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Strength Experiment and Mechanism Analysis of Cement Mortar with Sticky Rice Pulp

□ ZHANG Huzhi¹, XIONG Xincui¹, LI Xiaobao¹, ZHOU Luyun¹, LI Li¹, WU Shengfeng¹, LI Yuqi¹, FENG Shuai¹, ZHOU Xiaofeng²

1. School of Civil Engineering, Hunan University of Science and Technology, Xiangtan 411201, Hunan, China;

2. College of Civil Engineering, Hunan University, Changsha 410008, Hunan, China

Abstract: Cement mortar with sticky rice pulp is an innovative composite material. Investigating its mechanical properties and strength mechanism is essential for the future engineering application. Taking the pulp concentration and the mortar ages as the variables, we tested five groups of blocks for the compressive strength and flexural strength, and observed their microstructures with a scanning electronic microscope. The results indicated that the microstructure got dense if the added pulp had a concentration of about 0.3%, and thereby its flexural strength would significantly improve, while the hydration products agglomerated and the microstructure got loose if the added pulp had a concentration of more than 1.0%, which caused a substantial decline in flexural strength. Besides, the hydration reaction was hindered at the early stage due to the addition of the pulp; hence the early strength of the mortar is on the low side. According to the strength mechanism analysis, all the results are mainly attributed to the effects: "water-reduction", agglomeration and retarding, caused by the addition of the pulp.

Key words: sticky rice pulp; cement mortar; compressive strength; flexural strength; age; microstructure; strength mechanism

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0 Introduction

Trinity mixture fill^[1,2], an ancient Chinese engineering construction adhesive material, is made by mixing lime, clay, sand, and water. The addition of sticky rice pulp, which is rich in branched starch that acts as an inhibitor, controls the formation of calcium sulfate crystals. More importantly, it generates a dense microstructure, resulting in higher compressive strength, as well as enhanced corrosion and moisture resistance for the improved trinity mixture fill, also known as sticky rice lime mortar^[3-5].

Mainly aiming at the restoration of ancient build-

ings, the research on sticky rice lime mortar is quite advanced^[6,7]. In terms of its macro performance^[2,8,9], all argued that there are compatibility of macroscopically homogeneous materials between trinity mixture fill and sticky rice pulp, and amylopectin in sticky rice would play a role of inhibitor. Moreover, the addition of sticky rice pulp improves the water retention, the water absorption and the curing effect of the trinity mixture fill, and prolongs its setting time and slows down the carbonation of the mortar. Therefore, the sticky rice lime mortar has improved physical and mechanical properties. Yang *et al.*^[10] concluded that sticky rice lime mortar subject to

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Biography: ZHANG Huzhi, male, Ph.D., Associate professor, research direction: optimization design of concrete structures. E-mail: zhanghz_hnu@163.com

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wetting-drying exhibited a heterogeneous strain field that correlates well with its heterogeneous microstructure. On the basis of analysis for the micro mechanism of sticky rice lime mortar, Zhao *et al*^[11] found that gelatinized amylopectin would induce carbonation of calcium carbonate, promote the production of Mg^{2+} and Fe^{3+} in calcite, and adsorb Pb(II) for an extremely high level. Yang *et al*^[12] considered that the formation of hydration products of cementitious materials was strongly affected by amylopectin as a main ingredient in sticky rice.

Since the emergence of cement in 1824, cement-based materials such as cement mortar and concrete have rapidly developed into some of the most mainstream construction materials. Although these materials exhibit satisfactory compressive strength, their brittleness during compression and weaker tensile and flexural performance indicate a need for improvement. The addition of sticky rice pulp may offer a solution by enhancing these properties, necessitating research into its effects. Currently, there is almost no research in this area. This paper, therefore, conducted experimental research on cement mortar with sticky rice pulp to understand the compressive and flexural strength of this new material and to explore the underlying mechanisms of how sticky rice pulp influences strength.

1 Experimental

1.1 Base Materials

The base materials include slag Portland cement with grade of P. S 32.5, medium sand with fineness modulus of 2.7, tap water, and common water milled sticky rice flour.

The preparation for sticky rice pulp can be divided into three steps:

Step 1: Mixing we calculated the dosage of sticky rice flour and tap water as follows:

$$s_t = \frac{m_g}{m_g + m_w} \times 100\% \quad (1)$$

where s_t denotes the concentration of the thick sticky rice pulp and it is 5% in the process, m_g the dosage of sticky rice flour, and m_w the dosage of tap water. Accordingly, both sticky rice flour and tap water were weighed for mixing. It should be noted that the actual dosage of water should be obtained by deducting the water content of the natural accumulated sand on the basis of dosage of the tap water calculated in formula (1). After determination, the moisture content of the sand was 5%. In order to avoid agglomeration during heating, we stirred the

sticky rice flour in water at normal temperature.

