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Microstructural insights into the lime mortars mixed with sticky rice sol–gel or water: A comparative study

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HIGHLIGHTS

- Sticky rice slurry refines pore structure and increases strength of lime mortar.
- Fractal dimension of pore structure is decreased by adding rice slurry.
- Sticky rice slurry forms more compact inter-granular microstructure.

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ABSTRACT

This paper is dedicated to studying the effect of sticky rice sol–gel on the microstructure (including pore structure and texture) and properties of lime mortar. Uniaxial compressive strength tests, scanning electron microscopy (SEM), and mercury intrusion porosimetry (MIP) were utilized to investigate the macroscopic behaviors and microstructure, respectively. Based on the MIP data, a surface fractal dimension analysis is performed to study the impact of sticky rice sol–gel on pore structure. The addition of sticky rice sol–gel is demonstrated to improve the uniaxial compressive strength of lime mortar. The SEM, MIP and surface fractal dimension analysis results show that the addition of sticky rice sol–gel facilitates the formation of compact texture, fine pore structure and elevates the bonding strength of the lime mortar. A microstructrual mechanism is proposed to explain how properties of the lime mortar are affected by the addition of sticky rice sol–gel.

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1. Introduction

Acting as "Roman mortar" in ancient Europe, tabia (referred to as lime mortar), composed of clay, lime and/or other assemblies in designated proportions, is extensively used as an essential building material in ancient China. The lime mortar is often mixed with the organic admixture, e.g. sticky rice sol–gel, tung oil, juice of vegetable leaves, egg white and animal blood to form the inorganic–organic composites [1,2]. These composites, used as the main building materials in Chinese ancient relics, were found to greatly improve the performance and durability of the ancient Chinese buildings [1]. Among these inorganic–organic composites, the sticky rice sol gel–lime mortar (SLM) has been most widely used in the historical monuments, e.g. the Great Wall and the Forbidden city in Beijing.

As shown in Fig. 1, owing to the weathering and/or other deterioration actions such as drying-wetting and freezing-thawing cycles [3,4], most of the ancient relics are subjected to surface spalling and scaling [2]. The fresh organic admixture–lime mortars have been often used in situ replacement to preserve ancient earthen ruins [1,5]. Inappropriate use of the organic admixture–lime mortars can result in the failure of the restoration work, and even probably further damage to the original historical construction [1]. Therefore, it is indispensable to understand the microstructure and macroscopic properties of these replacing (fresh) organic admixture–lime mortars.

In order to understand the relationship between the microstruture and macroscopic properties of organic admixture–lime mortars, extensive studies were undertaken experimentally [1,2,5–8]. However, little work has been carried out to investigate the pore structure of organic admixture–lime mortars so far. Such pore structure is believed to relate intimately to the macroscopic transport and mechanical properties of the organic admixture–lime mortars.

The most used parameters in characterizing the pore structure are porosity, pore size distribution and specific surface [9]. However, these parameters are global features of the pore structure,

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Fig. 1. Surface spalling arising from the weathering on the lateral side of the Great Wall.

and no information upon the texture is provided [9]. To overcome this shortcoming, an additional parameter, fractal dimension, is introduced to characterize the packing patter of the solid grains [9–12]. Experimental devices such as nitrogen adsorption/desorption (NAD) [10–12], small-angle X-ray/neutrons scattering (SAXS/SANS) [13,14], nuclear magnetic resonance (NMR) [15], scanning electronic microscopy (SEM) [15,16], and mercury intrusion porosimetry (MIP) [17,18] are used extensively to evaluate the fractal properties of internal surface of porous media [9]. Among these available methods, MIP was the most used characterization method owing to its ability to cover a large pore size range, from nanometer to millimeter [9,17,18].

The objective of this study is to investigate the influence of the sticky rice sol–gel on the macroscopic properties and microstructure, particularly the pore structure of the lime mortars by means of uniaxial compressive strength test, SEM, MIP test and surface fractal dimension analysis. A microstructural mechanism is proposed to address how the sticky rice sol–gel affects the bonding strength of the organic admixture–lime mortar.

