Journal of Cultural Heritage 16 (2015) 831–837

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Original article

Study on workability and durability of calcined ginger nuts-based grouts used in anchoring conservation of earthen sites

Jingke Zhang[a,*], Wenwu Chen[a], Zuixiong Li[b], Xudong Wang[b], Qinglin Guo[b], Nan Wang[a]

[a] Key Laboratory of Mechanics on Environment and Disaster in Western China, and School of Civil Engineering and Mechanics Lanzhou University, Lanzhou, 730000 Gansu, PR China
[b] National Research Center for Conservation of Ancient Wall Paintings Dunhuang Academy Dunhuang, 736200 Gansu, PR China

ARTICLE INFO

Article history:
Received 21 September 2014
Accepted 19 February 2015
Available online 16 March 2015

Keywords:
Earthen sites
CGN (calcined ginger nuts)
Fly ash
Quartz sand
Workability
Durability

ABSTRACT

In this study, calcined ginger nuts (CGN) grouts admixed by fly ash (F) and quartz sand (S) was investigated on its suitability for anchoring use in earthen sites. According to requirement for the consistency of grout, the mix proportions were determined with 0.45 for CGN_F, 0.33 for CGN_S and 0.35 for CGN_F_S, by mass, to study their physical and mechanical property and durability. Test results indicated that use of fly ash can prolong the initial setting time of grout and admixture by fly ash and quartz sand leaded to lowest density and shrinkage, higher porosity, and highest strength. Accelerated aging tests indicated that admixture by fly ash led to a high resistance to fluctuation of temperature and humidity, sulfate attack and alkali environment; meanwhile, admixture by quartz sand resulted in high resistance to freeze-thaw action and water environment. As a compromise, CGN_F_S can get predominant durability. The paper shows that CGN_F_S grout is basically compatible to earthen sites and suitable for anchoring use in the conservation of earthen sites in terms of workability and durability.

1. Research aims

Anchor technology is playing an important role in preventative conservation of earthen sites in China. As an intermediate layer between bolt and soil medium, anchoring grout is to some extent regarded as the guarantee of long-term anchoring force. For that reason, workability and durability of anchoring grout should be relied in order to effectively control the stability of earthen sites. Therefore, the aim of this research is to investigate the property of calcined ginger nuts (CGN) (originated from Dadiwan sites, China) grouts admixed by fly ash (F) and quartz sand (S), and evaluate their suitability to earthen sites. These new grout materials could be used in not only anchor technology but also crack filling and could support the compatibility between consolidation material and fabric of earthen sites.

2. Introduction

Anchor technique has been in common use to treat unstable earthen sites in china since the 1980s [1]. The technique involves the insertion of bolts, such as wood and bamboo, into earthen body. The bolts are usually installed in pre-drilled holes and then fixed in place using special grouts. Therefore, the role of grout is multiple: it assumes a primary function of transferring stresses between the soil medium and the bars and, if it is not cracked, also provides a nominal level of corrosion protection for the reinforcement [2]. With full compatible consideration, anchor technique in earthen sites differs from that of other geotechnical engineering in materials and crafts, for example, cement mortar and iron bolt are unacceptable in earthen sites. Although many works have already addressed the anchoring performance [3,4], interfacial mechanical distribution [5,6], and property of bolts [7] in anchoring conservation of earthen sites, relatively few detailed studies have been reported on the workability and durability of grouts, which makes huge senses to the feasibility of application and long-term anchoring performance.

Nowadays, it is well realized that cement mortars present several problems regarding their use in restoration of earthen sites [2]. Some of the main problems are associated to their incompatibility in terms of mechanical, physical and chemical properties. Consequently, cement mortar is seldom used in earthen sites. Afterwards,

* Corresponding author. Key Laboratory of Mechanics on Environment and Disaster in Western China, and School of Civil Engineering and Mechanics Lanzhou University, Lanzhou, 730000 Gansu, PR China. Tel.: +86 09318914308; fax: +86 09318914308.
E-mail addresses: zhangjink@lzu.edu.cn (J. Zhang), sungp@lzu.edu.cn (W. Chen), lizuixiong@163.com (Z. Li), wxd23@hotmail.com (X. Wang), 3037582@qq.com (Q. Guo), 350718900@qq.com (N. Wang).

http://dx.doi.org/10.1016/j.culher.2015.02.007
1296-2074/

originating from success of crack grouting in the restoration of earthen sites, grouts based on potassium silicate (PS) solution were widely used in anchor practice of earthen sites due to their reasonable anchoring force (> 3KN/m) and compatibility with bolts and soil medium [8]. Yet, there are still some disadvantages for them, such as long setting time in anchor hole with sealed environment, and limit when encountering requirement of larger anchoring force [6]. Therefore, exploring more suitable and compatible grouts is of importance.