Step 2: Boiling Its concentration should remain constant in the process of keeping boiling. This process usually takes about two hours as least, and hence it needs to be stirred all the time during the process to prevent the concentration from decreasing due to the paste pot; at the same time, it is also necessary to add tap water regularly to the initial volume scale marked in the pot to make up for the water loss caused by vaporization.

Step 3: Dilution with different concentrations The prepared thick pulp is divided into four parts by volume and then diluted into sticky rice pulp with concentration of 1.5%, 1.0%, 0.6%, 0.3% according to the volume ratio of the thick pulp to tap water is 1:2.3, 1:4.0, 1:7.3 and 1:15.8, respectively.

1.2 Grouping and Preparation of Test Blocks

Test blocks of cement mortar with design concentrations of 0.3%, 0.6%, 1% and 1.5% of sticky rice pulp are set as the four test groups, and one group of test blocks of common cement mortar is used as the control group. Firstly, we designed the mortar in the control group according to the mix proportion of the common cement mortar with strength grade of Chinese M20, which represents a characteristic cube mortar compressive strength of 20 MPa with 95% guarantee rate. The mortar in the test groups were designed with the same proportion, except replacing water with equivalent sticky rice pulp completely and directly. The dosage of each base material is listed in Table 1. There were 24 blocks in each group, which included 12 characteristic cube blocks of 70.7 mm × 70.7 mm × 70.7 mm for compressive strength test and twelve characteristic prism blocks of 40 mm × 40 mm × 160 mm for flexural strength test. The blocks were cured to the ages under standard conditions required by Chinese Code^[13]. Let it be added here that the cement mortar with sticky rice pulp in a concentration of 1.5% had poor fluidity, and the consistency was only about 30 mm.

2 Test Results

2.1 Compressive Strength and Flexural Strength

The compressive strength test and the flexural strength test were completed in accordance with the provisions of the Chinese Codes^[14,15]. After the test, the mean value of the measured cube compressive strength and the measured prism flexural strength were calculated respectively first, and then the characteristic values

Table 1 The dosage of base materials

Mortar type	Group	Design concentration of sticky rice pulp /%	For compressive strength test				For flexural strength test			
			Sticky rice pulp /g	Tap water /g	Cement /g	Natural accumulated sand /g	Sticky rice pulp /g	Tap water /g	Cement /g	Natural accumulated sand /g
Common cement mortar	I	0	0	124			0	91		
	II	0.3	124	—			91	—		
Cement mortar with sticky rice pulp	III	0.6	124	—	190	580	91	—	140	420
	IV	1.0	124	—			91	—		
	V	1.5	124	—			91	—		

of the strength with a 95% guarantee rate were calculated according to the following formulas:

$$f_{cu,k}^{3d} = f_{cu,m}^{3d} - 1.645\sigma_c^{3d} \quad (2)$$

$$f_{cu,k} = f_{cu,m} - 1.645\sigma_c \quad (3)$$

$$f_{f,k}^{3d} = f_{f,m}^{3d} - 1.645\sigma_f^{3d} \quad (4)$$

$$f_{f,k} = f_{f,m} - 1.645\sigma_f \quad (5)$$

where $f_{cu,k}^{3d}$ and $f_{cu,k}$ are the characteristic cube compressive strengths; $f_{f,k}^{3d}$ and $f_{f,k}$ are the characteristic prism flexural strengths; $f_{cu,m}^{3d}$ and $f_{cu,m}$ are the mean cube compressive strengths; $f_{f,m}^{3d}$ and $f_{f,m}$ are the mean prism flexural strengths; σ_c^{3d} , σ_c , σ_f^{3d} and σ_f are the standard deviations corresponding to the strength test results, respectively. The above parameters with a superscript of 3 d denote they are related to 3 d age, as well as the ones without superscripts denote they are related to 28 d age. The test results are as listed in Table 2.

