property index to measure its resistance under vertical pressure, and is one of the important indexes to evaluate the mechanical properties of glutinous rice mortar. There are many factors affecting the compressive strength of glutinous rice mortar, among which the most critical factor is the amount of glutinous rice. In order to test the compressive properties of glutinous rice mortar with different mass ratios of glutinous rice lime, Xie Yonggui prepared glutinous rice mortar samples with sticky rice content of 0%, 1%, 3%, 5%, 7% and 9%, and made a standard test block of 70.7mmx70.7mmx70.7mm. The test results showed that the sticky rice mortar test blocks with 0% and 1% added glutinous rice were brittle under the action of pressure, while the sticky rice mortar test blocks with more than 3% added glutinous rice were plastic damaged. At the same time, it can be seen from the curve of compressive strength over time that the compressive strength of the test block of glutinous rice mortar with 5% content of glutinous rice is much greater than that of other test blocks, and the compressive strength at 28-day age can be 1.5Mpa larger and the maximum can reach 2.8Mpa[20].

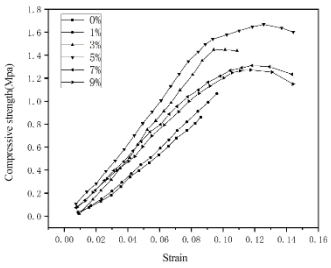

Fig. 5. Stress-strain relationship curve of 28d mortar compressive strength test

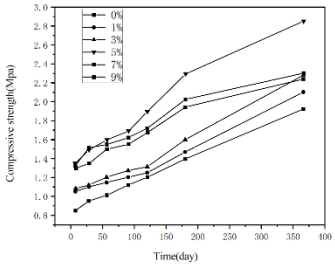

Fig. 6. Compressive strength versus time curve

3) Shear resistanceShear resistance

Shear resistance of glutinous rice mortar refers to the stability and strength of glutinous rice mortar when subjected to shear forces, which is usually evaluated by shear tests. In order to test the shear resistance of glutinous rice mortar, Xie Yonggui arranged glutinous rice mortar with the content of 1%, 5% and 9% respectively, and used the configured glutinous rice mortar to lay the concrete test blocks with the section size of 10cmX10cm and the thickness of 5cm into cube test blocks. During the test, the cube test block was subjected to three kinds of axial pressures of 0kPa, 75kPa and 150kPa, and the failure of the test block was observed, and the stress-strain curve was drawn.

Xie Yonggui observed the stress-strain curve and found that the maximum stress of glutinous rice mortar appeared at the place where the strain was less than 4% under the curing conditions of 7d and 28d room temperature. At the same time, the constitutive relationship between shear stress and shear strain of glutinous rice mortar was fitted by cubic spline interpolation formula. By comparing the shear resistance test of cement mortar conducted by Xue Pengfei under the same specimen size and similar test conditions [21], it is found that the shear strength of glutinous rice mortar with 5% glutinous rice content is 25kPa, about 1/5 of that of cement mortar.

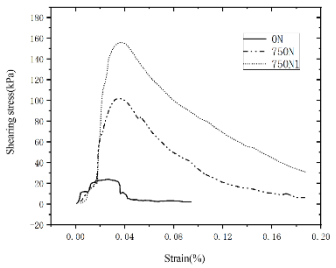

Fig. 7. Shear Stress-Strain Curve for 7d at Room Temperature

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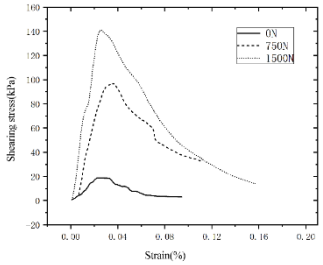