2. Materials and methods

In order to study the impact of the sticky rice sol–gel on the microstructure and macroscopic properties of lime mortar, two groups of lime mortars, one mixed with water (denoted as WLM) and another with sticky rice sol–gel (denoted as SLM), were prepared.

2.1. Materials and preparation

The clayey soil came from Bajia, Haidian district, Beijing, having a liquid limit of 24.2% and a plastic limit of 13.7%. The sticky rice is a species grown widely in Southeast and East Asia, with amylopectin as its main component [1]. The accumulative particle size distribution of the clayey soil is depicted in Fig. 2.

The sticky rice sol–gel was made by heating a mixture of sticky rice powder (1 kg), distilled water (10 kg) and potassium alum (0.055 kg) at 100°C for 4 h. The addition of the potassium alum was to prevent the sticky rice sol–gel from decaying during preservation, because generally the sticky rice sol–gel would be preserved for several months before adding into the lime mortar. In order to ensure the final concentration of the sticky rice sol–gel to be 10 wt.%, the distilled water was subsequently added into the mixture.

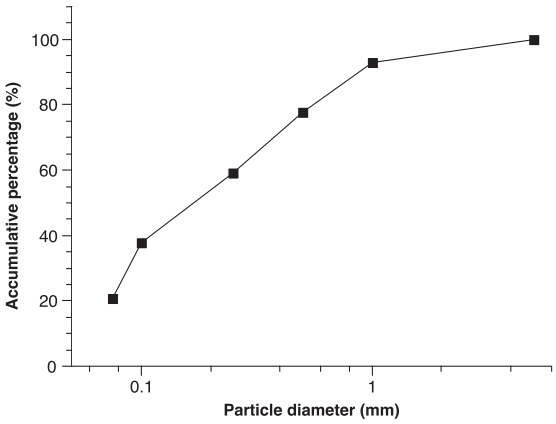

Fig. 2. Accumulative particle size distribution of the clayey soil.

The clayey soil and hydrated lime were mixed following a mass ratio of clayey soil: hydrated lime = 7:3, which was consistent with the ratio reported in the ancient building work "Tian Gong Kai Wu" [19]. According to ASTM-D1557, we estimated the optimum water content of WLM and SLM by determining their maximum density. Thus, as shown in Table 2, the optimum water contents of WLM and SLM were wt.22.4% and wt.21.5%, respectively. More precisely, the mix proportion for WLM (i.e., water: (soil + lime)) was wt.22.4% and that for SLM (i.e., sticky rice sol–gel: (soil + lime)) was wt.21.5%. Following ASTM-D3551 [20], the soil and lime mixture were placed in the mixer and dry-mixed the mixture for 1 min. Afterwards, distilled water or sticky rice sol–gel was added in the mixture and stirred for an additional 5 min until a stable consistency was achieved. Immediately after mixing, lime mortar mixed with water (WLM) and lime mortar mixed with sticky rice sol–gel (SLM) were respectively poured in the cubic steel molds of 40 mm × 40 mm × 40 mm. The specimens were compacted by hammer following ASTM-D1557 [21] to achieve the optimum water content (OWC). After compaction, the specimens were covered with a thin plastic film and cured in the curing room at 20°C, 62% relative humidity (RH). After curing for 3 days, the specimens were demolded and remained in the same curing room until testing. A total of 12 specimens for each material were prepared for the following experimental study.

The chemical compositions of the clayey soil, hydrated lime, WLM and SLM measured through the X-ray fluorescence spectrometer (XRF) are given in Table 1.

2.2. Experimental methods

Several experimental methods were employed to investigate the microstructure and properties/strength of WLM and SLM. The cubic specimens were used to measure the uniaxial compressive strength. Cut from the cubic specimens, several samples with a characteristic size of 5 mm were prepared for the scanning electron microscopy (SEM) and mercury intrusion porosimetry (MIP) experiments, respectively. A prepared sample was ground and filtered with 0.075 mm sieve, and the obtained powder with characteristic size less than 0.075 was prepared for the X-ray diffraction (XRD) experiment.

The X-ray diffraction (XRD) patterns were recorded on a Rigaku D/Max 2500H diffractometer with Cu-Kα radiation source. The 2θ

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