International Journal of GEOMATE, Jan. 2019, Vol.16, Issue 53, pp.70-77
Geotec., Const. Mat. & Env., DOI: https://doi.org/10.21660/2019.53.68522
ISSN: 2186-2982 (Print), 2186-2990 (Online), Japan

MARGINAL LATERITIC SOIL TREATED USING CERAMIC WASTE FOR RURAL ROAD APPLICATION

Panich Voottipruex[1], Chairat Teerawattanasuk[2,] and *Ittipon Meepon[3]

[1,3] Department of Teacher Training in Civil Engineering, Faculty of Technical Education, King Mongkut's University of Technology North Bangkok, Bangkok, Thailand; [2] Department of Civil and Environmental Engineering Technology, College of Industrial Technology, King Mongkut's University of Technology North Bangkok, Bangkok, Thailand.

*Corresponding Author, Received: 17 Sept. 2018, Revised: 13 Oct. 2018, Accepted: 08 Nov. 2018

ABSTRACT: This research aims to improve lateritic soil from Chachoengsao province 82 km from Bangkok with ceramic wastes. Engineering properties of lateritic were tested that included liquid limit, plastic limit, specific gravity, and modified compaction, permeability, and Los Angeles abrasion tests. Sieve analysis and engineering properties of mixed materials were also conducted. The maximum dry density (Modified Proctor Density) and the optimum water content of the natural studied soil were 1.95 g/cm^3 and 10% while the maximum MDD and OMC obtained from the specimen with lateritic soil: CM ratios of 90:10 are 2.23 kN/m^3 and 8%, respectively. The lateritic soil was mixed with ceramic fragments of 3, 5, 7, 10, 15 and 20% by weight of dry soil. The results show that lateritic soil replaced by 10% ceramic fragment or the so-called proper blended samples exhibit the highest California Bearing Ratio (CBR) values and engineering properties conformed to the specification of Department of Rural Roads (DRR) of Thailand.

Keywords: Lateritic soil, Ceramic waste, CBR, Unconfined compressive strength

1. INTRODUCTION

Nowadays, the population in the developed area has increased dramatically. As a result, the demand for communication infrastructure has become increasingly important. Natural resources may facilitate or become components of infrastructure and services used and consumed. Therefore, it is necessary to have natural resources, especially soil and rock, as civil engineering materials. Initially, high-quality materials are available for construction but when the construction progresses, the soil, especially with the appropriate engineering properties for backfill or construction material decreases very rapidly. The lateritic soil in Thailand is popular for road construction or as a backfill material because of its high performance in terms of bearing capacity. Besides, this is not always the case since there are a wide variety of lateritic soils in tropical areas in the world and sometimes they do not satisfy a minimum bearing capacity. Nowadays, high quality of lateritic soil can be found especially in the reserved forest area. However, deforestation has had severe impacts on the environment, such as carbon dioxide in the atmosphere, changing water cycles, increased soil erosion and reduced biodiversity. Therefore, locally marginal lateritic soils need to be improved by mechanical improvement, chemical stabilization, or by adding waste materials from industrial products [1]. Pavement materials can be improved by adding waste from buildings and demolition as well as recycling glass fragments [2-4]. Recently, research was carried out to evaluate the feasibility of water treatment sludge as a substrate for producing geopolymer as construction materials [5-9] which meet the strength requirement of bearing masonry units in accordance with the Thai Industrial Standard TIS (TIS).

Environmental issues are important and of interest in the industry. Ceramic industry produces solid wastes from production process such as biscuits, deteriorated working molds etc. The biscuits defect final products such as porcelain or unglazed ceramics, which are often called terracotta or, most commonly, an intermediary stage in a glazed final product. Ceramic fragments have an irregular shape, with sharp angles and rough texture. According to the Ministry of Industry, in 2013, the amount of ceramic waste (CM) is about 175,000 tons/year or 7% of ceramic products 2,500,000 tons/year. Most of working molds and biscuits are dumped or landfilled which are inappropriate methods. Ceramic incineration using high temperature increases the risk of hydrogen sulfide gas and causes global warming. The CM can be used as an aggregate by classification and mixing with poor quality soil. The CM treated soil can be used as embankment material instead of destroying natural resources. Ameta [10] improved sand dune with CM tile and reported that the loose sand dune was transformed into a more harden soil after improvement with CM.

This research is an experimental study to investigate the effect of improved marginal lateritic soil by replacing CM at the ratio of 3, 5, 7, 10, 15 and 20 by weight of dry soil. This research aims to evaluate the physical and engineering properties of lateritic soil and ceramic improved lateritic soil. The appropriate ratio of ceramic waste and lateritic soil was investigated. The bearing capacity of ceramic improved lateritic soil was assessed by the CBR test. In addition, the permeability of lateritic and ceramic improved lateritic was also investigated and the equation for bearing capacity prediction of both lateritic and ceramic improve lateritic was proposed. The profit gained from this study in term of economic is the utilization of CM waste from an industry that has been incinerated at 1200 °C.