Fig. 8. Shear Stress-Strain Curve for 28d at Room Temperature

B. Effect of lime type on the properties of glutinous mortar

Different kinds of lime often have a great influence on the micro-morphology of glutinous rice mortar formed after carbonization. In view of this aspect, Wei Guofeng et al. prepared glutinous rice mortar by analyzing four different kinds of lime: pure calcium hydroxide, industrial lime calcium powder, analytical pure calcium oxide and industrial calcium oxide, and tested the surface hardness, compressive strength, freeze-thaw resistance and other properties of these four kinds of glutinous rice mortar respectively, observed the microscopic morphology of different glutinous rice mortar, and analyzed and discussed the influence of lime types on the properties of glutinous rice mortar. Studies have shown that the compressive strength, surface hardness and freeze-thaw resistance of glutinous rice mortar prepared by analytical pure calcium oxide and industrial calcium oxide are superior to those prepared by analytical pure calcium hydroxide and industrial lime calcium powder, among which, the compressive strength and other properties of glutinous rice mortar prepared by analytical pure calcium oxide are the best [22].

C. Effect of aggregate type on the properties of glutinous mortar

Aggregate usually plays a role in cementing materials to increase the strength and structural stability of the material. In order to explore the influence of different aggregate types on the properties of glutinous rice mortar, Hu Yue et al. prepared glutinous rice mortar with three different aggregates of brick particles, river sand and quartz sand, and analyzed and compared its surface strength, compressive strength and frost resistance. The experimental results show that the addition of brick particles, river sand and quartz sand can greatly improve the shrinkage and freeze resistance of glutinous rice mortar [23]. Because the brick particles can react with the lime in the mortar, the bonding strength between the aggregate and the lime paste is improved, so the author suggests that the brick particles should be used as the aggregate of glutinous rice mortar in the protection practice of brick and stone cultural relics.

D. Effect of Temperature on the Properties of Glutinous Mortar

The influence of temperature on chemical reaction can not be ignored. In previous research experiments, heating time is usually used as the critical standard for cooking glutinous rice pulp. However, different scholars do not have a clear basis for the selection of heating time. In view of this, Chen Wenwu et al. studied the glutinous rice mortar prepared by glutinous rice pulp at different temperatures, and concluded that the best reinforcement effect was obtained when the temperature of glutinous rice pulp was controlled at 75℃ ~ 80℃ [24].

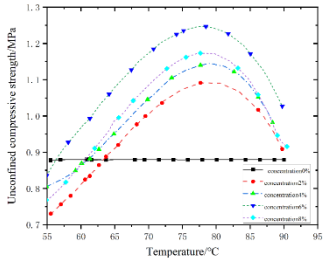

Fig. 9. Unconfined compressive strength as a function of temperature

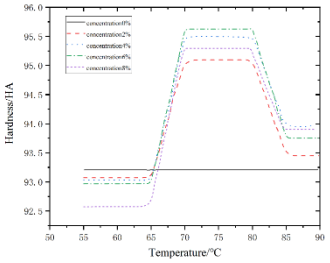

Fig. 10. Hardness versus temperature

V. REACTION MECHANISM OF GLUTINOUS RICE MORTAR

A. Curing Mechanism of Glutinous Mortar

The glutinous rice mortar invented by ancient Chinese artisans gave full play to the stickiness of glutinous rice and turned glutinous rice into an organic building material. Modern scientific research shows that the composition of quicklime is CaO, which becomes $Ca(OH)_2$when it meets water, and $Ca(OH)_2$combines with CO_2in the air to form $CaCO_3$calcite crystal. The lower the crystallinity of calcite, the smaller the particles and the denser the structure. The carbonization process of lime is as follows:

