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Strength and Durability of Bottom Ash and Lime Stabilized Bangkok Clay

Akanksha Bhurtel[a] **and Amin Eisazadeh**[a]

[a]School of Civil Engineering and Technology, Sirindhorn International Institute of Technology, Thammasat University, Pathum Thani 12120, Thailand

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ABSTRACT

High rainfall is observed in a tropical climatic country like Thailand that results in higher chances of natural calamities like flood. High plastic clay known as Bangkok clay is present in Thailand. The clay is famous for displaying variability in its geotechnical properties under dry and wet conditions. Therefore, such clay must be treated with some other materials for the stability of roads along with vehicles running through them. Bottom ash that is one of the waste materials produced from coal combustion has been used for this study along with lime. Tests like unconfined compressive strength test, durability test has been conducted by determining the strength under dry and wet condition. Two methods of soaking have been adopted when performing wetting-drying namely complete and capillary soaking. The results showed improvement in strength as well as durability after replacement with bottom ash and lime. The strength of the soil specimen after treatment with bottom ash and lime has improved 2-fold with 50% amount of bottom ash and 12% lime. The same ratio of materials: 50% bottom ash and lime with the clay showed the optimum amount in terms of durability.

1. Introduction

Tropical climatic countries like Thailand, Malaysia, Singapore have a high frequency of rainfall which is one of the leading causes of many flood cases there. According to Haraguchi (2015), floods have a direct effect on the roads leading to formation of potholes, cracking etc. Furthermore, Bangkok clay (BC) is a highly plastic soil found in Thailand. It has plasticity index more than 30 that increases with depth. Swelling with water contact is one of the problematic characteristics of the clay (Tanaka et al., 2001; Horpibulsuk et al., 2007) that can cause difficulty in operation of vehicles after rainfall. Therefore, stabilization of road with BC, is necessary before performing any road pavement construction.

Soil stabilization of roads using various materials like cement, lime, rice husk ash, polymers, palm oil fuel ash, bottom ash have been performed (Huang, 1990; Kumar et al., 2004; Mohamedzein et al., 2006; Kumar and Stewart, 2010; Phummiphan et al., 2016). According to Horpibulsuk et al. (2012), in-situ cement stabilization techniques can increase the strength and reduce the plasticity of clayey soil. However, production of cement has been under scrutiny for its large carbon footprint (Kampala et al., 2014; Phetchuay et al., 2014). Therefore, cement production should be minimized that makes recycling of waste byproducts such as fly ash and bottom ash (BA) necessary (Donrak et al., 2016; Phummiphan et al., 2016; Phummiphan et al., 2017; Phummiphan et al., 2018). Sathonsaowaphak et al. (2009) has mentioned that approximately, 0.8 million tons of BA is produced in Mae Moh power plant annually which is one of the biggest power plants in Thailand. The BA produced is generally neglected and dumped in the environment because of its porous and coarse-grained structure in comparison to fly ash. Such dumping has given rise to various environmental issues like air pollution, groundwater pollution, etc. So, the excess BA can be utilized for road construction similar as in Europe as explained by Colonna et al. (2012). Hence, it has been considered as one of the materials used for this study. However, BA is found to not have proper amount of free lime in it which is one of the important compounds for cementation along with silica and alumina. Moreover, Lime (L) is reported to form good cementing products such as CSH and CAH gel with clayey soil (Bell, 1996; Ghosh and Subbarao, 2007; Al-Mukhtar et al., 2012; Obuzor et al., 2012; Garzón et al., 2016; Cheshomi et al., 2017; Wild et al., 2018). Thus, L is used as an activator material along with BA for this research.

According to previous studies performed, BA has been

CORRESPONDENCE Amin Eisazadeh aeisazadeh@siit.tu.ac.th School of Civil Engineering and Technology, Sirindhorn International Institute of Technology, Thammasat University, Pathum Thani 12120, Thailand

