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Compaction characteristics of Bangkok clay stabilized using rice husk ash, bottom ash, and lime

A Eisazadeh^{*1}, A Bhurtel¹, and H Phai¹

¹ School of Civil Engineering and Technology, Sirindhorn International Institute of Technology, Thammasat University, Thailand

^{*}Corresponding author e-mail: aeisazadeh@siit.tu.ac.th

Abstract. Amount of waste is becoming increasingly undesirable as human population increases day by day. For this reason, recycling wastes produced in different industries and thus lowering their quantities is one of the main focuses for researchers. Soil stabilization using waste by-products especially in road projects that require large amount of earth materials are currently popular and the successful utilization of these wastes can have positive impact on the environment. This can also reduce the construction costs significantly. Bangkok Clay is a well-known soil in Thailand that can possess poor engineering properties and hence there is a need for its improvement. Among all different kinds of waste, rice husk ash (RHA) and bottom ash (BA) are among the cheap materials that are produced in high volumes annually in Thailand and have the potential to be considered as replacement for earth materials. Lime has also been used in this study as common traditional binder in clayey soils that produces the cementitious materials via pozzolanic reaction with materials that are rich in silica and alumina. One of the main steps of construction in road projects is the compaction of stabilized materials which requires the preliminary collection of data from lab performed compaction tests. In this paper, the compaction characteristics of RHA- and BA-Bangkok clay mixtures with lime as a binder were studied. The results show that the MDD reduces and OMC rises with respect to increase in the ash content. Furthermore, the mix designs with RHA are more sensitive to the ash content. Bottom ash mix designs show higher MDD than rice husk ash-soil mixtures and have more potential to be used in road projects based on the compaction characteristics.

1. Introduction

Soil Stabilization is the process of mixing the soil that has undesirable properties with superior materials for enhancing their engineering properties. A lot of waste materials are produced around the world due to the rise in population and industrial development. Therefore, their utilization is highly important for preservation of environment. This has made it a focus point for most of the researches going on today.

Bangkok Clay is one of the two common clay types which engineers in Thailand would likely to encounter, especially during the interstate highway projects [1]. This clay can be found near Chao Phraya River surrounding Bangkok City as well as some other provinces like Pathum Thani. It is said to be a type of marine clay [2]. Bangkok clay contains great amount of water. It tends to swell when in contact with water and shrinks in absence of water. In addition, the swelling potential increases with depth [1]. Because of its undesired swelling and shrinking nature this clay has low shear strength and poor properties concerning engineering indexes. Low strength causes destruction of any structures



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above it and would not satisfy the required strength norms for road projects as well. Due to this reason, there are many different types of stabilizers that are used to enhance the engineering properties of soil. However, considering the carbon footprint of materials like cement and the fact that huge amounts of waste by-products are produced annually around the world which have the potential to be recycled, the latter might be a much better option, especially if it shows self-cementing properties as well. Utilization of waste materials such as fly ash, bottom ash, and rice husk ash could benefit the soil by improving its strength and the environment by conserving the natural earth materials. Bottom Ash (BA) is one type of Coal Combustion Byproducts (CCB)s produced when the coal is burnt in coal power plant. The ash rests at the bottom of the furnace and gathered via ash hoppers after combustion. The other one flowing upwards, which is caught by air precipitators, is known as Fly Ash (FA). Fly ash has been applied in concrete industry and in geotechnical improvement of soils, whereas, bottom ash has almost been neglected due to its coarse grained particle size and porosity [3], [4]. Bottom ash has an irregular shape and sometimes angular shape. According to Huang [4], materials with greater angularity and rough surface texture are preferred for highway base and sub-base material and hence, the bottom ash has the potential to be used as highway material.

Bangkok clay is usually excavated from the area of construction and replaced by some other high strength soil [5]. Another waste material that could be used for soil stabilization is Rice Husk Ash (RHA). The product of rice husk combustion is RHA which almost world-widely considered as waste in countryside. Generally, for every 1000 kg of rice paddy milled, about 200 kg of rice husk is produced, and right after combustion of this husk, approximately 25% of RHA is generated. Nevertheless, the generated amount of RHA is subject to temperature of combustion and type of rice [6]. World-wide, 100 million tons of RHA are annually produced [7], [8]. In 2013, Office of Agricultural Economics of Thailand announced that the rice production was approximately 30 million tons [9]. In terms of particle size, RHA is said to be suitable as a soil stabilizer [10]. With regard to chemical property, RHA principally constitutes of silicon oxide (SiO_2) which as a pozzolanic material has the potential to be mixed with other binding materials like cement and lime for soil improvement. Hence, in this research, aside from studying the potential of BA and RHA as the replacement material for natural soil, their cementitious properties were also taken into consideration with addition of lime as an activator.