$$CaO + H_2O = Ca(OH)_2 \quad (1)$$

$$Ca(OH)_2 + CO_2 = CaCO_3 + H_2O \quad (2)$$

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At the same time, the main component of glutinous rice amylopectin is a polysaccharide, and many studies have shown that polysaccharide can often be used as a template agent in the process of biomineralization. When added to glutinous rice pulp, $CaCO_3$ will "biomineralize" with amylopectin, the main source of glutinous rice viscosity. In this case, glutinous rice pulp will act as a template agent in the biomineralization process, and play a role in restricting and regulating the size, morphology and structure of $CaCO_3$ crystal formed by inorganic ions during crystallization [4]. The Laboratory of Cultural Relics Conservation of Zhejiang University [25] studied the samples of glutinous rice mortar in traditional Chinese stone monument, and found that the precipitated crystal form of $CaCO_3$ is irregular at a higher concentration of glutinous rice, but when the concentration of glutinous rice solution decreases, the precipitated crystal form of $CaCO_3$is mostly cubic, similar to calcalite, which fully indicates that the concentration of glutinous rice solution controls the crystal form of $CaCO_3$. It reflects the characteristics of biomineralization. In addition, Zhao Qinjiang investigated the microscopic morphology of $CaCO_3$mineralization induced by amylopsin [26]. With the increase of the concentration of glutinous rice paste, hexagonal flake $CaCO_3$was formed and stacked into hexagonal pumpkin shaped spherulocarpel $CaCO_3$crystals with a uniform particle size of 40~45μm. The $CaCO_3$ crystal produced by this biomineralization reaction is much smaller and denser than the common calcite crystal type $CaCO_3$crystal.

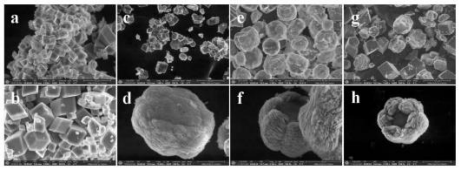

Fig. 11. $CaCO_3$ crystal stacking process

In addition, the components of glutinous rice paste are embedded in $CaCO_3$ crystals, wrapped around each other and packed tightly, forming an organic/inorganic synergistic composite structure. This composite structure makes glutinous rice mortar have good toughness and strength, which is also the reason why glutinous rice mortar has high compressive strength and surface hardness.

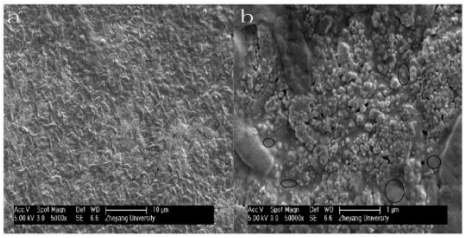

Fig. 12. SEM photos of glutinous rice mortar solution

B. Anti-corrosion mechanism of glutinous rice mortar

Glutinous rice is a very perishable crop, and studies have found that the presence of amylopectin of glutinous rice that has not been completely degraded can still be found in the mortar samples collected from some relics [3]. The main reason why highly perishable glutinous rice does not rot in mortar for a hundred years is that during the curing process of glutinous rice mortar, the partially reacted hydrated lime $Ca(OH)_2$wrapped in glutinous rice mortar provides a strong alkaline environment for glutinous rice mortar, which can inhibit and kill bacteria and prevent starch spoilage. However, as more and more $CaCO_3$is generated, the glutinous rice mortar gradually solidifies, and the CO_2penetrated into the glutinous rice mortar is limited. Before $Ca(OH)_2$is completely transformed into calcium carbonate, the ionization reaction of $Ca(OH)_2$always exists, maintaining such a strong alkaline environment [4], so the glutinous rice component in the glutinous rice mortar is always retained.

VI. MODIFICATION OF GLUTINOUS RICE MORTAR

Although glutinous rice mortar has a long history, the scope of its application has been greatly limited due to its characteristics such as high shrinkage, low early strength and poor erosion resistance. Based on the development of modern science, many researchers have adopted the addition of different types of modifiers to glutinous rice mortar to improve its mechanical properties, etc., so that it can be used to solve many ecological problems in modern society.