Table 1. Works Done Related to Durability Assessment by Different Researchers

Author	Materials used	Curing period (days)	Type of Soaking	Soaking periods (hour)	Tests performed after soaking
Garcia and Coutinho (2013)	Cement and Bottom Ash mixture	81	Capillary	4.5	Capillary Absorption test
Gonzalez-Lopez et al. (2018)	Sand (different gradation) and clay, lime and cement	28	Complete	24	absorption, abrasion and compressive tests (parallel and normal direction)
Georgees et al. (2017)	Soil and water anionic polyacrylamide (PAM) mixture	14	Partial	0.5	abrasion resistance test, erosion resistance test
		30, 180, 360	Capillary	48, 120	Water absorption test
Jin et al. (2018)	Cement-treated soil with water reducer	28	Complete	-	Weight loss test
Kamei et al. (2013)	Soil cement and basanite mixture	28	Complete	24 hour wetting and 24 hour drying	Compressive strength test(14 wet dry cycle)
Ahmed and Ugai (2011)	Soil stabilized with cement and recycled gypsum	7	Complete	24 hour wetting and 24 hour drying	volume change, UCS and weight loss
Ahmed and Issa (2014)	Soil, gypsum, lime or cement	3,7,28	Complete	4, 7, 15, 30, 60 days	UCS, deformation, absorption, soil deterioration

deployed as replacement material for clayey soil (Forteza et al., 2004; Mohamedzein et al., 2006; Kumar and Stewart, 2010; Lopez et al., 2015; Rangaswamy, 2016). All the authors mentioned above have performed tests like unconfined compressive strength (UCS), Compaction, California bearing ratio (CBR), Permeability with BA and other materials like fly ash, bentonite, lime etc. Based on the studies conducted, the use of BA as a stabilizer for soil has shown improvement in terms of CBR and UCS by more than 2 folds which proves that use of BA as a road material is significant. However, none of the research have been focused on the durability aspect of road. As, vehicles can operate properly in roads that are durable during adverse climatic conditions like heavy rainfall, analyzing the durability of road is necessary. Durability test is generally done through wetting drying test and freeze-thaw test. Nevertheless, freeze-thaw test performed by Güllü (2015) with BA, L, clay and superplasticizer showed durability in terms of strength. Yet for tropical countries like Thailand, freezing and thawing test cannot show relevance. Therefore, it is necessary to assess the wetting-drying strength of soil that has been replaced with BA and L. Several tests have been previously performed to assess durability through wetting and drying that have been explained in Table 1.

The following research focuses on the strength of BC treated with BA and L that is cured for different periods. It also studies the effect on the strength of the samples on wetting and drying. For wetting-drying, two types of soaking have been used, i.e., capillary soaking and complete soaking.

2. Materials

2.1 Bangkok Clay

BC used in this research was collected from Nonthaburi province of Thailand from 3 m depth. The texture for the brownish to black colored clay has been shown in Fig. 1. The properties of soil after performing preliminary tests have been tabulated in Table 2. According to the table, the specific gravity of the soil is 2.69. The liquid limit (LL), plastic limit (PL), and plasticity index (PI) has been obtained as 62.23%, 29.07% and 33.16% respectively which is matching with the range of Atterberg limits and specific gravity as specified by other authors (Horpibulsuk et al., 2007; Horpibulsuk et al., 2011; Horpibulsuk et al., 2012;

Fig. 1. Texture of Bangkok Clay

Table 2. Properties of Materials

Properties	BC	BA
Natural Moisture Content [%]	79.81	29.62
Plastic Limit [%]	29.07	Non-Plastic
Liquid Limit [%]	62.23	NP*
Plasticity Index [%]	33.16	-
Specific Gravity	2.69	2.05
Maximum Dry Density (Mg/m^3)	1.49	0.966
Optimum Moisture Content (%)	22.5	12.5
Color	Black or Brown	Blackish Grey
UCS (kPa) (Lab Samples)	264	NP*

NP* = Not Possible

Fig. 2. Texture of Bottom Ash

Table 3. Chemical Composition of Different Materials as per XRF

Oxide (% weight)	BC	BA	L
MgO	2.39	-	2.29
Al_2O_3	16.41	19.86	-
SiO_2	65.99	72.48	0.89
SO_3	4.35	-	2.64
K_2O	2.21	1.21	-
CaO	0.89	1.36	94.18
TiO_2	0.97	1.38	-
MnO	0.13	-	-
Fe_2O_3	6.69	3.72	-

Vichan et al., 2013; Teerawattanasuk et al., 2015). The clay can be classified as high plasticity clay (CH) and, A-7-6 according to USCS and AASTHO classification respectively.

