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Durability of autoclaved construction materials of sewage sludge–cement–fly ash–furnace slag

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HIGHLIGHTS

- New construction materials are made from dewatered sewage sludge with autoclave process.
- Autoclaved specimens exhibit good long-term performance.
- The gel-like and honeycomb-like hydrated products of autoclaved samples are katoite and C–S–H phases.

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ABSTRACT

In the present work, we demonstrate an alternative for the final disposal of sewage sludge by using it as an additive in a mixture with cement, fly ash and furnace slag, which can potentially be used to develop newly promising construction materials by autoclave curing. The dewatered sewage sludge is obtained with fly ash and lime. These physical conditioners contribute to both dewatering process and solidifying/stabilizing of sludge.

Various mechanical properties such as flexural strength, compressive strength and the toxicity characteristic leaching procedure (TCLP) were evaluated. To evaluate long-term performance, different types of accelerated attacks, i.e. freezing–thawing cycles, accelerated carbonation, wet–dry cycles, and heat–cool cycles were also determined. The obtained test results were indicated that the autoclaved samples exhibit good long-term performance after evaluations of different durability tests. XRD patterns show that the hydration products of autoclaved samples are katoite and C–S–H phases, which mainly contribute to strength of autoclaved products. Morphologies of autoclaved samples also demonstrate the existence of the gel-like and honeycomb-like hydrated products. The results show that this new construction material could be applied as many construction and building materials, i.e. landfill liners and building blocks.

1. Introduction

The disposal of sewage sludge is becoming an increasing concern in many urban municipalities. Some traditional methods for disposal of sludge have been developed, such as applications of landfill, incineration, and utilization in agriculture [1]. Since sewage sludge contains heavy metals, organic matters, and high content of water, these traditional disposal methods could face long-term risk of environmental pollution or problems of uneconomical energy-consuming drying process. Therefore, many researchers have been seeking alternatives for the final disposal of sewage sludge by using it as a component in construction and building materials. Tay et al. carried out the research in the area of sludge reutilization as building bricks, lightweight aggregates, and cementitious materials [2]. Valls et al. demonstrated the application of dried sewage sludge or wetsludge as an additive in mortar or concrete [3–5]. Katsioti et al. investigated properties of stabilized/solidified admixture of cement–bentonite or cement–jarosite/alunite and sewage sludge as new construction materials [6–8].

Although many researchers have shown potential applications of sewage sludge utilized as building and construction materials, further investigations should be carried out. Firstly, long-term performance of non-conventional construction materials with the addition of sewage sludge should be paid more attentions [5,9]. Secondly, some construction or cement materials with the addition of sewage sludge have been prepared by traditional sintering process at higher temperature [2,10,11]; some composite binders with the addition of sewage sludge have been prepared and cured at room temperature [3–8]. Autoclave process could improve long-term performance of construction and building materials compared with curing condition at room temperature [12]. However, autoclave process for construction materials containing sewage

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sludge was seldom investigated in the previous literatures. Thirdly, the addition of wet sewage sludge causes lumps in mixtures because of its high water content and high organic compounds content [13]. Such inhomogeneous lump is potential the Achilles' heel when specimens are subjected to environmental erosion.

Dewatered sewage sludge conditioning with organic polymer i.e. PAM was commonly used in previous researches. However, fly ash and lime, inorganic materials, were proved as effective physical conditioners since fly ash and lime could act as skeleton builders to form a more porous and incompressible cake structure [14,15]. Conditioning with skeleton builders will produce cakes of high solids content that can be more easily disposed of. At the same time, fly ash and lime can be used in solidification/stabilization of sewage sludge and preparation of construction materials. In the present work, sewage sludge was conditioned with fly ash and lime in dewatering process, and then dewatered sludge was used in the following preparation of construction materials. This novel route combined the sludge dewatering with the following reutilization of dewatered sludge, which made the mixture homogenised easily and lumps diminished effectively because fly ash and lime could remain uniform rigid lattice structure in dewatered sludge cake with higher solids content and lower organic compounds content. The flow-sheet of the whole route combined the sludge dewatering with the following reutilization of dewatered sludge as construction materials is presented in Fig. 1. Dewatered sludge cake with addition of cement, fly ash and furnace slag were uniformly blended in a mechanical mixer. The homogenous mixture was pressed into shape with a hydraulic machine at a pressure of 20 MPa. Then shaped brick specimens were cured by autoclave process.

This work studied long-term performance of new construction material specimens made from dewatered sludge with conditioners of fly ash and lime as skeleton builders. Mineral phases and microstructure characteristics were investigated on specimens after being subjected to different types of accelerated attacks.