A. Physical modification

In order to solve the problem of Jiuzhaigou Calcium Wah geological crack repair, Fan et al. added Jiuzhaigou Calcium Wah particles and modifiers to the traditional glutinous rice mortar formula, and carried out the flow test, compression test and flexural test on the made modified glutinous rice mortar, which were used to test its basic physical and mechanical properties and microstructure. The results show that the modified glutinous rice mortar has good initial fluidity, controllable setting time and significantly improved early strength. When the dosage was 0.52 kg of glutinous rice slurry, 0.23 kg of quicklime, 0.77 kg of gypsum, 1 kg of calcareous particles, and 0.01 kg of modifier, the performance of the slurry was better, and the 60d compressive strength reached 19.37 MPa and the flexural strength reached 5.75 MPa [27]. Exploring the curing mechanism, it can be found that calcium particles as calcium carbonate "nuclei", play an important role in the curing process, which provides a stable adhesion environment to induce the growth of calcium carbonate crystals, the

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generated calcium carbonate crystals through the "agglomeration - bridging - winding and wrapping The generated calcium carbonate crystals, through the process of "agglomeration - bridging - winding and wrapping", optimize the pore structure inside the mortar. The application of modified glutinous rice mortar in the field test of repairing cracks and reinforcing the cliff body in Jiuzhaigou achieved remarkable results, greatly reducing the amount of running water leakage, which fully demonstrated that the glutinous rice mortar has excellent compatibility with calcium China particles [28].

Yang Lingming et al. explored the effect of cooked tung oil on glutinous rice mortar and its mechanism of action through modern scientific and technological means. The results showed that the encapsulation of cooked tung oil accelerated the carbonization of slaked lime in glutinous rice mortar, enhanced the peak strength of calcite crystals, and improved the early strength and freeze-thaw properties of glutinous rice mortar [29]. Meanwhile, silica fume and slaked lime produced water-hardened calcium silicate, which significantly improved the mechanical properties and shrinkage of the glutinous rice mortar, in which the early compressive strength was increased by 23 %, the flexural strength was increased by 15 %, and the 7d shrinkage was decreased by 71 %.

In recent years, China's rapid social and economic development at the same time, a large number of coal mining has led to a large number of coal gangue residue open piles, resulting in land occupation, ecological damage and many other problems. The key difficulty in repairing the ecology of coal gangue slag hill is to reduce the porosity of the slag, for the slag large porosity Su Jinyuan et al. added gypsum monohydrate, organic water retention materials and three kinds of modifiers in the traditional glutinous rice mortar to improve its compressive strength and hydrological properties. The experimental results showed that the addition of brown silk fiber and sodium rosinate significantly increased the compressive strength, while the addition of diatomaceous earth decreased the compressive strength, and at the same time, the effect of modified glutinous rice mortar and organic water retention materials on the hydrological properties was very significant, the permeability coefficient and evaporation rate decreased significantly, and the water holding capacity of the field was significantly increased[30] .

Revolutionary sites in northern Shaanxi, which are dominated by loess kilns, have suffered serious damage in recent years from rain erosion, wind erosion, and natural effects such as freezing and thawing caused by the alternation of seasons, as well as drying and wetting. These effects have led to a variety of wall defects, including water seepage from the top of the kilns, flourization and peeling of the internal and external walls. As one of the birthplaces of the Chinese Revolution, the conservation and restoration of revolutionary sites in this region is of great historical and cultural value. It was found that the damage of kiln walls was mainly related to the water sensitivity of loess, while Jia Dongqin et al. summarized the previous studies and found that these studies were mainly aimed at changing the mechanical properties of cured loess, but relatively little research was done on the water sensitivity of loess. Therefore, Jia Dongqin et al. adhered to the principle of not using chemical materials in the restoration process, modified the glutinous rice mortar by adding green building materials, and explored the effect of modified glutinous rice mortar on the improvement of water sensitivity of loess. The experimental results showed that the gypsum and calcite crystals in the modified glutinous rice mortar filled the pores, changed the original pore structure of loess, and enhanced the bonding between soil particles, which changed the water sensitivity of loess [31], and could reduce the damage due to water sensitivity very effectively.