2.2 Bottom Ash

BA was used as replacement material in this research. The BA was collected from BLCP power plant in Rayong province, Thailand. The BA produced there is of bituminous coal. The basic properties of bottom ash have been shown in Table 2. Similarly, the texture of BA used for research work can be seen in Fig. 2. The specific gravity of BA was determined as 2.05 which tallies with the range as specified by Huang (1990) which shows a lower value than that of clay. It is a non-plastic material. The ash can be classified as fine but poorly graded sand (SP) and A-1-b based on USCS and AASTHO classification respectively.

2.3 Lime

L has been used as a binding material in the mix design. It was manufactured by Golden Lime Pvt. Ltd. The chemical composition (oxide content) of raw materials used in this research are shown in Table 3.

3. Methodology

3.1 Basic Tests and Compaction

First, BC and BA were oven dried to remove moisture. Then BC was crushed to smaller pieces. After crushing and sieving of the materials was done, basic tests like Atterberg limit tests (ASTM D 4318), specific gravity test (ASTM D 854), hydrometer test, and sieve analysis were performed. Then, compaction test was performed in order to determine the optimum moisture content for each mix designs according to ASTM D 698, i.e., using standard proctor effort. Each test was performed 3 times.

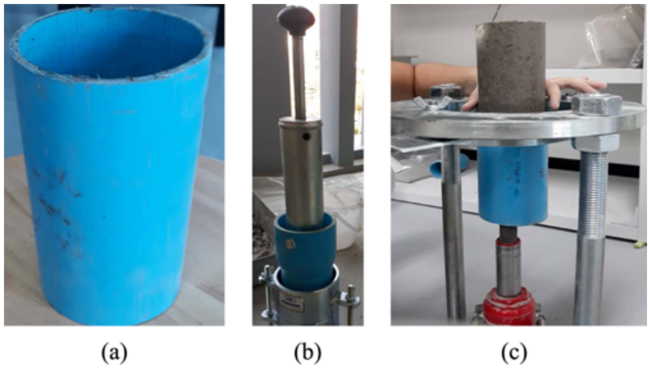

Fig. 3. Preparation of Samples for UCS Test: (a) PVC Pipe, (b) Compaction of Samples, (c) Extruding of Samples

3.2 Unconfined Compressive Strength

After the compaction test was performed, the samples were compacted at their respective optimum moisture content (OMC) to a PVC pipe of dimension of 69.2 mm diameter and 140 mm height as in Fig. 3(a). For this, the pipe was inserted in the Proctor mold, and outer space between the pipe and proctor mold was filled with sand to erect in a position that is shown in Fig. 3(b). Then, the pipes were filled and compaction was done with the same hammer used for proctor compaction. The number of blows was calculated such that the energy of compaction was the same as that of the standard proctor compaction. 3 samples were prepared for each mix designs. After compacting, the samples were extruded as shown in Fig. 3(c). and cured for 28 days. The UCS test was performed as mentioned in ASTM D 2166 at 1% strain rate. The curing was done by wrapping the specimens in plastic and placing those samples in a water bath to maintain 100% humidity condition. The best five mix designs with highest strength were used for UCS determination at shorter and longer curing periods as well as durability analysis.

3.3 Wetting-Drying Test

For durability assessment, the 28 days cured samples were soaked in water for 24 hours in two conditions. One was completely soaked in water, i.e., Fig. 4(a). Whereas, the other one was soaked only with its base touching the porous surface placed above water and allowing water to rise in a capillary manner as shown in Fig. 4(b). These two soaking conditions represented the two cases of rainfall, i.e., light rainfall for capillary soaking and heavy rainfall for complete soaking. After the soaking period was over, the samples were oven dried for 24 hours at 70ºC to complete one wetting-drying cycle similar as worked by other researchers (Ahmed and Ugai, 2011; Georgees

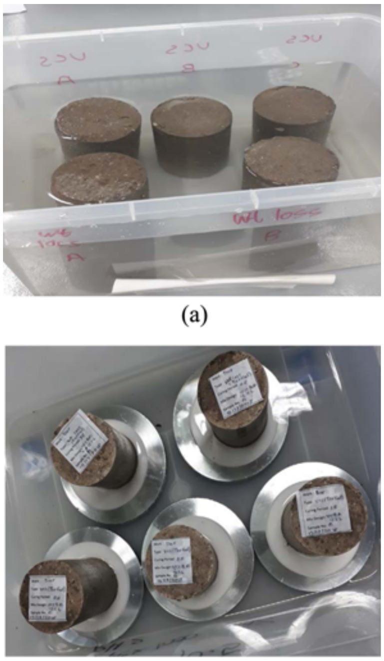

Fig. 4. Condition of Soaking: (a) Complete Soaking, (b) Capillary Soaking

et al., 2017). However, the samples were again soaked in water for another 24 hours before testing.

