Construction and Building Materials 82 (2015) 20–30

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Compressive strength development in fly ash geopolymer masonry units manufactured from water treatment sludge

Cherdsak Suksiripattanapong [a], Suksun Horpibulsuk [a,*], Pimsin Chanprasert [a], Patimapon Sukmak [b], Arul Arulrajah [c]

[a] Suranaree University of Technology, Nakhon Ratchasima 30000, Thailand
[b] Walailak University, Nakhon Si Thammarat 80160, Thailand
[c] Swinburne University of Technology, Hawthorn, VIC 3122, Australia

HIGHLIGHTS

- A green geopolymer masonry unit from water treatment sludge.
- Strength and microstructural analysis of sludge–FA geopolymer.
- Role of liquid alkaline activator on strength development.
- Role of heat temperature and duration on strength development.
- Role of curing time on strength development.

ARTICLE INFO

Article history:
Received 12 April 2014
Received in revised form 22 January 2015
Accepted 18 February 2015
Available online 5 March 2015

Keywords:
Sludge
Fly ash
Geopolymer
Liquid alkaline activator
Microstructure
Masonry units

ABSTRACT

A novel water treatment sludge–fly ash geopolymer is investigated in this research with the intention to develop an alternative green construction and building materials, without the usage of Portland cement as a cementing agent. Two waste by-products namely water treatment sludge from the Bang Khen water treatment plants of the Metropolitan Waterworks Authority of Thailand (MWA) and fly ash (FA) from the Mae Moh power plants of the Electricity Generating Authority of Thailand (EGAT) were used in this research. The liquid alkaline activator, L used was a mixture of sodium silicate solution (Na_2SiO_3) and sodium hydroxide solution (NaOH). This article investigates the effect of the various influential factors on compressive strength of sludge–fly ash geopolymer. The various influential factors studied are mixing ingredient (L content and Na_2SiO_3/NaOH ratio), heat condition (temperature and duration) and curing time. Scanning Electron Microscopy (SEM) and X-ray Diffraction (XRD) analyses were undertaken to understand the role of influential factors on strength development. Test results show that the optimum ingredient providing maximum unit weight and strength is Na_2SiO_3/NaOH ratio of 80:20 and L/FA ratio of 1.3, irrespective of heat condition and curing time. The optimum heat temperature and duration for the optimum ingredient are 75 °C and 72 h, respectively. The higher heat temperature of 85 °C causes the loss of moisture, which results in micro-cracks and strength reduction. The water treatment sludge traditionally destined for landfill can be used in a sustainable manner to develop geopolymer masonry units, with their compressive strengths comfortably meeting the Thailand Industrial Standards.

1. Introduction

In recent years, there has been an environmental push worldwide to continually seek new reuse applications for various waste materials inclusive of demolition wastes [1,2], municipal solid wastes [3–5], biosolids [6,7], commercial and industrial wastes [8–14] and organic wastes [15]. Waste materials are increasingly being implemented in various projects for use as an aggregate in applications such as pavements [16–21], pipe bedding [1], road embankments [11] and footpaths [22].

Water production requires the extraction of water from natural sources. The water treatment process results in a muddy sludge by-product. The clarifier system employed in water treatment plants results in the sludge flocculating and falling to the bottom of the treatment tank. The liquid sludge is subsequently drained to sludge lagoons for disposal. The increasing demand of treated

* Corresponding author.

http://dx.doi.org/10.1016/j.conbuildmat.2015.02.040
0950-0618/

water produced by the Metropolitan Waterworks Authority of Thailand (MWA) and in similar water treatment plants worldwide, has resulted in increasing quantities of sludge by-products generated annually. For MWA, the water treatment sludge is generated with the maximum capacity of 300×10^3 m^3 per day in the dry season and about 700×10^3 m^3 per day in the wet season. With the continuous increase in water demand due to growing population in many developed and developing countries, including Thailand, the quantity of water treatment sludge is subsequently increasing at ever increasing rate and hence the urgent need to find a sustainable reuse option for the growing stockpiles of sludge, which in the past have been disposed to landfills.

There has been a recent initiative by MWA to research the usage of water treatment sludge as construction and building materials according to the zero-waste directive. This sludge has previously been mixed with sand and cement to manufacture a cement–sludge bearing unit. However, the use of conventional Portland cement will result in a large carbon footprint since the production of 1 ton of Portland cement releases about 1 ton of carbon dioxide [23].

Alkali-activated alumino-silicate cement, known as 'geopolymer' has become increasingly popular in recent years as an environmentally friendly alternative to ordinary Portland cement [24]. Geopolymers are furthermore touted for their high performance (high strength and durability), low CO_2 emission and low energy consumption. Silica rich materials such as clay or kaolin [25], fly ash, and bottom ash [26] are used as a precursor to react with the liquid alkaline activator.