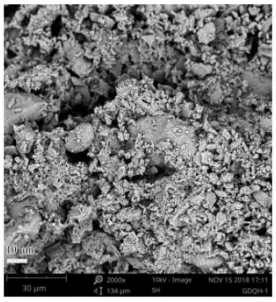

Fig. 13. Encapsulation of soil particles by modified glutinous rice mortar

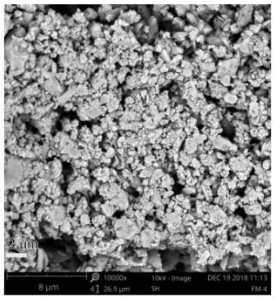

Fig. 14. Pore filling by calcite crystals

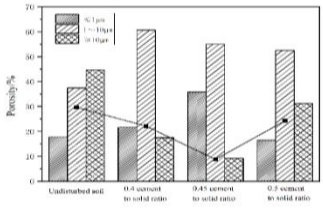

Fig. 15. Comparison of void fraction between in-situ loess and cured soil at 28d maintenance age

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Masonry structure because of its high strength and durability in my long architectural history has an inestimable cultural value, but the masonry structure is very dependent on the collodion material between the blocks, once the collodion material is subjected to weathering and erosion, the overall performance of the masonry structure will be greatly weakened. Therefore, it is imperative to find a suitable repair material for the restoration of masonry ancient buildings. In order to solve this problem, Lu Che et al. added 12.5%, 25% and 50% of metakaolin and 1% of hemp fiber to the traditional glutinous rice mortar as the background of the frost damage of masonry, and investigated the durability of the new modified glutinous rice mortar by using infrared light diffraction, X-ray powder diffraction, and scanning electron microscopy and other microscopic analysis methods. The results showed that the mixed incorporation of hemp fiber and metakaolin significantly improved the strength, frost resistance and salt resistance of the glutinous rice mortar, and the durability of the glutinous rice mortar under the coupled conditions of chloride and salt erosion-freeze and thaw cycles was slightly enhanced with the increase of hemp fiber incorporation, and showed a tendency to increase and then decrease with the increase of the metakaolin incorporation [32]。 Therefore, it is shown that the modified glutinous rice mortar with 1% hemp fiber and 25% kaolin clay has the best performance.

B. Chemical modification

Li Zuguang et al. found that aluminum sulfate played a significant role in improving the mechanical properties, freeze-thaw resistance and water resistance of glutinous rice mortar, while alum mainly played a role in improving the mechanical properties of glutinous rice mortar. Gypsum did not significantly improve the mechanical properties and weathering resistance of glutinous rice mortar[33] .

Zheng Xiaoping and others improved the surface hardness, compressive strength and water resistance of glutinous rice mortar by adding homemade silicate to the mortar. It was found that the best improvement of the performance of glutinous rice mortar was achieved when 6% homemade silicate was added. Among them, the 66d compressive strength was as high as 1.41 MPa, the freeze-thaw resistance was increased by 133% compared with the blank sample, and the water resistance was increased by 43.8%. The improvement of the properties such as water resistance of the modified glutinous rice mortar may be related to the generation of hydrated calcium silicate in the mortar[34] .

Wei Guofeng et al. investigated the microstructure and composition of glutinous rice mortar by using SEM and XRD, and explored the effects of three additives, namely, paper reinforcement, aluminum sulfate and gypsum dihydrate, on the properties of glutinous rice mortar. The experimental results showed that paper reinforcement improved the compressive strength and freeze-thaw resistance of glutinous rice mortar most obviously, and aluminum sulfate had the best effect on improving the drying shrinkage of glutinous rice mortar [35]. In addition, the addition of gypsum dihydrate not only failed to improve the freeze-thaw property of glutinous rice mortar, but also decreased the compressive strength and surface hardness of the samples with the increase of gypsum dihydrate content. Based on the results of the study, the author gives the suggestion that 6% aluminum sulfate or 3% paper tendon is preferably used as an additive for glutinous rice mortar in cultural heritage conservation practice .