4. Results and Discussion

4.1 Particle Size Distribution

The particle size distribution curve for BC and BA has been shown in Fig. 5. Based on the curve, BC has a fine-grained texture with more amount of clayey sized particles. The percentage of sand-sized particles, silt-sized particles and clay-sized particles in the soil is about 3.71%, 38.77%, and 57.52% respectively. On the other hand, BA is a coarse-grained material based on the particle size distribution curve. The value of C_u is 12.5 and C_c is 0.38. The percentage of gravel-sized particles are

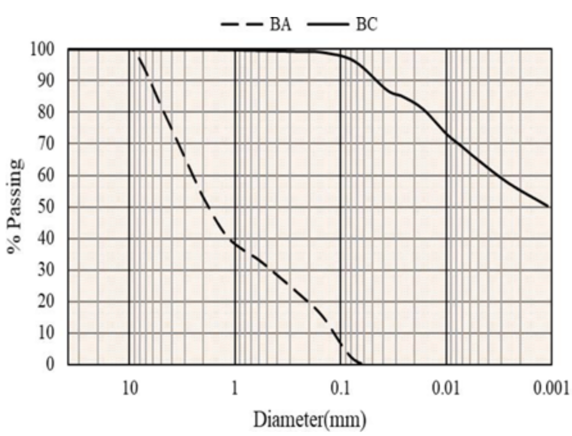

Fig. 5. Particle Size Distribution Curve

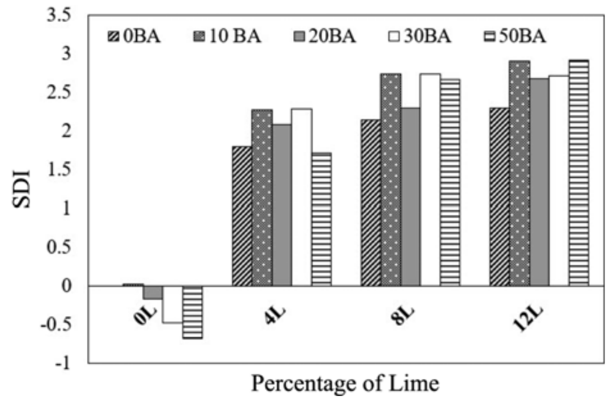

Fig. 6. Strength Development between Various Mix Design in 28 Days

13.46%, sand-sized particles are 84.76%, and clay along with silt-sized particles are 1.76%.

4.2 Strength Development of Various Mix Designs

Figur 6 shows the strength development index (SDI) of the mix design. The SDI has been calculated using the following formula :

$$SDI = \frac{q_{u(mix)} - q_{u(bc)}}{q_{u(bc)}} \quad (1)$$

where,

$q_{u(bc)}$ = UCS value of untreated BC i.e., 100% BC

$q_{u(mix)}$ = UCS value of the respective mix design

According to the results in Fig. 6, the highest SDI value which is approximately 2.92 is shown by 38BC50BA12L mix design (i.e., 38% BC, 50% BA, and 12% L) followed by 78BC10BA12L mix design that is about 2.91. The higher value for the former is due to mixing of clay with high silica containing bottom ash along with calcium-rich lime material that results in formation of more cementitious materials that binds the clay particles together.

In general, the strength has increased with replacement of BC with BA and L. The result also reveals that when only BA is replaced with BC, the trend has decreased which proves that use of L as a binding material is necessary (Güllü, 2015). The latter can be attributed to the low free lime content of BA (Table 3).