2.2 Influence Functions of the Strength

The influence functions of concentration of sticky rice pulp on strength of cement mortar are defined as follows:

$$\eta_c^{3d}(s) = f_{cu,k}^{3d} / f_{cu,k}^{3d,0} \quad (6)$$

$$\eta_c(s) = f_{cu,k} / f_{cu,k}^0 \quad (7)$$

$$\eta_f^{3d}(s) = f_{f,k}^{3d} / f_{f,k}^{3d,0} \quad (8)$$

$$\eta_f(s) = f_{f,k} / f_{f,k}^0 \quad (9)$$

where $\eta_c^{3d}(s)$, $\eta_c(s)$, $\eta_f^{3d}(s)$ and $\eta_f(s)$ are the influence functions of 3 d compressive strength, 28 d compressive strength, 3 d flexural strength and 28 d flexural strength, respectively; s is the design concentration of sticky rice pulp and all the functions take it as the variable; $f_{cu,k}^{3d,0}$, $f_{cu,k}^0$, $f_{f,k}^{3d,0}$ and $f_{f,k}^0$ are the 3 d characteristic cube compressive strength, 28 d characteristic cube compressive strength, 3 d characteristic prism flexural strength, 28 d characteristic prism flexural strength of common cement mortar (i.e. its design concentration of sticky rice pulp is 0) in group I. The fitting curves are as shown in Fig. 1.

2.3 Strength Characteristic Analysis

The following strength characteristics can be seen from Table 2 and Fig. 1:

1) Early strength The early strength of all cement mortar in the test groups was lower than that in the control group, including both compressive and flexural strengths. Among them, the mortar in group II (i.e., with a pulp concentration of 0.3%) had the relatively lowest early strength, being about 40% lower than the control group (i.e., common cement mortar). The early strength of the mortar in the test groups showed an increasing

Table 2 The test results

Group	Design concentration of sticky rice pulp/%	Compressive strength test/MPa						Flexural strength test/MPa					
		3 d age			28 d age			3 d age			28 d age		
		$f_{cu,m}^{3d}$	σ_c^{3d}	$f_{cu,k}^{3d}$	$f_{cu,m}$	σ_c	$f_{cu,k}$	$f_{f,m}^{3d}$	σ_f^{3d}	$f_{f,k}^{3d}$	$f_{f,m}$	σ_f	$f_{f,k}$
I	0.0	3.16	0.17	2.89	20.49	1.00	18.84	1.13	0.15	0.88	4.54	0.19	4.23
II	0.3	1.80	0.02	1.76	19.60	0.26	19.17	0.59	0.02	0.55	5.06	0.15	4.82
III	0.6	2.16	0.14	1.93	19.54	1.31	17.38	0.89	0.07	0.78	4.55	0.11	4.36
IV	1.0	2.04	0.04	1.98	18.35	0.47	17.59	0.81	0.00	0.81	4.67	0.16	4.40
V	1.5	2.18	0.08	2.05	19.58	1.73	16.73	0.91	0.04	0.84	4.20	0.89	2.74

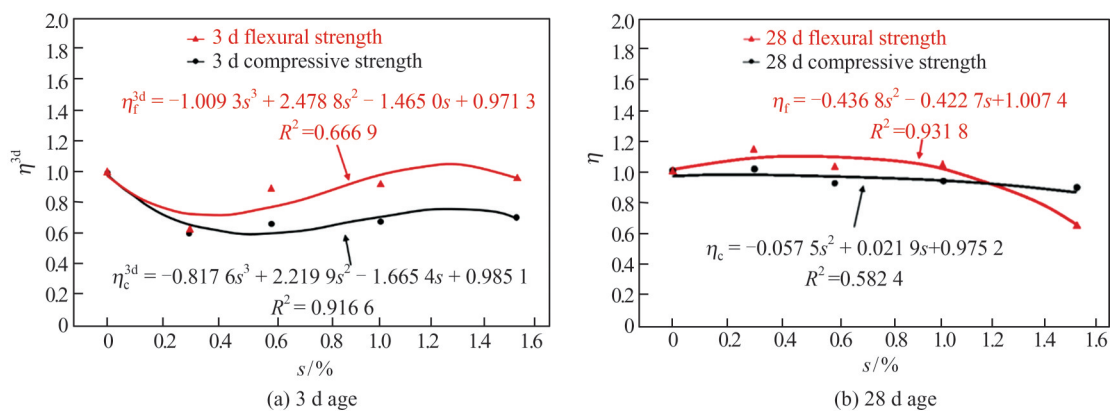


Fig. 1 Fitting curves for influence function of strength

trend with the increase in pulp concentration from 0.3% to 1.5%. The mortar in groups III, IV, and V (i.e., with pulp concentrations of 0.6%, 1.0%, and 1.5%, respectively) had relatively similar early strengths. Their early compressive strength was 10% to 16% higher than that in group II, while their early flexural strength was even 40% to 50% higher than that in group II.