Fly ash (FA) derived from coal-fired electricity generation provides the greatest opportunity for commercial utilization of this technology due to the plentiful worldwide raw material supply [27,28]. Palomo et al [29] found that the different FA activated with 8–12 M NaOH cured at 85 °C for 24 h produced a material with compressive strength of 35–40 MPa and about 90 MPa if sodium silicate (Na_2SiO_3) is added to the NaOH solution. Xie and Yunping [30] and Phetchuay et al. [31] reported that the hardening process of FA activated with Na_2SiO_3 is mainly attributed to the gel-like reaction products that bind FA particles together. FA is extensively used as a precursor for geopolymers in Australia [32,33] and Thailand [34,35].

Sukmak et al. [36,37] previously investigated the possibility of using FA as a precursor and silty clay as aggregates to develop a clay–FA geopolymer brick. The liquid alkaline activator (L) was a mixture of Na_2SiO_3 and NaOH. The ingredient for this clay–FA geopolymer was Na_2SiO_3/NaOH ratio of 0.7 and L/FA ratio of 0.6, which are lower than those of FA geopolymer. The 7-day strength of the clay–FA geopolymer is greater than 10 MPa, which is suitable as bearing masonry unit according to the Thailand Industrial Standard. The strength requirement is 2.5 MPa for non-bearing and 7.0 MPa bearing masonry units. It has been illustrated that the durability against sulfate attack of clay–FA geopolymer is superior to that of clay–cement; i.e., there is no major change in the microstructure and pH of clay–FA geopolymer when exposed to sulfate solutions [38].

This research investigates strength characteristics of sludge–FA geopolymer to ascertain its performance as a masonry unit. The sludge is used as aggregates without any additional sand, FA is used as a precursor and a mixture of NaOH and Na_2SiO_3 is used as a liquid alkaline activation. The geopolymerization reaction is accelerated by applying appropriate heat temperature and duration. The role of influential factors on strength development in sludge–fly ash geopolymer is also investigated. The influential factors include mixing ingredient (L content, Na_2SiO_3/NaOH ratio), heat condition (temperature and duration) and curing time. The microstructural observation of sludge–FA geopolymer is undertaken using Scanning Electron Microscopy (SEM) and X-ray Diffraction

Table 1
Chemical composition of sludge and fly ash.

Chemical composition (%)	Sludge	Fly ash
SiO_2	67.33	49.32
Al_2O_3	22.47	12.96
Fe_2O_3	6.15	15.64
CaO	0.68	5.79
MgO	N.D.	2.94
SO_3	1.04	7.29
Na_2O	N.D.	2.83
K_2O	1.26	2.83
LOI	0.78	7.29

Remark: N.D. = not detected.

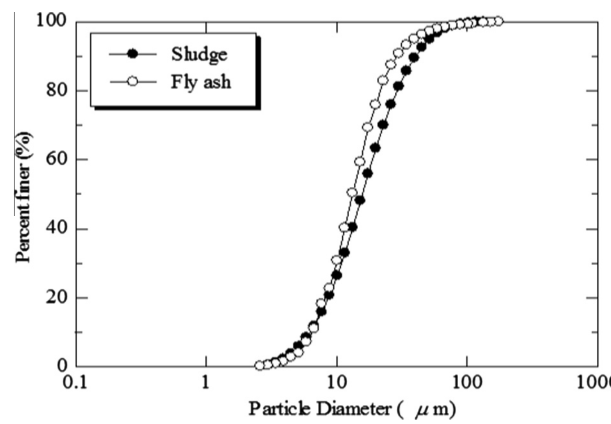

Fig. 1. Grain size distribution of sludge and FA.

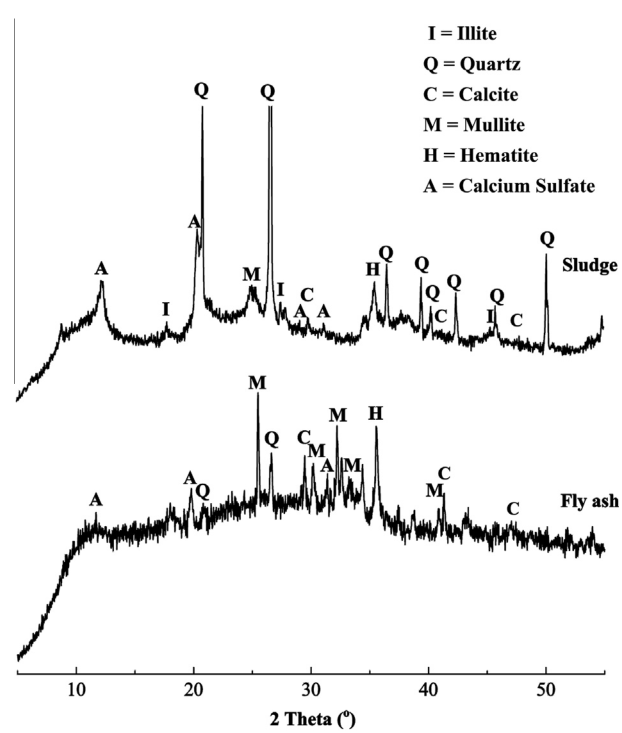

Fig. 2. X-ray Diffraction (XRD) pattern of sludge and FA.