Cao Zedjie et al. In view of the traditional glutinous rice mortar in the modern practical application of glutinous rice mortar is easy to corruption, paste glutinous rice mortar is easy to delamination and segregation, as well as ordinary glutinous rice mortar carbonation reaction rate is slow and other problems, the use of pre-gelatinized glutinous rice as a reinforcing agent, by accelerating the carbonation of the high-strength pre-pasted glutinous rice mortar (HPR-LM), and pre-pasted glutinous rice mixing and the water-solid ratio on the degree of reaction of the HPR-LM and mechanical properties and mechanism to carry out a study on the influence law and mechanism. The influence of pre-glutinous rice and water-solid ratio on the reaction degree and mechanical properties of HPR-LM was studied. Through XRD, infrared spectroscopy (IR), thermogravimetric analysis(TG) and other means of characterization, it was shown that the carbonation reaction of HPR-LM was reduced when the water-solid ratio was too high or too low, and the reaction degree of HPR-LM was highest when the water-solid ratio was 0.3, when the HPR-LM was sufficiently hydrated and with high porosity. Meanwhile, it was also shown that the compressive strength of HPR-LM first increased and then decreased with the increasing dosage of pregelatinized glutinous rice, and the compressive strength of HPR-LM reached the highest when the dosage of pregelatinized glutinous rice was 3%[36] .

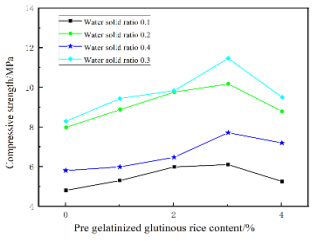

Fig. 16. Compressive strength of pregelatinized glutinous rice mortar

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In order to meet the requirements for grouting materials for dam reinforcement in the calcified area of Jiuzhaigou, Wang Wenjun et al. modified the traditional glutinous rice mortar by adding admixtures, silica fume, and gypsum into the glutinous rice mortar after summarizing the previous research, aiming to obtain a glutinous rice mortar slurry with good initial fluidity, easy to be pumped and with high early strength, and investigated the mechanical properties of the glutinous rice mortar with different lime/gypsum mass ratios [37]. The results showed that the slurry exhibited excellent initial fluidity and high early strength when the mass ratios of lime and gypsum were 0.11 and 0.25, respectively, and it is also worth noting that increasing the proportion of lime also helped to reduce the setting time and improve the fluidity.

VII. CONCLUSIONS AND OUTLOOK

For thousands of years, glutinous rice mortar has been favored by ancient craftsmen for its excellent durability and mechanical properties, and has become an important invention on behalf of traditional Chinese mortar. This paper summarizes the research on glutinous rice mortar, explains in detail the development history, production process, properties and influencing factors of glutinous rice mortar, as well as the improvement of glutinous rice mortar in response to modern ecological problems, and explores the properties and application effects of modified glutinous rice mortar.

(1) Glutinous rice mortar production process. First of all, the preparation of glutinous rice slurry, the selection of high-quality glutinous rice in proportion to the boiling and attention to the water content and temperature, so that the starch is fully pasted, and then add lime, the use of lime and water hydration reaction exothermic, the control of the hydration rate to slow down the cooling of the glutinous rice slurry, and at the same time to absorb some of the water to achieve the optimization of the organic / inorganic composite structure.

(2) Mechanical properties of glutinous rice mortar. The mechanical properties of glutinous rice mortar include surface hardness, compressive strength and shear resistance. Studies have shown that the surface hardness of glutinous rice mortar increases with the increase of glutinous rice content, and the prolongation of maintenance time also increases the surface hardness. In terms of compressive strength, the specimen of glutinous rice mortar with 5% glutinous rice content showed the highest compressive strength, and the compressive strength at the age of 28 days could be up to 2.8 Mpa. In terms of shear resistance, the maximum stress of the glutinous rice mortar appeared at the strain of less than 4%, and the shear strength of the glutinous rice mortar with 5% glutinous rice content was about 1/5 of that of the cement mortar.