2) Long-term strength Among the four test groups and the control group, the mortar in group II exhibited the highest long-term strength; its long-term flexural strength was about 14% higher than that in the control group, and its long-term compressive strength was just slightly higher than that in the control group. The long-term strength of the mortar in the test groups showed a downward trend with the increase in pulp concentration from 0.3% to 1.5%. Their long-term compressive strength declined slowly, such that the strength of the mortar in group V was only 11% lower than that in group II. With the increase in pulp concentration, their long-term flexural strength initially dropped slowly and then more rapidly. The strength of mortar in groups III and IV was both slightly higher than that in the control group and slightly lower than that in group II, while the long-term flexural strength of the mortar in group V was only 57% of that in group II.

According to the above strength characteristic analysis, it could be preliminary inferred:

1) In Fig. 1, it is evident that the addition of sticky rice pulp at concentrations between 0.3% and 1.0% results in excellent performance at both 3rd and 28th days flexural strength of cement mortar. Notably, the 0.3% concentration exhibits the lowest flexural strength at 3rd day but the highest at 28th day. However, when the concentration of sticky rice pulp exceeds 1.0% up to 1.5%, there is a significant decrease in flexural strength, particularly at 28th day.

2) In the tests at 3rd day, the compressive strength

of the cement mortar with the addition of 0.3% sticky rice pulp concentration is 40% lower than that of common mortar. As the concentration increases to 0.6%-1.5%, the compressive strength improves by 10% to 16%. By the 28th day, the compressive strength at 0.3% concentration is slightly higher than that of common mortar, while it is 11% lower at a 1.5% concentration. This indicates that the addition of an appropriate sticky rice pulp concentration can significantly affect the performance of cement mortar, making the enhancement of its compressive strength crucial.

3) It can be understood that the reduction in early strength with the addition of sticky rice pulp may be attributed to its retarding effect on the setting of cement mortar.

3 Microstructure Analysis

After strength tests, cement paste block samples with sizes of 10 mm to 20 mm were taken from crushed test blocks of each age of each group. They were retained in absolute ethanol to terminate the hydration reaction. After all the samples were collected, they were taken out for drying, sample preparation, gold spraying, and then the microstructures with magnification of 2 000 times, as shown in Fig. 2, were obtained by the Scanning Electronic Microscope (SEM) of FEI Q45-type.

According to Fig. 2, the microstructure analysis is carried out as follows:

1) The common cement mortar It can be seen from a comparison between Fig. 2(a) and Fig. 2(b) that the flocculent gel substance of C-S-H was constantly produced in the mortar of the control group, and the holes and some other defects at the early stage were gradually filled and patched by these hydration products as the hydration reaction progressed. Consequently, the

compactness of the microstructure increased, and meanwhile, the separation between the grains decreased.

2) The cement mortar with sticky rice pulp in a concentration of 0.3% As can be seen from Fig. 2(c), the mortar in group II initially had few hydration products, indicating that the hydration reaction was somewhat hindered at this stage. This likely explains why both its compressive and flexural strengths were lower than those in the control group initially. Over time, however, the hydration products in group II became well-distributed, as evidenced by Fig. 2(d), indicating that the hydration reaction eventually occurred fully. As a result, the grains were well aggregated, and almost no obvious hole defects remained in the microstructure, resulting in higher compactness at this stage compared to the control group. This likely contributes to its long-term compressive strength being significantly higher and its flexural strength slightly higher than those in the control group.

3) The cement mortar with sticky rice pulp in a concentration of 1.0% As shown in Fig. 2(e), at the early stage, the hydration reaction of the mortar in group IV was slightly more extensive than that in group II but was much slower than that in the control group. Consequently, its compressive strength was slightly higher, and its flexural strength was much lower compared to those in mortars with a lower concentration of the pulp and the standard one at this stage. Additionally, as

shown in Fig. 2(f), although its hydration products seemed to increase significantly at the later stage, they were excessively aggregated in some areas, leading to uneven distribution. Thus, its compressive strength became lower than that in mortars with a lower concentration of the pulp at this stage. However, the microstructure generally appears dense with few defects, so its long-term flexural strength is not lower than that in the control group.