As an ideal repair material, natural hydraulic lime (NHL) is widely used in conservation of stone heritages in Europe [9–11]. Natural hydraulic lime are obtained by calcining mixtures of clayish or siliceous limestone at temperatures below the clinkering point, before being reduced to a powder by adding controlled amounts of water [12]. Plenty researches [13–15] prove that NHL limes are considerably compatible to old masonry by having low shrinkage, resistance to salt and frost damage, higher deformability and water vapor permeability. Indeed, NHL was also taken as an admixture in earthen plasters traditional used on earthen walls [16]. Researches [17–20] indicated that Earthen plasters admixed by NHL feature two advantages: they are permeable to water vapor, and their mechanical behavior is similar to that of earthen walls, which make them compatible with earthen walls. In addition, it was proved [21–23] that soil treated by natural hydraulic lime (NHL) can get considerable strength capacity without soluble salt contamination problems. A fundamental characteristic of these lime mortars is the fact that they have two hardening phases [24,25]: a hydraulic phase, based on its hydration, resulting in the formation of calcium and calcium-aluminum silicate hydrates, and another developed during the CO_2 contact and designated as carbonation. With consideration to NHL's compatibility and consolidation, it is recommended that NHL-based grout be applied on anchoring conservation of earthen sites.

In China, based on the studies of conventional building material (originated from Yangshao sites, Gansu Province, China), it was discovered that after burned at 1000 °C for 3 hours CGN shared the similar characteristics with those of European NHL limes [26]. Currently, CGN has been attempted to use into stone repairs [27,28], whilst, there are no reports about their application on earthen sites. Based on CGN, this paper aims to evaluate workability and durability of CGN-based grouts rather than that of anchor performance. CGN-based grouts with different admixtures (fly ash, quartz sand) were analyzed. The results will be particularly useful for the suitability evaluation of CGN grouts in earthen sites.

3. Methodology

3.1. Materials

For CGN, different admixtures and mixture ratio for improving its workability and durability are further researched. For examples, as the replacement of a certain amount of hydraulic binder, fly ash can improve grout durability and increase grout density as well as reduce the applied shear stress needed to initial flow [29–31]. Due to chemical stability and physical performance, quartz sand also is welcome as an admixture in NHL lime mortars [32].

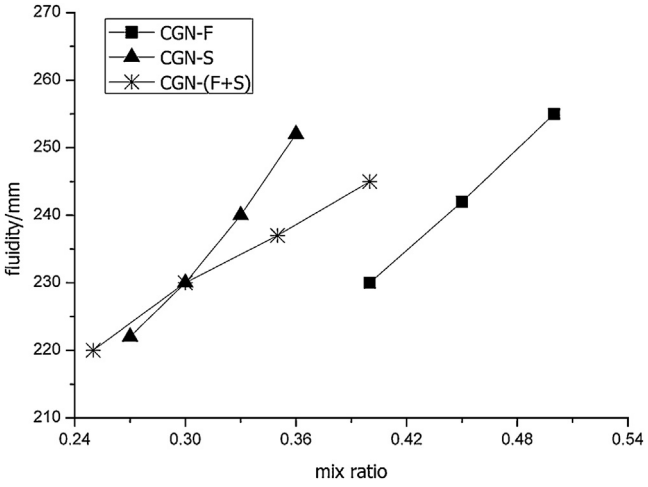

Fig. 1. Fluidity under different mix proportions for grouts.

With consideration to popular admixtures, the productions of grout in this study were carried out by using raw materials namely CGN, fly ash, quartz sand and water. With the raw materials from Dadiwan sites, Gansu Province, China, CGN was made at laboratory and its chemical composition can be seen from Table 1. Produced by Tianshan power plant of Hebei province, China, fly ash belongs to grade I and its chemical constitution is listed at Table 2. Quartz sand (400 mesh; 7 in hardness; 2.65 g/cm^3 in relative density) is purchased from market and water is from clean tap at the laboratory.

3.2. Mix proportions

The identification of grout mixes, percentage of CGN weight substitution by fly ash (F) and quartz sand (S) are shown in Table 3.

Existing study [33] revealed that the optimum consistency of anchoring grout in earthen sites is approximately 240 mm. Therefore, different mix proportions were tested using the flow meter (with mode of JC/T958-2005). As a result (Fig. 1), mix proportions are determined with 0.45 for CGN_F, 0.33 for CGN_S and 0.35 for CGN_F_S.

3.3. Specimens' preparations and curing conditions

Before preparing the grouts, the dry CGN (with fly ash or quartz sand or both) was hand-mixed with a trowel to avoid the aggregation. The mixer blade had a helicoidal shape, with a diameter slightly smaller than the cup diameter so that all the grouts can be mixed. The gap at the bottom, between the blade and the cup was 4 mm ± 1 mm. Mixing procedure was chosen to ensure that the

Table 1
XRD Half-quantitative analysis results of calcined ginger nut (CGN).

Formula	SiO_2	CaO	$Ca(OH)_2$	β-$CaSiO_3$	$Ca_2Al_2Si_2O_8$	Clay
% by mass	1.1	26.6	5.9	55.7	8.7	2.0

Table 2
Chemical composition of fly ash.

Constitution	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	$K_2O + Na_2O$	Ignition loss
% by mass	54.11	34.44	5.34	0.69	0.70	1.23	1.08