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Modification of traditional Chinese ginger nut and its mechanical behavior

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HIGHLIGHTS

- The effect of calcination temperatures on ginger nut was studied in terms of calcined product analysis.
- Optimal water binder ratio was determined according to basic properties of mortar.
- Mechanical properties and weather resistance abilities of cement mortar under optimal ratio were studied.

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ABSTRACT

The ginger nut has been used as building materials in Dadiwan site in Qin'an County, Gansu Province, China, and it was confirmed as the earliest lightweight concrete in China. However, the ginger nut is not a proper construction material because it does not contain cementitious components. In this paper, original ginger nut were calcined under different temperatures and the properties of the resultant modified ginger nut were analyzed. 1100 °C was chosen as optimal calcination temperature according to CaO, β-$CaSiO_3$ and $Ca_2Al_2SiO_7$ content. Based on mortar workability and strength as result of curing time, 0.33 was selected as the optimal water binder ratio of the ginger nut mortar. The results of the mechanical tests revealed that the mortar exhibited ductile behavior, and it is possibly due to the special structure between aggregates and hydration or carbonation products. Finally, several tests carried out to determine weathering resistance abilities of the ginger nut mortar showed that they will probably serve as restoration material for stone or soil relics.

1. Introduction

Most historic masonry mortars were made with lime [1]. Hydraulic lime is one of the most common building materials used in ancient and modern architectures [2–5]. Recently, hydraulic lime have been modified and applied in conservation of historical buildings in some countries [4,6–9]. The application results [2,3,6,10] show that the hydraulic lime is more durable and environmental friendly than cement and air-setting lime. The hydraulic lime first react with water. This is then followed by air-settings phase which promote the long term strength of the stone body. The heat and CO_2 generated during air-settings phase increase the porosity and improve water or air permeability, which satisfied the requirements for the restoration of cultural relics.

In China, the first recorded restoration work using Europe hydraulic lime was on Huashan rock paintings, in Guangxi Province [11]. In this restoration work, the European natural hydraulic lime (known as NHL) was applied. NHL-2, NHL-3.5 and NHL-5 types were studied and applied. Since then, a lot of effort have been put into developing hydraulic materials for conservation applications.

Archaeologists in Dadiwan site in Qin'an County, Gansu Province, China, discovered a ground material locally called the "ginger nut" [12]. This material retains about 10 MPa after over 5000 years and it use serve as the first evidence of natural hydraulic lime in China.

The ginger nut is a kind of calcite concretion in the Quaternary sedimentary ore deposit, mainly composed of calcite and clay minerals [13]. These calcareous concretions were usually considered as product of leaching deposition in soil [14–15]. Because of climatic processes such as freeze-thaw and dry-wet processes, calcite in soil

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was dissolute, precipitated and crystallized repeatedly and consolidated in the soil eventually.

It has been proven that the ginger nut is not a proper construction material, since there were no cementitious components present in the ginger nut [12]. However, ginger nut could be improved by calcination or sintering process. Previous researches have shown that most construction materials are sensitive to calcination conditions. Through the method of calcination, Cordeiro [16] determined the optimum pozzolanic activity of sugar cane bagasse ash. Roman cement-stone were calcined in a laboratory kiln and effects of calcination temperature and residence time were examined [17]. Belite sulphoaluminate cement [18] and kaolinite clays [19] were also modified by sintering process.

The aim of this study is to explore the properties and application prospect of modified ginger nut as well as provide a way for studying Chinese hydraulic lime for conservation or restoration purpose. In this study, several calcination temperatures were screened to improve the cementitious properties of ginger nut. According to the chemical analysis of modified ginger nut powders produced under different calcination conditions, optimum calcination temperature was determined. Then, the basic properties including optimal water binder ratio, setting time, fluidity of slurry and shrinkage, porosity of stone body were tested and screened. In addition, under the premise of obtaining the best water binder ratio, samples were prepared and then the mechanical properties and weathering resistance abilities of the samples were evaluated.