4) The cement mortar with sticky rice pulp in a concentration of 1.5% As shown in Fig. 2(g), the hydration reaction of the mortar in group V had progressed to a certain extent, and therefore its compressive strength and flexural strength were close to those in the control group at the early stage. As shown in Fig. 2(h), at the later stage, the hydration products seriously agglomerated, resulting in a very loose microstructure with a large number of hole defects. Thus, both its long-term compressive and flexural strengths were far lower than those in the control group. It was also evident that the test blocks were prone to crumbling, lacked integrity, and were brittle when crushed or broken. Additionally, with such a concentration, the mortar had very poor fluidity and consistency, which would also make it difficult to ensure construction quality. Therefore, no further comparative tests on cement mortar with sticky rice pulp concentrations higher than 1.5% were conducted.

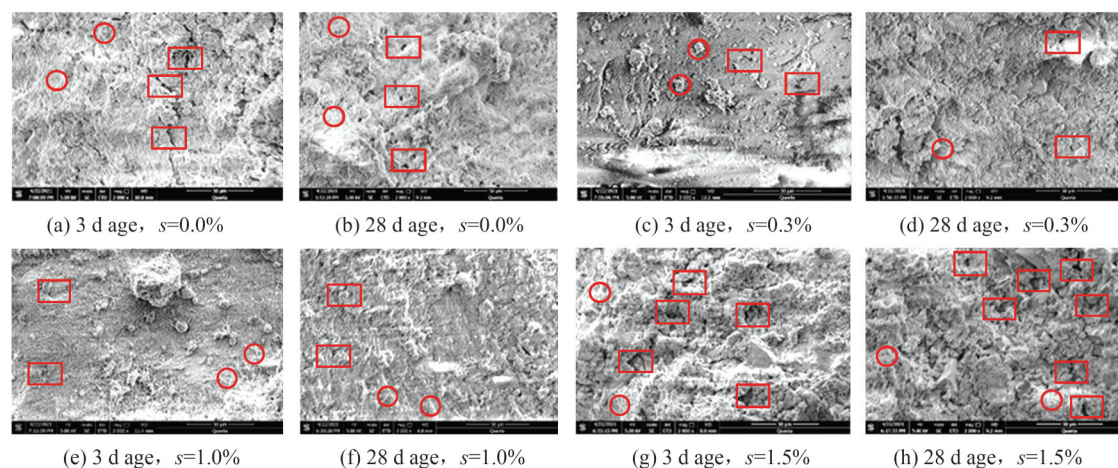


Fig. 2 SEM images for microstructures in magnification of 2 000 times

Circular shapes represent calcium silicate hydrates (C-S-H), while rectangular shapes denote pores

4 Strength Mechanism Analysis

4.1 "Water Reduction" Effect of Sticky Rice Starch

Sticky rice starch is mainly composed of amylose (sugar starch) and amylopectin (gum starch), whose

chemical structures^[16,17] are shown in Fig. 3. It can be seen from Fig. 3 that the molecular composition of amylose includes hydrogen (—H), amino (—NH_2) and hydroxyl (—OH), while the molecular composition of amylopectin is mainly hydroxyl (—OH)^[17]. Note that hydroxyl is a kind of hydrophilic group.

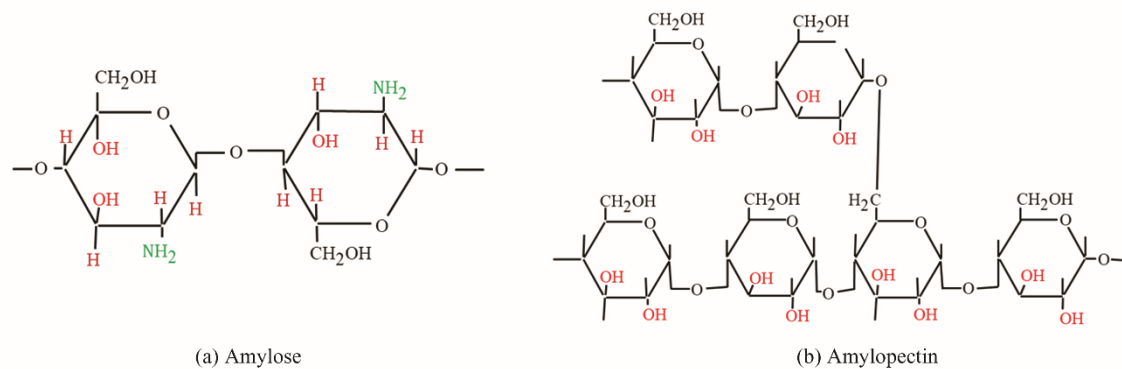
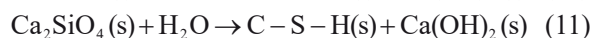
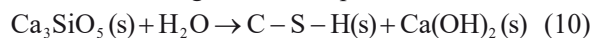


Fig. 3 Chemical structures of sticky rice starch

When boiling (thick) sticky rice pulp, some free water combines with amylopectin, becoming bound water, thus reducing the free water available for the hydration reaction. This creates a "water reduction" effect^[16]. If the concentration is low enough that the remaining free water in the pulp is sufficient for the hydration reaction throughout the process, this effect is equivalent to reducing the actual water-cement ratio, and accordingly, the long-term strength of the mortar must be higher than that of the common one. Conversely, if the concentration increases to a point where there is a shortage of free water for the hydration reaction at a later stage, the long-term strength will be lower than that of the common cement mortar.

