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A study of traditional blood lime mortar for restoration of ancient buildings

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ABSTRACT

Aerial lime-based mortars are recommended by many experts to restore the ancient buildings due to their great compatibility with ancient building materials. But their shortages (like long hardening time, relatively low mechanical strength, high water absorption capacity, etc.) limited their application in many fields. In this paper, the performance and mechanism of different simulated blood mortars are presented. The results showed that the mortar prepared by blood with lime had better binding strength, waterproof property, weather resistance and curing speed than common lime mortar. Through the conductivity, FT-IR, XRD, SEM, TG and curing speed test, it was found that the excellent performance of blood lime mortar was caused by the hydrolysis of blood proteins under alkaline condition and their special multilayer structure.

1. Introduction

At present, many ancient buildings and sites are suffering from serious damages, physically and chemically. In order to allow the future generations to enjoy the cultural diversity of our society, we should focus on the conservation and preservation of these precious heritages [1]. For the conservation of buildings, renders play an important role. Their application not only serves an aesthetical purpose but also to protect the brick, masonry and wood against moisture and rain to reduce the degree of their deterioration [1,2].

However, it has been shown that the use of cement-based mortars in repair and restoration of historic relics caused rapid and significant deterioration in a short time [3–6], also the modern polymer-based materials are incompatible with the construction materials of the original masonries [7]. Moreover, the use of these materials for the replacement of originals doesn't respect the features of the originally applied materials and traditional technology [8]. Thus, applying the traditional materials like lime mortar, natural cement, Roman mortar, etc., is highly recommended because modern research and history have confirmed that some of them exhibit good compatibility, appropriate strength with ancient buildings, and are more effective than modern materials.

The traditional renders are usually prepared with binder (lime, natural cement), aggregate (lime stone, sand) and additives (fibers, adhesion promoters). Among them, aerial lime-based mortars are widely applied around the world. In order to overcome their defects (for instance, the long hardening time, relatively low mechanical strength, high water absorption capacity and strong shrinkage) [9], the aerial lime should be modified by other agents like starch, fly ash, fiber, protein, fat, etc. Furthermore, modern air-entraining, hydrophobic agent and water-repellent mass [10] also proved fit to promote the aerial lime mortar's performance. Although these modern additives work well, the prices are quite high and each one of them targets a certain performance. Thus they are usually combined in utilization and increase the workload.

In this paper, we choose blood to modify the aerial lime-based mortar following an ancient oriental technology. The blood lime mortar is widely used around the world. Akbulut [11] described fresh blood was commonly used in ancient Europe. Jasiczak [12] applied blood powder to modify the mortar and found it played as an air-entraining substance and promoted the frost-resistance of mortar. Moreover, better performance and lower price of blood made it a valuable air-entraining substance for mortars and concrete blends. Alonso [13] also reported using bovine blood and other materials to prepare mortar for the restoration of the ancient buildings in Mexico. However, their work didn't display very prominent improvement of effects with addition of blood. Fang [14] and Rao [15] found blood was applied in a similar manner in ancient China as in the Western world by analyzing the rendering mortars in ancient oriental wooden buildings with different methods.

Although several researches have been done, much information of this mortar regarding its scientific principles, the specific formula, scope of application and performances are still insufficient. Thus, the aim of this research is to study the ingredients of blood lime mortar and to understand its performance mechanism. First, the ingredients and performances of blood lime mortar were studied through the simulated mortar in lab. Then the effect of traditional craftsmanship on

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the properties of blood lime mortar was investigated. Finally, how the animal blood modified the lime mortar and improved its performance was studied. We hope this work will provide some useful information about this traditional material and enrich mortar technology for conservation and restoration of historic buildings.

2. Experiment

2.1. Reagent

Calcium hydroxide, calcium carbonate, silicon dioxide, hydrogen peroxide, bovine serum albumin (BSA), calcium oxide, from the Sinopharm Chemical Reagent Co. Ltd.; fresh blood without anticoagulant, from slaughter house.

2.2. Mortar preparation

Preparation of blood mortar: first, certain amount of fresh blood (without anticoagulant) and lime water (5% w/w) were mixed thoroughly and then this mixture was kept in water bath (30 °C) for 3 h. This mixture was called "blood glue" and the ratio of blood to lime water was 10:7 (w/w). Second, appropriate $Ca(OH)_2$, $CaCO_3$ or SiO_2 was added into the above "blood glue" and mixed thoroughly. The mass ratio of blood glue and added inorganic is 1:1 (the ratio is selected according to the workability of fresh mortar and old masonry craftsmen's experience [16]). At last, the mixture was kept in sealed containers for 24 h before use (Fig. 1).