2. Experimental program

2.1. Materials

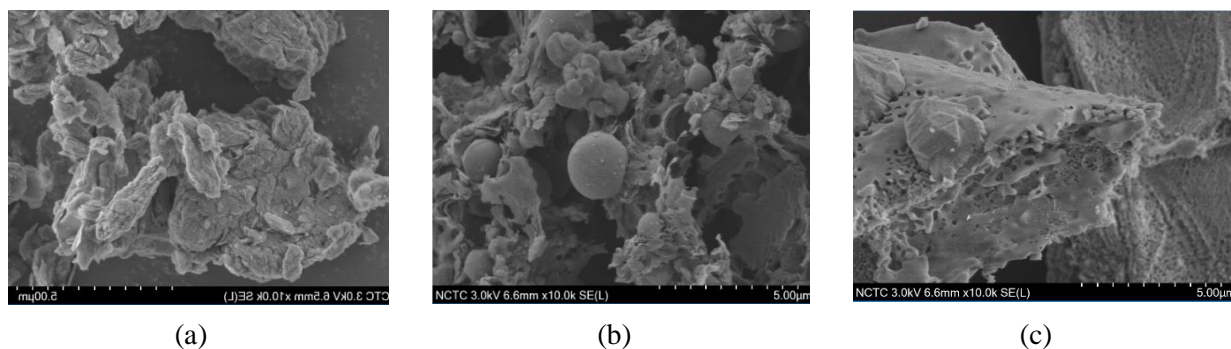


Figure 1. SEM images of pure materials (a) Bangkok Clay, (b) Bottom Ash and (c) Rice Husk Ash

2.1.1. Soil. Clay soil was collected from pile borings of a construction site located in Chang Wat Nonthaburi, Thailand. The soil was at 2.5 to 6 m depth beneath ground surface. Atterberg limits, specific gravity, and particle-size analysis of soils were performed in accordance with ASTM D 4318 [11], ASTM D 854 [12], and ASTM D 422 [13], respectively. Based on Unified Soil Classification

System (USCS) ASTM D 2487 [14], Bangkok clay is classified as High Plasticity clay (CH). The soil can also be classified as A-7-6, according to American Association for State Highway and Transportation Official (AASHTO) [15].

2.1.2. Bottom Ash. Bottom ash was collected from BLCP power plant in Rayong Province, Thailand. It is produced during combustion of Bituminous Coal that is imported to Thailand from Australia, Indonesia etc. The specific gravity of bottom ash was found to be 2.08 which is similar to that specified by other researchers [16], [17]. The specific gravity of bottom ash is found to be lower than soil. The material is non-plastic in nature. Based on the USCS and AASTHO classification, it can be classified as fine but poorly graded sand (SP) and A-1-b, respectively.

2.1.3. Rice Husk Ash. Another material used for replacement of soil is rice husk ash which is formed after combustion of Rice Husk. It was collected from Chang Wat Ang Thong. The rice husk is used to fire brickworks. It was black to greyish in color. Its specific gravity was determined as 2.14 which is also lower than that of soil. The material is also non-plastic in nature. In table 1, the basic properties of Bangkok clay, bottom ash and rice husk ash are shown. The Scanning Electron Microscopy (SEM) image of the pure materials is shown in figure 1. In addition, the powder form texture of the raw materials is shown in figure 2.

2.1.4. Lime. The binding material used for this study is quicklime in form of powder. It was bought from Golden Lime Public Company Limited branch, Chang Wat Saraburi, Thailand. The chemical composition of quicklime using XRF analysis is presented in table 2.

Table 1. Properties of Materials

Properties	Bangkok Clay	Bottom Ash	Rice Husk Ash
Natural Moisture Content [%]	79.81	29.62	3.5
Plastic Limit [%]	29.45	Non-Plastic	Non-Plastic
Liquid Limit [%]	66.80	NP*	NP*
Plasticity Index [%]	37.35	-	-
Specific Gravity	2.68	2.05	2.14
Maximum Dry Density(Mg/m ³)	1.49	0.966	0.64
Optimum Moisture Content (%)	22.5	12.5	92.07
Color	Black or Brown	Blackish Grey	Blackish Grey
UCS (kPa) (Lab Samples)	264	NP*	73.96
NP* = Not Possible			