4.2 Polymerization Effect of Sticky Rice Pulp

Sticky rice pulp contains amylopectin and other bonding substance, thus the added pulp can enhance the polymerization of molecules of hydration products, that is, polymerization effect. According to Ref. [18], the hydration reaction in common cement mortar is mainly going on as the following chemical equation:



where C-S-H is an amorphous colloidal substance with an indeterminate chemical composition and accounts for about 70% of hydration products of cement. Calcium hydroxide ($\text{Ca}(\text{OH})_2$) accounts for only about 20%, existing in a crystalline state. The rest of the products are solid particles, such as calcium aluminate hydrates (C-A-H), among others. The microstructure diagrams are shown in Fig. 4. If the concentration is at a relatively low level of about 0.3%, moderate polymerization will lead to reinforced cohesiveness of the mortar and improved compactness of the microstructure, as shown in Fig. 4(b). In this state, the mortar with the pulp significantly enhances long-term compressive strength and slightly improves long-term flexural strength compared to the standard mortar. However, if the concentration is 1.0% or stronger, excessive polymerization results in serious agglomeration and tremendous heterogeneity among the hydration product molecules, resulting in a loose microstructure, as shown in Fig. 4(c). In this case, the long-term strengths, especially the flexural strength, are lower than those of mortars with lower pulp concentrations and the standard mortar. Moreover, according to the SEM images of microstructures shown in Fig. 2(d), 2(f), and 2(h), granularity becomes more pronounced

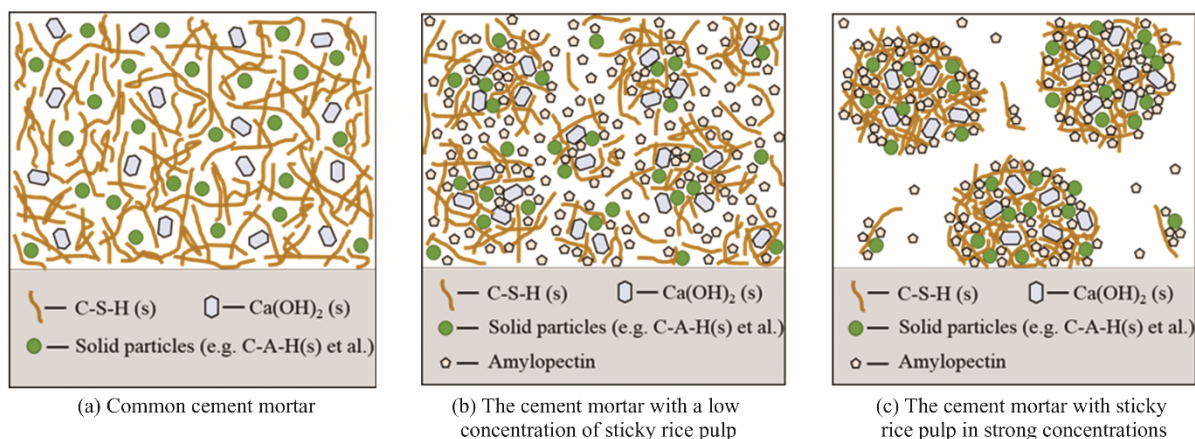


Fig. 4 Microstructure diagrams

with the increase in pulp concentration. This is also caused by the polymerization effect of sticky rice pulp.

Besides, cement mortar and sticky rice pulp are compatible, meaning they easily accommodate each other and form a macroscopically uniform material. According to Refs. [19,20], amylopectin in sticky rice pulp, a bonding material with a multi-branch structure, can fill the hole defects inside the microstructure of cement mortar to increase its compactness, as shown in Fig.2(d) and 2(f). Thus, the tensile capacity of the mortar is improved, which is ultimately beneficial to its flexural strength.