4.3 Effect of Curing Period

The SDI of mix designs for different curing times is shown in Fig. 7. In general, the strength of BC is found to increase with time with use of other materials (Bell, 1996; Mohamedzein et al., 2006; Ghosh and Subbarao, 2007; Al-Mukhtar et al., 2012; Güllü, 2015). According to the stress-strain curve in Fig. 8, 1 day and 7 days cured samples did not show much change in the ductile behavior in comparison to 28 and 56 days cured samples. The optimum SDI value was shown at 56 days curing period for 50% BA and 12% L content mix design. The result is also justified by Fig. 9, that shows denser morphology of 38BC50BA12L mix design after 56 days of curing in comparison to pure Bangkok

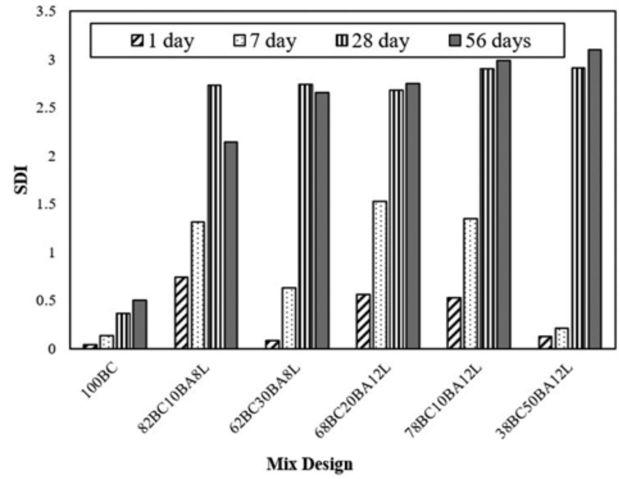

Fig. 7. SDI for Different Time

clay (100BC), pure bottom ash (BA), and 12% lime treated clay (92BC0BA8L).

4.4 Effect of Wetting-Drying

UCS results obtained after performing 1 cycle of wetting-drying can be seen in Fig. 10. Moreover, strength reduction index (SRI) after performing wetting-drying is shown in Fig. 11. The SRI was determined as follows:

$$SRI = \frac{q_{u(u)} - q_{u(s)}}{q_{u(u)}} \quad (2)$$

where, $q_{u(u)}$ = UCS value at 28 days curing for a mix design (un-soaked condition)

$q_{u(s)}$ = UCS value at 28 days curing after wetting and drying for the same mix design

In general, the strength has reduced on subjection to 1 wetting and drying for both completely and capillary soaked samples after 28 days of curing. The result seems to be in consistence with other researchers (Ghosh and Subbarao, 2007; Obuzor, 2012). The reduction in strength is due to the filling of voids by water that caused back pressure and softening of the specimen on soaking along with shrinking on drying. This back pressure, softening and shrinkage resulted in disintegration of materials present causing reduction in strength as explained by Ghosh and Subbarao (2007). However, the reduction in strength was less for 12% L containing mix designs. 38BC50BA12L showed least amount of strength reduction for both capillary and completely soaked samples after undergoing wetting and drying. This is because this mix design had gained the highest strength for the