2. MATERIAL AND METHODS

Nowadays, quarry materials such as lateritic soil which popular for road construction in Thailand is becoming scarce and difficult to obtain for infrastructure. When the quarry is located in a reserve area away from the construction site, construction cost is increased as a consequence. This research aims to improve the engineering properties of locally available lateritic as subbase material. The soil samples were collected from a borrow pit in Chachoengsao province 82 km from Bangkok, Thailand. The lateritic soil composes of 7 % fine grain particle and 93% coarse particles in which 65 % is gravel and 28 % is sand. The specific gravity of coarse grain particle is 2.67 and the liquid and plastic limits are 30 % and 19 %, respectively. According to the unified soil classification system, the lateritic soil is classified as clayey sand (SC). The grain size distribution curve is shown in Fig.1.

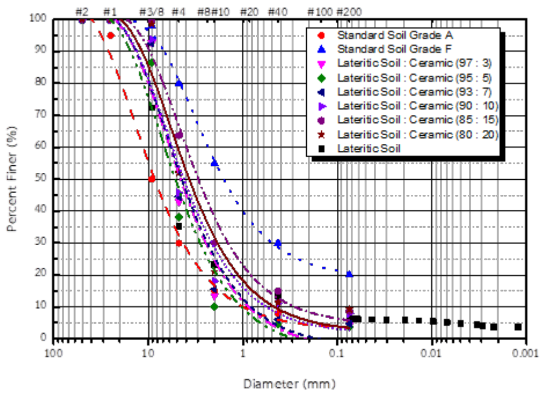

Fig.1 Grain size distribution of lateritic soil/CM.

According to the local road authority specification for subbase [11], this lateritic soil meets the requirement in term of grain size distribution but does not meet the requirement in term of CBR as shown in Table 1.

Table 1 Comparison between soil sample and engineering properties of subbase material (DRR-202-2545, [11])

Properties	DRR-202/2545	This soil sample
Liquid Limit (%)	≤35	30.21
Plastic Index (%)	≤11	11.36
CBR (γ_{dmax}≥95%)	≥25	17
Swelling (%)	≤4	0.069
Abrasion (%)	≤60	63.27

Therefore, this lateritic soil needs to be blended with a higher quality material such as ceramic waste to meet the requirement of subbase material in term of CBR. Chemical compositions of lateritic soil and ceramic are listed in Table 2.

The Utilization of CM wastes obtained from industry in Samutprakarn, Thailand, which has been incinerated at 1200 ° C. The ceramic waste (CM) was crushed into small pieces and sieve according to ASTM D-422-63 [12]. The lateritic soil and CM was blended with lateritic soil: CM ratios of 97:3, 95:5, 93:7, 90:10, 85:15, 80;20.

Table 2 Chemical composition of studied materials

Chemical Compound	Chemical Compound Content (%)	
	Lateritic Soil	Ceramic
SiO_2	58.82	70.80
Al_20_3	23.06	15.20
Fe_20_3	13.38	3.86
TiO_2	0.86	0.46
K_20	0.82	4.26
Na_2O	0.32	1.80
Cao	1.42	2.42
Mn0	0.36	0.12
Mg0	0.84	0.94

Sieve analysis in each mix was conducted and Atterberg limit was performed according to AASHTO T 90 [13]. Fig.1 shows the particles size distribution of lateritic soil/CM. To determine the maximum dry density (MDD) and optimum moisture content (OMC) of the lateritic soil/CM blends, Modified compaction tests were conducted on the lateritic soil/CM by following AASHTO T 180 [14]. The Los Angeles abrasion test (LA) is widely used for evaluating the resistance of aggregates to abrasion and impact forces. LA tests were conducted on all blended material by ASTM D-131-96 [15]. The application of this blended material is road embankment, therefore, permeability need to be conducted according to ASTM D-2434-68 [16]. California Bearing Ratio (CBR) was investigated in accordance with AASHTO T 193 [17]. The CBR tests were performed on the blended material subjected to modified Proctor compaction effort at the optimum water content and soaked for 4 days to simulate the rainy season [18].