4.3 Retarding Effect of Polysaccharide Molecules

Polysaccharide molecules in sticky rice pulp have a retarding effect on cement hydration^[21]. Two major changes occur when sticky rice pulp, rich in starch—a polysaccharide molecule—participates in the reaction. First, the dissolved calcium ion (Ca^{2+}) and silicate ion (SiO_4^{4-}) agglomerate into a dense but thin layer of C-S-H at stage I. This layer acts as a barrier, delaying hydration for a certain period at stage II, thereby maintaining fluidity for construction before hardening. Additionally, the added polysaccharide molecules can increase the solubility of cement^[21]. Second, the polysaccharide molecules likely detrimentally affect the surface of hydration products^[22]. They are always adsorbed on $\text{Ca}(\text{OH})_2$ and C-S-H, inhibiting the nucleation and growth of crystals at stage III and thus further slowing down the hydration reaction^[23]. Consequently, mortar with sticky rice pulp generally has substantially lower compressive and flexural strength compared to common mortar at an early stage; however, this difference may not persist at later stages^[24].

5 Conclusion

1) The addition of sticky rice pulp at a concentration of about 0.3% significantly benefits the long-term flexural strength of the cement mortar. However, concentrations higher than 1.0% can severely harm this strength, while those lower than 1.5% only slightly affect its long-term compressive strength.

2) The results of SEM analysis of microstructures indicated that the added sticky rice pulp reduced the hydration products of cement at the early stage. If the pulp is added at a relatively low concentration, the hydration reaction of cement can fully proceed at the later stage and the microstructure of the mortar tends to be dense.

However, if the concentration is high, the hydration products seriously agglomerate at the later stage, resulting in a microstructure that is loose and grainy with many holes and other defects.

3) The strength of cement mortar with sticky rice pulp is affected by three effects: the "water reduction" of sticky rice starch; the polymerization of sticky rice pulp; and the retarding of polysaccharide molecules. Among them, at low concentrations, the effects of "water reduction" and polymerization benefit the strength by reducing the actual water-to-cement ratio and improving the compactness of the microstructure, respectively. At higher concentrations, however, these two effects harm the strength due to the shortage of free water for the cement hydration reaction and the molecular agglomeration of hydration products. The retarding effect mainly makes the strength of cement mortar with sticky rice pulp significantly lower than that of common cement mortar at the early stage.

In addition, the fluidity and consistency of the mortar will decrease as the increase of concentration of the added sticky rice pulp. This problem related to its construction performance is also an aspect that needs further consideration in future research.

References

- [1] Tie F D. Conservation and restoration of wall paintings of early Western Han Dynasty (1)—Investigation of conservation history and actuality[J]. *Sci Conserv Archaeol*, 2004, **16** (1): 47-51(Ch).
- [2] Yang F W, Zhang B J, Pan C C, *et al.* Traditional mortar represented by sticky rice lime mortar—One of the great inventions in ancient China[J]. *Science in China Series E: Technological Sciences*, 2009, **52**(6): 1641-1647.
- [3] Wei G F, Zhang H, Wang H M, *et al.* 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**(1): 624-632.
- [4] Xu L, Ma X, Zhang B, *et al.* Multi-analytical studies of the lime mortars from the Yanxi Hall in the Yangxin Palace of the Palace Museum (Beijing)[J]. *Archaeometry*, 2019, **61**(2): 309-326.
- [5] Yang F W, Zhang B J, Ma Q L. Study of sticky rice-lime mortar technology for the restoration of historical masonry construction[J]. *Accounts of Chemical Research*, 2010, **43** (6): 936-944.
- [6] Jiang C S, Wang T, Ding Q J, *et al.* Influence of polymer addition on performance and mechanical properties of lightweight aggregate concrete[J]. *Wuhan University Journal of*