Reference groups: a. Common lime mortar was prepared. A certain amount of $Ca(OH)_2$ was added into H_2O ($m_{H_2O} : m_{Ca(OH)_2} = 0.7$), and the mixture was stirred until a homogeneous paste was obtained. b. Blood lime mortar was prepared directly. $Ca(OH)_2$ was mixed with fresh blood ($m_{blood} : m_{Ca(OH)_2} = 0.45$) and fully stirred. The mixtures were kept in sealed container for 24 h before use. The ratios and preparing methods of different mortars were shown in Table 1.

2.3. Sample preparation

Samples for bonding strength test: in this part, the substrates of samples are sandstone, wood block and marble cubes (their sizes are 5 cm × 5 cm × 2 cm). The substrates were bound through the narrow sides, on which the mortar was daubed. The thickness of the bonding layer was controlled within about 1 mm.

Samples for surface hardness, waterproof and weather resistance test were prepared with 5 cm × 5 cm × (0.9 ± 0.1) cm home-made plastic molds (the inner wall of mold was covered by tape to help demold). Mortars were poured into the mold and vibrated gently to make them fill the mold. Samples for surface hardness test needn't be demolded and samples for the other two tests were demolded after 2 d.

Mortars were applied on 5 cm × 5 cm × 2 cm sandstone to observe their apparent evolution. The thickness of mortar layers was about 2–3 mm.

All the above samples were kept in a relatively constant laboratory environment (T = (22 ± 3) °C, RH = (30 ± 2)%) before test, which is the default condition of the samples unless stated otherwise.

2.4. Performance of different mortars

2.4.1. Water-retaining capacity

The water-retaining capacity test was performed according to standard JGJ-70 [17]. Moreover, the appearance of mortars was applied on sandstone after 2 d and was recorded as a second measure to evaluate this property.

2.4.2. Bonding strength

The bonding strength was measured using a Yinchi YC-125B tension meter (Shanghai, China). The process of the measurement was shown in Fig. 2. Each group was tested five times.

2.4.3. The curing rate

The curing rate of lime mortar is important for the convenience and progress of actual construction. In this paper, the surface hardness was used to measure the curing rate of different mortar. The surface hardness was determined with a Qianzhou LX-A hardness scale (Wuxi, China). The hardness test procedure was done according to literature [17]. The hardness values were gathered after the mortar samples were cured for 6 h, 24 h, 2 d, 4 d, 7 d and 14 d in the lab.

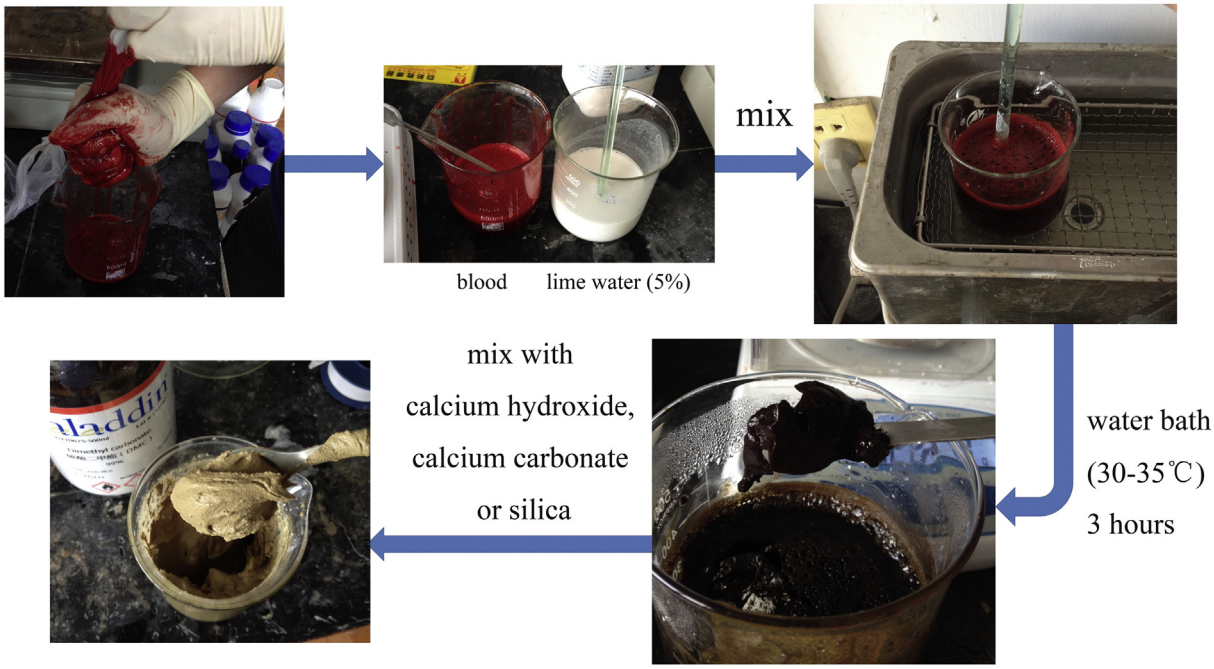

Fig. 1. The traditional production process of blood lime mortar in ancient China.