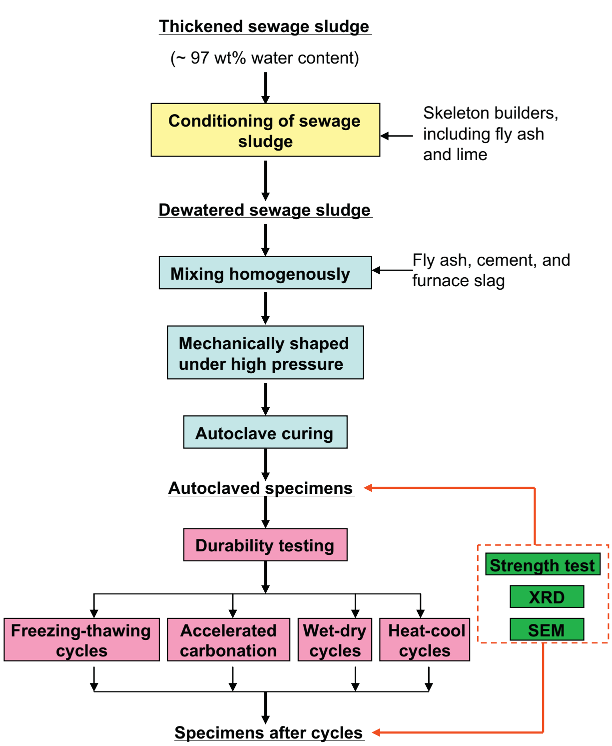

Fig. 1. The schematic of this study.

2. Experimental

2.1. Raw materials

2.1.1. Characterization of raw sewage sludge

Raw sludge (RS) used was the mixture of primary and secondary sludge that came from Longwangzui Wastewater Treatment Plant in Wuhan City, where municipal wastewater of 150,000 m^3/d can be treated with an anaerobic–anoxic–oxic process. The main characteristics of RS are shown in Table 1. The X-ray diffraction was used to identify crystalline minerals in dried sludge sample. Significant amount of quartz was detected, shown in Fig. 2. The concentrations of heavy metals in the digestion solution of dry sludge were measured by standard method of USEPA 3050, as shown in Table 2.

2.1.2. Dewatered sewage sludge

Dewatered sewage sludge was prepared by filter press with the inorganic conditioner of fly ash and lime. Both dosages of fly ash and lime were 50 g/L (volume of RS with water content of 98.5%). Thus the mass ratio of dry sludge:fly ash:lime was 1.5:5:5 in dewatered sludge cake. Dewatered sludge cake with the content of water of about 45% was dried for several days in the ambient air. Then it was used as a component of construction material specimens when the water content of dewatered sludge was less than 30%.

2.1.3. Lime

Quick lime was used as a skeleton builder in sludge dewatering. Lime also played an important role in pozzolanic reaction between reactive SiO_2/Al_2O_3 in fly ash and lime under humidity conditions. The content of the free-CaO was 60 wt% in used lime. The chemical compositions of lime are shown in Table 3.

2.1.4. Fly ash

Fly ash was collected from electrostatic precipitator in a local coal-combustion power plant. Fly ash was used as another skeleton builder in sludge dewatering. At the same time, fly ash was used as a component of the mixture of autoclaved construction materials. Fly ash could provide reactive SiO_2 and Al_2O_3 that could take place pozzolanic reaction with lime and water. The chemical compositions of fly ash are shown in Table 3.

Table 1
Characteristics of raw sludge.

pH	Water content (%)	COD (mg/L)	TSS (g/L)	VSS (g/L)	VSS/TSS (%)
7.2	98.5	13090.6	13.0	7.5	57.7

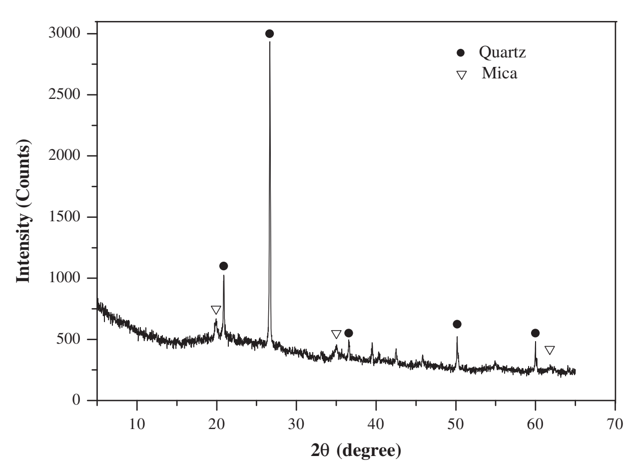

Fig. 2. XRD patterns of dry raw sludge.

Table 2
Concentrations of heavy metals in dry raw sludge (mg/kg dry sludge).

Cr	Cu	Pb	Zn	Cd
7.2	176.5	153.3	265.7	76.5