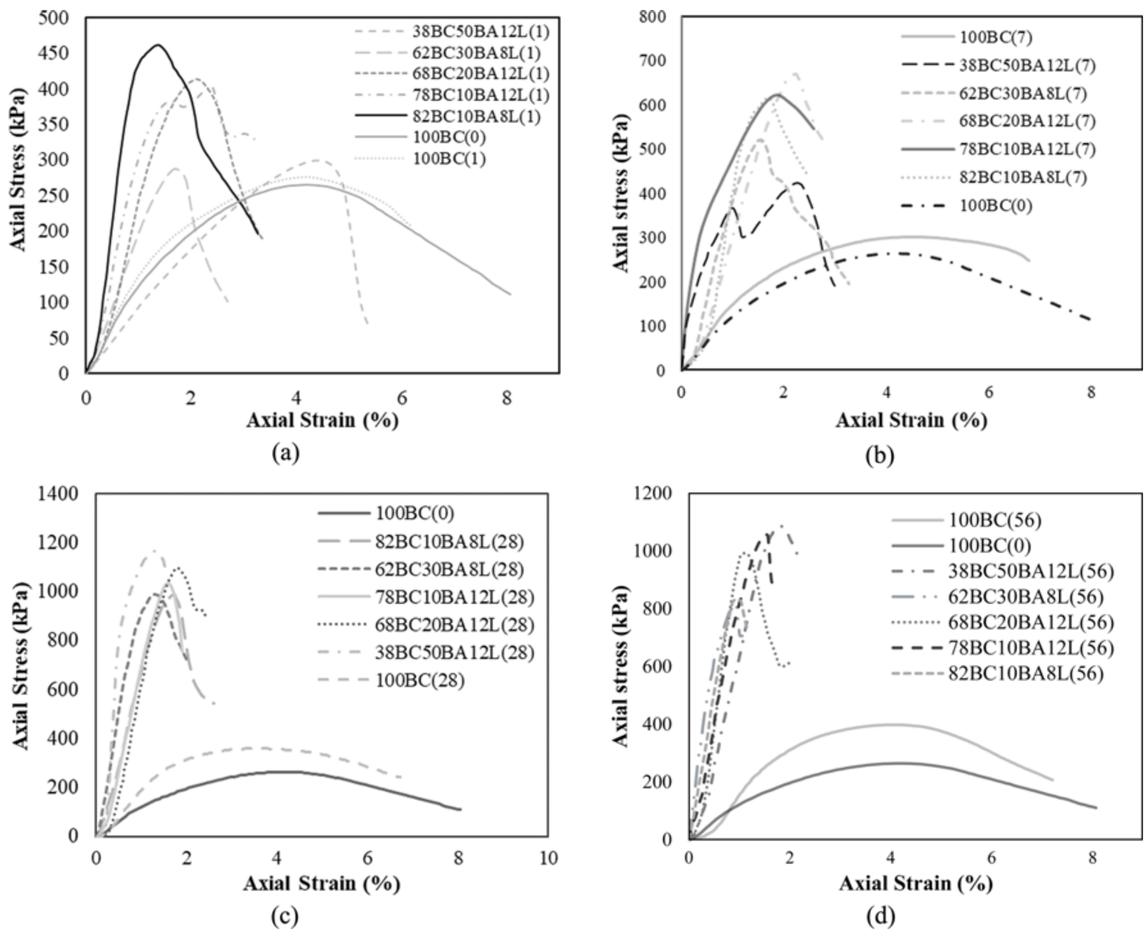

Fig. 8. Stress-Strain Curve after: (a)1 Day Curing, (b) 7 Days Curing, (c) 28 Days Curing, (d) 56 Days Curing

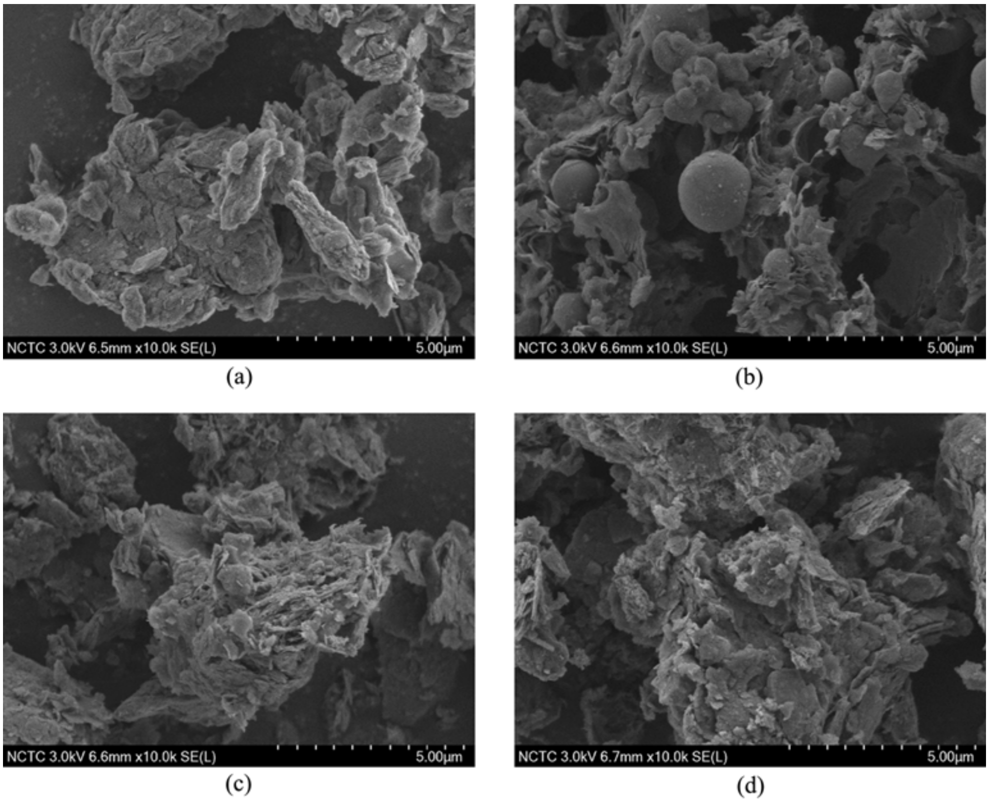

Fig. 9. Change in Morphology of Materials: (a) Bangkok Clay at 0-Day Curing, (b) Bottom Ash at 0-Day Curing, (c) 92BC0BA8L at 28 Days Curing at 10k, (d) 38BC50BA12L at 56 Days Curing at 10k