3. RESULTS AND DISCUSSIONS

3.1 Atterberg's Limit

The Lateritic soil and CM was blended with lateritic soil: CM ratios of 97: 3, 95: 5, 93: 7, 90:10, 85:15, 80:20. The replacement of CM waste led to a reduction of the liquid limit, plastic limit and plasticity index values as shown in Fig.2. This reduction is achieved due to the thickness of double layer water of clay particles present in the laterite soil decrease as a result of cation exchange reaction, which causes an increase in the attraction force leading to a flocculation of the particles. The results showed that the liquid limit (LL) of plain lateritic soil was 30 % and decreased rapidly to 23 % and 5% CM was replaced. As the CM fraction increased from 5 % to 20 %, the LL does not significantly change with an average of 22 % which less than 35% as specified by Department of Rural Road, Thailand [20]. Considering the plastics limit (PL), it was found that the PL of plain lateritic soil was 19 % and decreased rapidly to 13% and 5% CM was replaced. As the CM fraction increased from 7% to 20%, the PL does not significantly change with an average of 14 %. Due to the decrease of LL and PL are consistent, the maximum PI was found to be 12 % for plain lateritic soil while the minimum PI was found to be 6.40% for the lateritic soil: CM ratios of 85:15. The average value of PI was 8% which less than 8% [11]. The relationship among Liquid Limit, Plastic Limit, and Plasticity Index with the percentage of ceramic is shown in Fig.2.

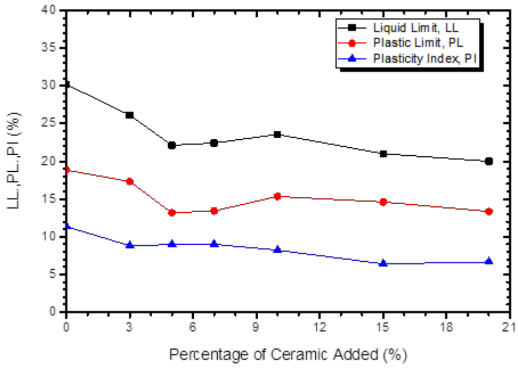

Fig.2 Relationship between Atterberg limit and ceramic replacement ratio.

3.2 Modified Compaction Test

Modified Proctor compaction effort was used to determine the maximum dry density (MDD) and optimum moisture content (OMC) of the blended material and was performed according to AASHTO T 180 [14], which is similar to ASTM D1557 [19]. The sample was compacted by a 10-pound hammer, down to 18 inches, with 25 blows on each of five lifts, for a compaction effort of about 56,250 ft-lbf/ft³. Based on the test results of modified compaction test of the blended lateritic soil:CM ratios of 97:3, 95:5, 93:7, 90:10, 85:15, 80:20; It can be observed that the lateritic soil: CM ratios of 90:10 exhibited highest MDD. The moisture content of the blended lateritic soil and CM waste is likely to decrease as the amount of CM waste increased due to the CM waste used in this study was incinerated at 1200°C and does not absorb water [20,21]. Therefore, the replacement of CM waste in lateritic soil resulted in reduced water content. The maximum dry density (modified Proctor density) and the optimum water content of the natural lateritic soil were 1.95 g/cm^3 and 10.00% respectively. In general, adding of CM waste into the lateritic soil led to a decrement of the optimum moisture content (from 10.00 to 8%) and an increment of the maximum dry density (from 2.20 to 2.23 g/cm^3). However, the maximum MDD and OMC obtained from the specimen with lateritic soil: CM ratios of 90:10 are 2.23 g/cm^3 and 8%, respectively. The relationship between moisture content and dry density of the blended specimens is shown in Fig.3.

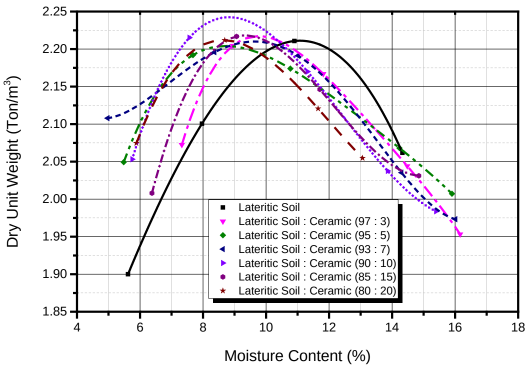

Fig.3 Relationship between dry density and moisture content.