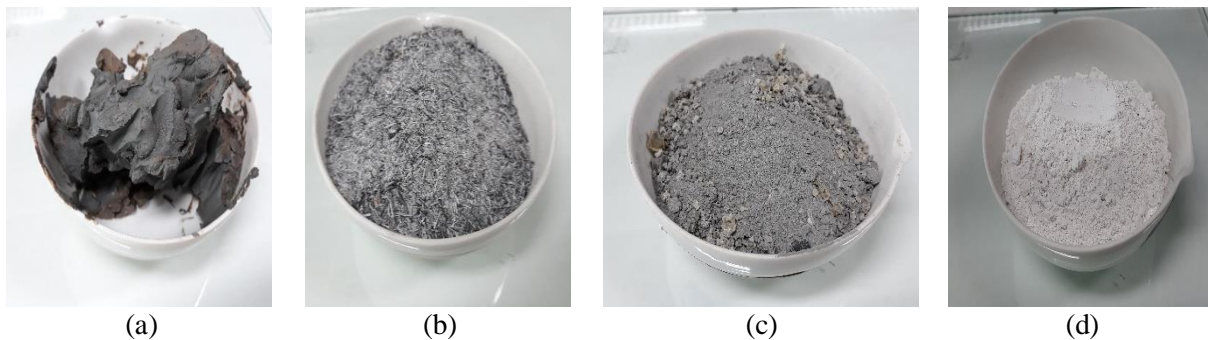


Figure 2. Natural materials (a) Bangkok Clay, (b) Rice Husk Ash, (c) Bottom Ash and (d) Lime

Table 2. Chemical Composition of Quicklime.

Analysis Item	Test Method	Percentage [%]
CaO	XRF	94.18
MgO	XRF	2.29
SiO ₂	XRF	0.89
SO ₃	XRF	2.64
Al ₂ O ₃	XRF	0
Fe ₂ O ₃	XRF	0
Residue (no. 100 mesh)	Air Jet Sieve	3.12
Color	Visual	Grayish-white

3. Test procedure

First of all, the soil and replacement/stabilizer materials, i.e., RHA and BA were dried in oven at $110 \pm 5^\circ\text{C}$. After drying the materials, they were broken down to pass the sieve sizes specified for different tests according to ASTM. For instance, to perform compaction and specific gravity test the materials were passed through 4.75mm sieve. The specific gravity test, liquid limit test, plastic limit test and particle size analysis were performed on Bangkok clay, bottom ash and rice husk ash in their laboratory prepared dry state. Sieve analysis was done on bottom ash and rice husk ash to understand their particle size distribution. For Bangkok clay, high amount of soil passed the 0.075mm sieve and hence, the hydrometer test needed to be carried out in order to determine the amount of clay fraction present in the soil. The standard proctor compaction test was done on various mix designs, i.e. 4, 8, 12% lime and 10, 20, 30, 50% of bottom ash and rice husk ash mixed with the soil.

The compaction test was done in accordance with ASTM D 698 [18] that is used for compacting the soil using standard effort. Different mix designs of soil and waste materials were used and three samples from top, middle and bottom layer of mold were taken for determining the water content after each compaction ASTM D 2216 [19]. The mix designs that contained lime were mellowed for 1 hour prior to their compaction according to ASTM D 5102 [20]. The samples then were passed through 0.425mm sieve to determine their Atterberg's limits and the degree of plasticity.