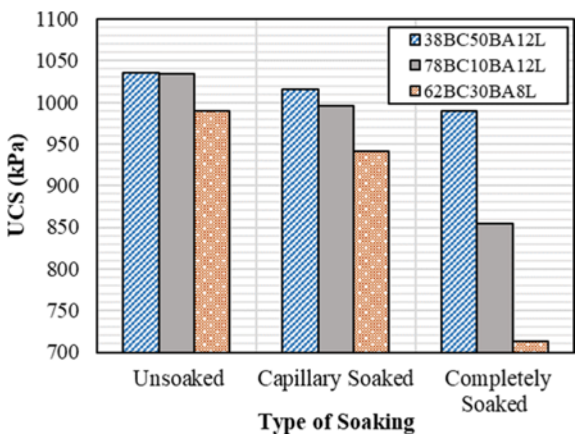

Fig. 10. UCS Values for Samples Subjected to 1 Wetting-Drying

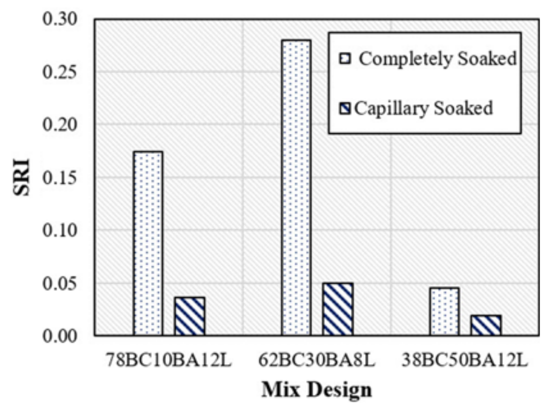

Fig. 11. Strength Reduction Index with respect to Un-soaked Samples after Wetting-Drying

un-soaked condition with formation of cementing products at 28 days that overpowered the backpressure applied by the water entering the pores showing higher stability as mentioned in Ghosh and Subbarao (2007). Though 78BC10BA12L had almost the same UCS value as that of 38BC50BA12L during the un-soaked condition. However, a higher ratio of clayey particles in 78BC10BA12L caused it to soften more compared to 38BC50BA12L on soaking. Therefore, 38BC50BA12L is considered the most durable mix design based on the wetting drying tests conducted.

5. Conclusions

During the research, the unconfined compressive strength test was performed with BC stabilized with BA and L for different ratios. Also, the strength after wetting and drying were determined, and two methods of soaking were adopted, i.e., complete soaking and capillary soaking. From the results and discussion, the following conclusions can be drawn:

1. Concerning the stabilization of soil with L and BA, the strength showed improvement with curing period as well as with increase in BA and L content. 38BC50BA12L mix

design showed optimum value after the curing period of 56 days. The higher amount of silica containing material with combination of slight amount of fine-grained material and presence of activator like quicklime has resulted in such optimum value compared to other mix designs.

2. On subjecting to 1 cycle of wetting-drying, the clay showed durability when replaced with BA and L. BC stabilized with 50% BA and 12% L was found to be the most durable one for both completely and capillary soaked condition after undergoing wetting and drying similar as for un-soaked condition. This was because it had already gained strength after higher curing period and had least amount of clayey particles in it causing least softening and disintegration of particles. So, this mix design is recommended for using as either subgrade or engineering filling material at places even with a high frequency of rainfall.

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Nomenclature

BA = Bottom ash
BC = Bangkok clay
C_c = Coefficient of curvature
C_u = Coefficient of uniformity
L = Lime
NP = Not possible
OMC = Optimum moisture content
SDI = Strength development index
SRI = Strength reduction index
UCS = Unconfined compressive strength

ORCID

Amin Eisazadeh https://orcid.org/0000-0003-0359-9357

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