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Development of sustainable masonry units from flood mud soil: Strength and morphology investigations

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HIGHLIGHTS

- A study on the use of the flood mud to develop a masonry unit was conducted.
- 3%, 5% and 10% of biomass silica (BS) stabiliser were used to stabilise the soil.
- The stabilised soils were cured under room and 105 °C temperatures.
- The strength was increased with the increment of stabiliser content and time.
- The optimum mix design was found to be 10% BS with 2% cooking salt at 105 °C.

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ABSTRACT

In the aftermath of the mega flood 2014–2015 event on the East Coast of the Peninsular Malaysia high piles of debris and mud were found deposited on the affected area. The cost of cleaning and removal of the debris and mud was extremely high. Utilisation of the flood mud soil as an aggregate to develop sustainable masonry units could be possible through chemical stabilisation to increase the strength of the soil. Biomass silica (BS) stabiliser was used to enhance the engineering properties of the flood mud. The flood mud soil sample was taken from Kuala Krai, Kelantan, after the flood event, which occurred during December 2014 and January 2015. The Unconfined Compressive Strength (UCS) of unstabilised samples and samples stabilised using 3%, 5% and 10% stabiliser, was measured after three and seven days of curing. The stabiliser could increase the soil strength up to 10-fold (1330 kPa) of the unstabilised strength but was still lower than the strength requirement specified by British Standard Institute. An addition of 2% of cooking salt at 105 °C curing could significantly improve the UCS. Microstructural analyses via Energy-Dispersive X-ray spectrometry (EDX) and Field-Emission Scanning Electron Microscopy (FESEM) tests were undertaken to examine the influence of BS stabiliser, cooking salt and heat curing on UCS development. The additional cooking salt with heat curing caused the aggregation and enhanced the chemical reaction of the BS stabilised soil. The formation of Calcium Silicate Hydrate (CSH) and Calcium Aluminate Hydrate (CAH), as shown by white-coloured lumps, filled the pore spaces of the biomass silica stabilised soils. The aggregation and CSH and CAH products resulted in a dense and strong soil structure and subsequent strength development. This research indicates that the mixture of BS stabiliser and cooking salt can be used to manufacture mud-based masonry units as a sustainable construction and building material.

1. Introduction

Natural disasters, such as floods, earthquakes, tsunamis and hurricanes cause great damage and loss of life. Flooding is a common natural disaster that occurs in most parts of the world. The Association of Southeast Asian Nations [1] reported that between

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15 December 2014 and 3 January 2015 the East Coast of the Peninsular Malaysia was hit by a serious flood event. The flood was considered as the worst flood event to affect the country in the decades. After the flood event large amounts of debris and mud were found within the affected area. In extreme circumstances the mud was found inside houses affected by the flood and along the roads. This damage required a large effort, in terms of manpower, energy and finance, to clean up. The removal of mud deposits was slow due to slow recovery actions, which resulted in temporary storage next to buildings and roads. It would be beneficial if the flood mud deposits could be used to develop construction and building materials [2].

Tse [3] used flood deposits as a raw material to develop burnt bricks for housing construction. Conventional mud brick manufacture was performed manually by mixing the mud with water to a plastic paste consistency. The paste was then compacted in a wooden mould and air-dried for 48 h before being fired at 1000 °C for 24 h. The compressive strength of the mud brick surpassed the minimum strength requirement of 2.5 MPa specified by Nigerian Institute of Standards [4]. Ibanga and Ahmad [5] reported that the basic standard for proper performance compressive strength of bricks is 3.5 MPa and that the water absorption should not exceed 20%. The minimum strength values of bricks required for two-storey buildings and non-load bearing walls are 2.75 MPa and 1.38 MPa, respectively, as per the British Standards Institute [6].

To reduce the manufacturing cost and carbon footprint, the masonry units can be produced via chemical stabilisation of soil without firing [7–9]. Chemical stabilisation is the process of improving the physical and engineering properties of soil to obtain some predetermined targets [10–13]. Materials containing mostly silicon (Si) and aluminium (Al) in amorphous phase are suitable to produce masonry units [14]. Tamizi et al. [15] conducted research on marine clay stabilised with an alkaline solution and reported that the compressive strength obtained was 7.94 MPa after three days of curing.