- Natural Sciences*, 2004, **9**(3): 348-352.
- [7] Luo X B, Si Y Y, Gu W Q. Effect of silica fume on mechanical properties of concrete incorporating steel slag powder[J]. *Wuhan University Journal of Natural Sciences*, 2019, **24**(1): 86-92.
- [8] Otero J, Charola A E, Starinieri V. Sticky rice-nanolime as a consolidation treatment for lime mortars[J]. *Journal of Materials Science*, 2019, **54**(14): 10217-10234.
- [9] Zhang K, Sui Y, Wang L Q, *et al.* Effects of sticky rice addition on the properties of lime-tile dust mortars[J]. *Heritage Science*, 2021, **9**(1): 4.
- [10] Yang R W, Li K F, Wang L L, *et al.* A micro-experimental insight into the mechanical behavior of sticky rice slurry-lime mortar subject to wetting-drying cycles[J]. *Journal of Materials Science*, 2016, **51**(18): 8422-8433.
- [11] Zhao Q J, Zhou L H, Du J, *et al.* Amylopectin regulated mineralization of calcium carbonate and its application in removing of Pb(II)[J]. *Crystal Research and Technology*, 2021, **56**(8): 2100012.
- [12] Yang H S, Che Y J, Liao Z, *et al.* The influence of amylopectin on the hydration products of cement[J]. *Applied Mechanics and Materials*, 2014, **638/639/640**: 1485-1489.
- [13] China Architecture and Building Press. *Standard for Basic Performance Test Methods of Building Mortar* (JGJ/T 70-2009) [S]. Beijing: China Architecture and Building Press (Ch).
- [14] China Architecture and Building Press. *Code for Design of Concrete Structures* (GB 50010-2010)[S]. Beijing: China Architecture and Building Press(Ch).
- [15] China Architecture and Building Press. *Standard for Test Method of Mechanical Properties on Ordinary Concrete* (GB/T 50081-2002) [S]. Beijing: China Architecture and Building Press(Ch).
- [16] Miles M J, Morris V J, Orford P D, *et al.* The roles of amylose and amylopectin in the gelation and retrogradation of starch[J]. *Carbohydrate Research*, 1985, **135**(2): 271-281.
- [17] Hassan B, Chatha S A S, Hussain A I, *et al.* Recent advances on polysaccharides, lipids and protein based edible films and coatings: A review[J]. *International Journal of Biological Macromolecules*, 2018, **109**: 1095-1107.
- [18] Flatt R, Schober I. *Understanding the Rheology of Concrete* [M]. Amsterdam: Elsevier, 2012.
- [19] Zeng Y Y, Zhang B J, Liang X L. A case study and mechanism investigation of typical mortars used on ancient architecture in China[J]. *Thermochimica Acta*, 2008, **473**(1/2): 1-6.
- [20] Thirumalini S, Ravi R, Rajesh M. Experimental investigation on physical and mechanical properties of lime mortar: Effect of organic addition[J]. *Journal of Cultural Heritage*, 2018, **31**: 97-104.
- [21] Yousuf M, Mollah A, Vempati R K, *et al.* The interfacial chemistry of solidification/stabilization of metals in cement and pozzolanic material systems[J]. *Waste Management*, 1995, **15**(2): 137-148.
- [22] Garci Juenger M C, Jennings H M. New insights into the effects of sugar on the hydration and microstructure of cement pastes[J]. *Cement and Concrete Research*, 2002, **32**(3): 393-399.
- [23] Thomas N L, Birchall J D. A reply to a discussion by S chatterji of "the retarding action of sugars on cement hydration" by N L Thomas and J D Birchall[J]. *Cement and Concrete Research*, 1984, **14**(5): 761-762.
- [24] Zhang H Z, Zhou X F, Wang G X, *et al.* Experimental investigation on compressive strength of concrete with sticky rice pulp at different ages (the experiment of concrete with sticky rice pulp)[J]. *Structural Concrete*, 2020, **22**: E884-E897.

糯米浆水泥砂浆的抗压与抗折性能试验研究

张鹄志¹, 熊新才¹, 李小宝¹, 周鲁云¹, 李立¹, 吴圣丰¹, 李玉琦¹, 冯帅¹, 周晓枫²

1. 湖南科技大学 土木工程学院, 湖南 湘潭 411201

2. 湖南大学 土木工程学院, 湖南 长沙 410008

摘要: 糯米浆水泥砂浆是一种创造性的新型复合材料, 探讨其力学性能和强度机理, 对于未来的工程应用是一项十分必要的工作。为此, 以糯米浆浓度和砂浆龄期为变量, 展开5组糯米浆水泥砂浆试块的抗压与抗折性能对比试验和微观结构电镜分析。结果表明, 浓度处于0.3%左右的糯米浆的加入, 可以使后期的水泥砂浆微观结构趋于密实, 抗折强度显著提高; 而浓度大于1.0%的糯米浆的加入, 将使后期的水泥水化产物聚集成团, 微观结构松散, 抗折强度大幅下降; 这是因为随着糯米浆的加入, 可以阻碍早期水泥水化反应的进行, 从而使水泥砂浆早期强度偏低。分析机理可知, 这种现象是由于糯米浆的加入引起浆体产生"减水"作用、聚合作用与缓凝作用造成的。

关键词: 糯米浆; 水泥砂浆; 抗压强度; 抗折强度; 龄期; 微观结构; 强度机理

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