(3) Influencing factors of the performance of glutinous rice mortar. The performance of glutinous rice mortar is affected by a variety of factors. In terms of external additives, aluminum sulfate and paper tendon can significantly improve the mechanical properties, freeze-thaw resistance and water resistance of glutinous rice mortar, while alum and gypsum dihydrate have relatively small effects. The addition of homemade silicate and cooked tung oil also enhanced the properties of glutinous rice mortar. In terms of lime types, the best properties such as compressive strength were found in the glutinous rice mortar prepared using analytically pure calcium oxide. In addition, different aggregate types also have an effect on the performance of glutinous rice mortar, and the addition of brick particles can improve the shrinkage and frost resistance of glutinous rice mortar. Finally, the temperature also has an important effect on the preparation and performance of the glutinous rice mortar, and the best reinforcement effect was obtained when controlled at 75°C to 80°C.

(4) Reaction mechanism of glutinous rice mortar. The curing and anti-corrosion mechanism of glutinous rice mortar is a complex process. During the curing process, CaO in quicklime reacts with water to form $Ca(OH)_2$, and subsequently combines with CO_2 in the air to form $CaCO_3$ crystals. Meanwhile, the branched-chain starch in glutinous rice acted as a template agent to promote the biomineralization process of $CaCO_3$, controlling the size, morphology and structure of the crystals. This biomineralization reaction generated fine and dense $CaCO_3$ crystals, and the glutinous rice slurry components were embedded in the formed $CaCO_3$ crystals to form a composite structure with organic/inorganic synergism, which endowed the glutinous rice mortar with better toughness and strength. In terms of the anti-corrosion mechanism, the incompletely reacted slaked lime provided a strong alkaline environment that inhibited and killed bacteria, preventing the corruption of glutinous rice, while this strong alkaline environment was maintained as the infiltrated CO_2 was restricted, so the glutinous rice components in the mortar were always preserved.

(5) Modification effect of glutinous rice mortar. In recent years, numerous researchers have applied modified glutinous rice mortar to improve modern ecological problems, and very effective results have been achieved. The method of adding calcified particles and modifiers to traditional glutinous rice mortar can improve the initial fluidity, setting time and early strength of glutinous rice mortar, and the initial fluidity as well as early strength of modified glutinous rice

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mortar is better when the mass ratio of added lime and gypsum is 0.11 and 0.25, respectively, and the compressive strength of the modified glutinous rice mortar with the addition of brown silk fibers and sodium rosinate is significantly improved, the permeability coefficient and the evaporation rate are greatly reduced, and the 1% of the modified glutinous rice mortar with the addition of brown silk fibers and sodium rosin is significantly improved. The compressive strength of the modified glutinous rice mortar with the addition of brown silk fiber and sodium rosinate was significantly improved, the permeability coefficient and evaporation rate were greatly reduced, and the strength, frost resistance and salt resistance of the glutinous rice mortar with the mixing of 1% hemp fiber and 25% metakaolin were significantly improved.

With the development of science and technology, a variety of modern cementitious materials emerge one after another, glutinous rice mortar is limited by its complex process, slow curing and other reasons, has long been unable to catch up with the pace of the times of the development of construction. However, due to the modern cement and ancient buildings in all aspects of the problem of incompatibility, glutinous rice mortar with its excellent performance in the stage of ancient building restoration shine. According to the summary of the current domestic research on glutinous rice mortar, the hardening of glutinous rice mortar belongs to the air-hardening material, so the application of glutinous rice mortar in the water environment is more limited, so for the glutinous rice mortar how to harden in the water environment is a research direction worth exploring in the future.

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