Recently, Suksiripattanapong et al. [16] used Water Treatment Sludge (WTS) as aggregate to manufacture green geopolymer masonry units. The durability against wetting-drying cycles of WTS-Fly Ash (FA) geopolymer bearing units was found to be superior to that of WTS-cement [17]. Suksiripattanapong et al. [18] manufactured lightweight cellular WTS-FA geopolymers and also investigated the influence of air content, liquid alkaline activator content, heat temperature and curing time on the unit weight, strength and microstructure. Suksiripattanapong et al. [18] reported that the high calcium oxide content in FA could react with silica in Na_2SiO_3 and WTS and form Calcium Silicate Hydrate (CSH), which co-existed with Sodium Alumino Silicate Hydrate (geopolymer products). Nimwinya et al. [19] used calcined WTS and rice husk ash blends to develop a lightweight geopolymer binder. Arulrajah et al. [20] evaluated the strength development of industrial by-products, namely Recycled Glass and FA in the manufacture of low-carbon masonry units. Horpibulsuk et al. [21] investigated the viability of using Calcium Carbide Residue and FA as a binder for the manufacture of non-bearing masonry units without Portland Cement.

Besides the geopolymer and industrial by-products, silica-rich binders are extensively used as a non-traditional green soil stabiliser to improve soil strength properties [22,23]. A commercial biomass silica product was used and proven as a suitable soil stabiliser [22]. Latifi et al. [24,25] reported that BS stabiliser improved soil strength with curing time due to the growth of cementitious products filling the pore space.

In this study, an attempt is made to investigate the chemical reaction mechanisms after mixing the BS stabiliser with flood mud soil, which contains a significant amount of Si and Al, to produce masonry units. The sodium chloride (cooking salt) was used as an additive and heat curing was applied to stimulate the chemical reaction. The influence of BS stabiliser, additive and curing temperature on strength and microstructure development is investigated in this research. Several tests were conducted on the stabilised soil, including Atterberg limits, Unconfined Compression Strength (UCS), Energy-Dispersive X-ray spectrometry (EDX) and Field-Emission Scanning Electron Microscopy (FESEM) tests. This research enables flood-related mud waste to be used in a sustainable manner to construct masonry units, which is significant in from engineering, economical and environmental perspectives.

2. Materials and methods

The flood mud soil sample was collected from Kuala Krai, Kelantan approximately a week after the end of the 2014–2015 flood event. The material was bright brown in colour. The flood mud soil was transported to the geotechnical laboratory of Universiti Teknologi Malaysia to determine index properties, UCS and microstructural characteristics of the flood mud soil under stabilised and unstabilised conditions.

Index property tests, such as Atterberg limit, specific gravity and gradation were carried out on air-dried soil in accordance with the British Standard Institution [26]. The grain size distribution of the flood mud soil was performed using sieve analysis and hydrometer tests. The Unified Soil Classification System was used for soil classification. The standard Proctor test was performed based on British Standard Institution [27] to determine the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) for UCS sample preparation. The UCS samples were compacted at OMC to attain the MDD in 38 mm diameter and 76 mm height moulds.

The particle size distribution curve is shown in Fig. 1. The soil consisted of 89.31% sand, 10.43% silt and 0.26% clay by weight. Fig. 2 shows the moisture content: the dry density curve was obtained from the standard compaction test. The OMC and MDD values were 18% and 1.626 Mg/m^3, respectively. The physical properties of the soil are shown in Table 1.

The BS stabiliser was supplied by Probase Manufacturing Sdn Bhd, a local company in the Johor state of Malaysia. Since it is a commercially registered brand, the exact chemical composition of this stabiliser has not been released. The general chemical properties of this stabiliser based on EDX results are shown in Table 2. The air-dried soil sample was crushed and sieved through a 425 μm sieve. The sieved sample was thoroughly mixed with BS stabiliser before slowly adding the pre-calculated amount of water. The mixture was then transferred to a stainless steel UCS mould. A pair of pistons was used to compress the sample at both ends of the mould. The cylindrical samples were then extruded using a steel plunger and put in a polythene bottle. Then, the bottle was placed above a water level in a closed container to maintain humidity and temperature.

Two sets of stabilising conditions were studied: BS stabilisation at room temperature and 105 °C curing and BS and cooking salt stabilisation at room temperature and 105 °C curing. For the first set, three different proportions of BS stabiliser (3%, 5% and 10% by weight of dry soil) were prepared for mixing with the flood mud soil. The samples were cured for three and seven days prior to UCS testing. Three samples were prepared for each mix and the average strength value was determined. For the second set, 2% by weight of cooking salt was added with the 10% by weight of BS stabiliser and cured for three days. Since cooking salt is widely available and heating at 105 °C is possible within the flooding affected area, this stabilisation condition could possibly be applied to manufacture the high-strength masonry units in prac-

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