4. Results and discussion

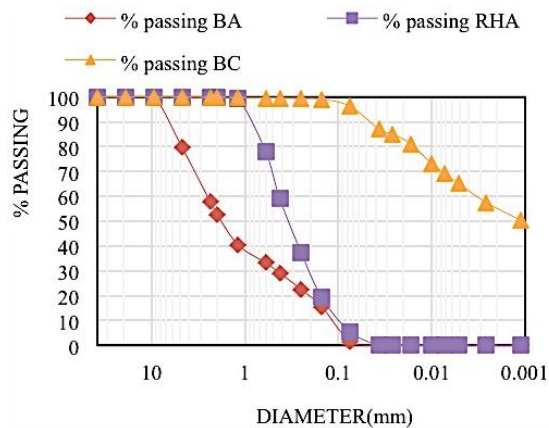


Figure 3. Particle Size Distribution curve of BA, BC and RHA

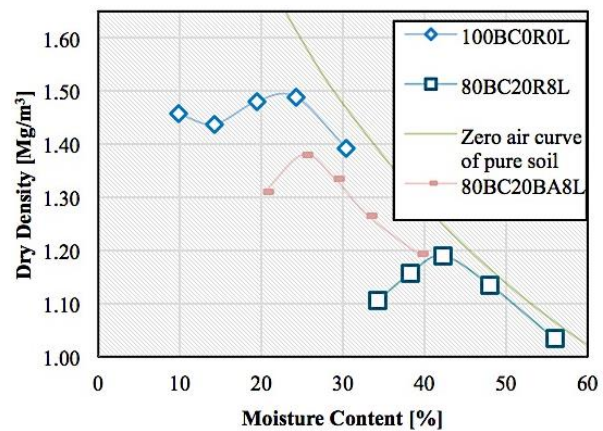


Figure 4. Compaction curve of sample mix designs

In figure 3, the particle size distribution of different materials are shown. According to the curve for bottom ash, the value of C_u was 18.51 and C_c was 0.25. The percentage of gravel-sized particles was 20.09%, and sand-sized particles was 78.25% (coarse grained (27.07%), Medium grained (23.73%) and fine grained (27.46%)). Fine-sized particles only comprised 1.65% of the material. Based on the curve for RHA, the values of C_u and C_c were 3.4 and 1.29, respectively. They were no gravel-sized particles present. The percentage of sand-sized particles was 94.53% (coarse grained sand (0.17%), medium grained sand (21.83%) and fine grained sand (72.52%)) and fine-sized particles comprised 5.46% of the RHA. This indicated a much finer particle size distribution of RHA in comparison to BA. The compaction curves representing sample mix designs can be seen in figure 4. It is clear that, the OMC value has increased and MDD has decreased with replacement of BA and RHA. RHA shows higher OMC value than BA. However, the MDD for BA is seen to be higher than RHA when they replace the soil.

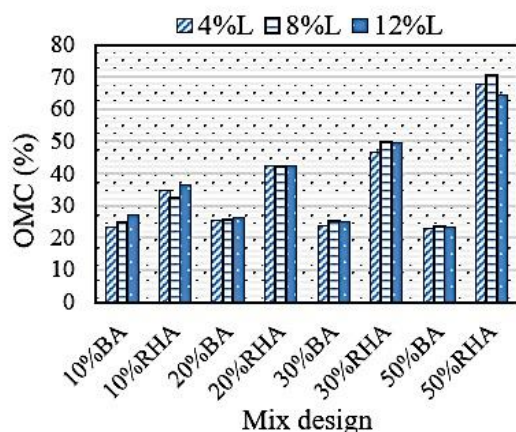


Figure 5. OMC for different mix designs

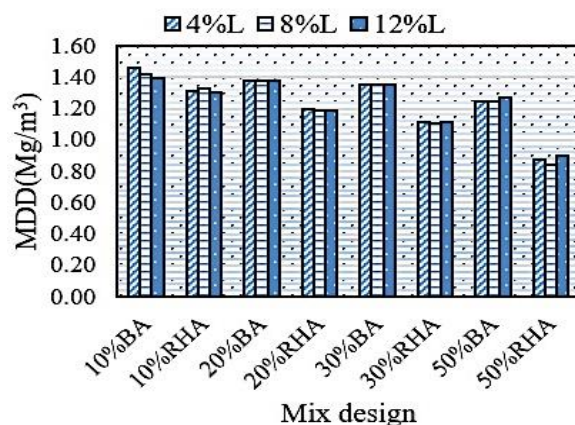


Figure 6. MDD for different mix designs

The optimum moisture content (OMC) and maximum dry density (MDD) obtained from different mix designs of Bangkok clay, rice husk ash, bottom ash and lime as activator are summarized in figures 5 and 6, respectively. Overall, the bar diagram shows increase in optimum moisture content values with increase in content of bottom ash, rice husk ash and lime which is consistent with results obtained by others [21] [22]. This is because of the reaction of rice husk ash, bottom ash and lime with water known as the hydration effect and also the affinity for more moisture during the chemical

reaction processes, which increases the demand for water. Increase of moisture content is more pronounced for RHA than BA for having more spongy surface area than BA as can be seen in the morphology and probably being more reactive with lime.

According to figure 6, the MDD values are decreasing with increase in RHA, BA and lime content. One reason is because of the introduction of ions with higher positive charges that would result in reduction of diffused water layer (less repulsion) thus making clay particles agglomerate and become more granular (flocculation/aggregation effect). In addition, the replacement of heavier soil particles with lighter materials (less specific gravity) would result in lower MDD values.

5. Conclusion

Based on the compaction results, mix designs with RHA are more sensitive to the ash content. In general, the MDD reduces with increase in the ash content. Bottom ash mix designs show higher MDD than rice husk ash-soil mixtures. The drop can be significant for RHA mix designs. The latter can be attributed to the finer size and lighter weight of RHA particles. According to the graph, the best mix design for compaction in terms of less reduction in MDD while having noticeable amount of natural soil replacement is 30% for BA and 10% for RHA. The mix design with highest OMC and lowest MDD is 50% RHA and 8% lime that is more suitable as filler materials in projects that lighter weight material is required for the soil structure.

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