2. Materials and methods

2.1. Raw materials

The ginger nut is a kind of calcite concretion in the quaternary sedimentary ore deposit. It was found as a ground building material (Fig. 1) in Dadiwan site, Qin'an County, Gansu Province, China. The ginger nut used in this paper was obtained from Zhuang Lang County, Pingliang city, Gansu Province, China. This ochre and in block-shaped material is mainly composed of calcium carbonate and clay minerals. The basic properties and chemical composition

Fig. 1. The ginger nut.

Table 1
Basic properties of ginger nut.

Bulk density	2.41 g/cm^3
density	2.52 g/cm^3
Saturated water absorption	5.58%
Porosity	5.0%
Compressive strength	12.16 MPa
Radiocarbon14 dating	6769 ± 312 years

Table 2
Major oxide (wt%) analysis of ginger nut (%).

Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O
0.90	1.49	6.44	22.06	0.11	0.98
CaO	Fe_2O_3	TiO_2	MnO	Loss	Total
36.82	2.07	0.35	0.08	28.60	99.90

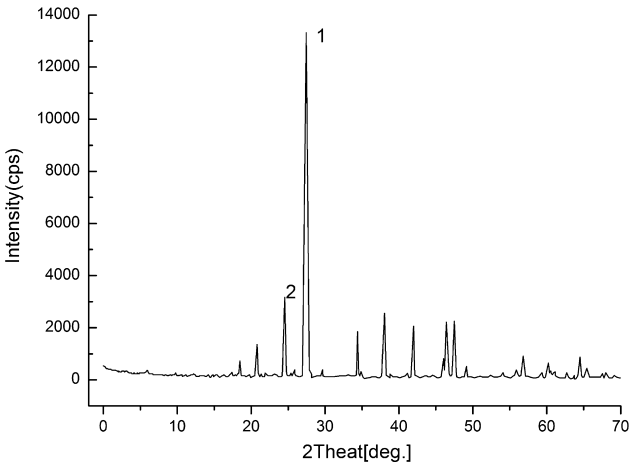

Fig. 2. The X-ray diffraction pattern of original ginger.

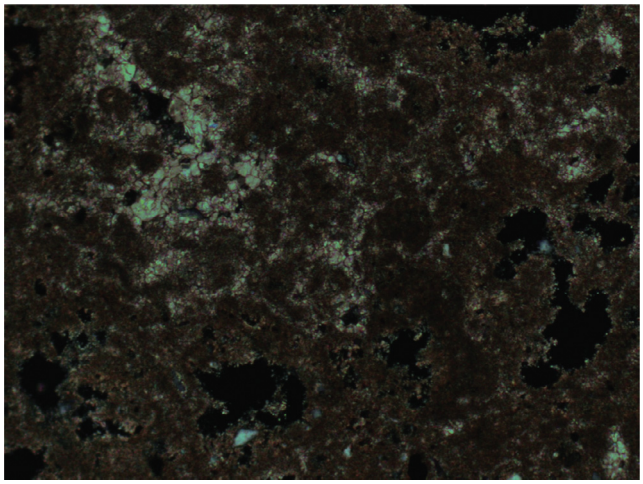

Fig. 3. The image of ginger nut under microscope (crossed polars100×).

are shown in Tables 1, 2 and Fig. 2. Fig. 1 shows the ginger nut specimen and Figs. 3and 4 shows the image of the ginger nut under microscope and scan electron microscope respectively.

The calcite particle size is about 0.005 mm. Quartz, muscovite and iron oxide are other clastic materials found in the ginger nut. Calcium silicates were observed in the SEM image (Fig. 4).

2.2. Improving method

In the Neolithic age, the kilns were usually heated by woods, so the temperature hardly exceed 900 °C. Under this condition, the ginger nut produced no cementitious component like Beta calcium silicate (β-$CaSiO_3$) but quick lime mostly. Part of the hydrated lime might react with clay minerals which produced amorphous cemented calcium silicate hydrate ($C_{1.5}SH$). However, this cemented calcium silicate hydrate were easily converted into calcium carbonate under the promotion of carbon dioxide.