3.3 California Bearing Ratio (CBR)

California Bearing Ratio (CBR) is a penetration test to assess the mechanical strength of natural ground, subgrades, subbase and base courses beneath embankment. The test is performed by measuring the required pressure to penetrate soil or aggregate with a plunger of the standard area. The measured pressure is divided by the required pressure to obtain an equal penetration on a standard crushed rock material. The CBR test is described in ASTM Standards D1883-05 [22] (for laboratory-prepared samples) and ASTM Standards D4429 (for soils in place in field) [23], and AASHTO T193 [17]. The CBR test provides an indirect shear strength measurement and is extremely depends on moisture content and compaction level. The soaked CBR tests were carried out on specimens with a diameter of 152 mm and height of 117 mm subjected to modified Proctor compaction effort at the optimum moisture content. The samples were soaked for 4 days and then the CBR tests were carried out by penetrating a steel cylindrical piston of 50 mm diameter into the samples at a rate of 1mm/min. The requirement for 4 days soak prior to the test is to simulate the likely worst case in the rainy season for a pavement. In this study, the unsoaked CBR was conducted immediately after compaction and the test results show that CBR values gradually increased as the amount of added ceramic waste increased. For plain lateritic, the unsoaked CBR values at 2.5 mm and 5.0 mm penetration depth are 38.59 % and 45.47 % respectively. The blended sample of lateritic soil: CM ratio 90:10 exhibited CBR values at 2.5 mm and 5 mm penetration depth of 61.21 and 77.35 %, respectively. It was noted that the CBR values of the blended sample were higher than those of the plain soil due to the addition of CM waste aggregate as shown in Fig.4. The soaked CBR indicated that the CBR values for both 2.5 mm and 5 mm penetration depth increase after adding 3% of CM waste and gradually decreased after adding 5% and 7% of CM waste. Then, the CBR values gradually increased after adding 10%, 15%, and 20%. The minimum soaked CBR value of lateritic soil replaced by 7% of CM waste was found to be 33% and 45% at a penetration depth of 2.5 and 5.0 mm, respectively, which is higher than the subbase standard [11] as described in Table 1.

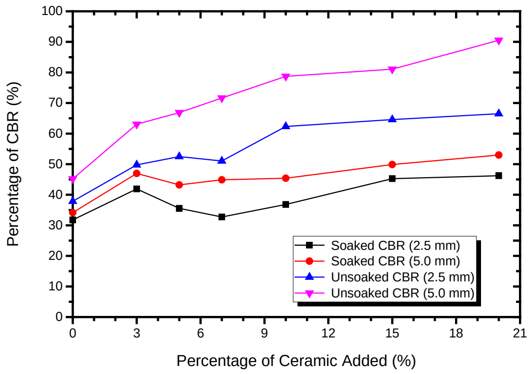

Fig.4 Relationship between CBR and CM replacement ratio.

The CBR-values of the compacted natural lateritic soil soaked in water for 4 days was 17%. Fig.5 presents the soaked CBR values at 95% modified compaction and the percentage of CM waste added. Base on the subbase standard as in [20] described in Table 1, the soaked CBR value of samples with CM waste replacement of 3%, 5%, 7%, 10%, and 15% is higher than the boundary line due to the high stiffness of the CM waste. The maximum of the blended sample of lateritic soil: CM ratio 90:10 CBR was found to be 35% and the CBR values decreased as the CM waste increased from 10% to 15% and 20% due to the void ratio increased.

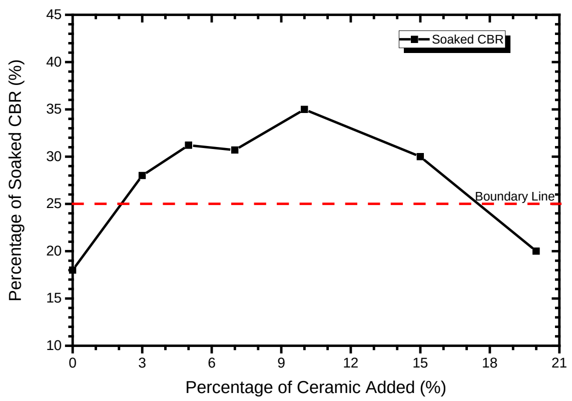

Fig.5 Soaked CBR values and CM waste replacement ceramic at 95% modified compaction

3.4 Swelling Test Results

Fig.6 illustrated the swelling percent values of the natural lateritic soil and the blended lateritic soil with CM waste. The samples were soaked for 4 days and the result showed that the swelling percent value of the natural lateritic soil used the CBR-instrument was 0.069%. The addition of CM waste led to a decrease in these values from 0.069 to 0.040%.

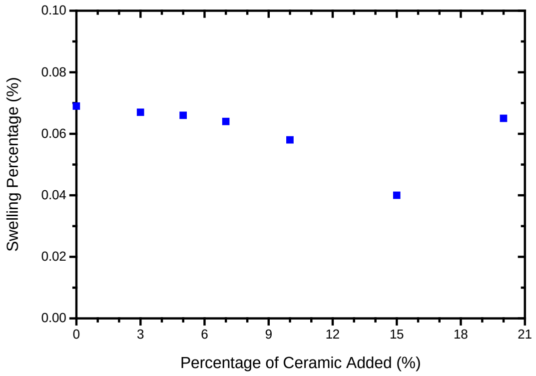

Fig.6 Relationship between percentage of swelling and CM replacement ratio.

3.5 Correlation of CBR with CM Replacement Ratio

Based on an analysis of normalized unsoaked CBR and CM replacement ratio, it is practical to relate the normalized unsoaked CBR and the various percentage of CM in term of replacement. The predictive equations (Fig.7) for unsoaked CBR in term of CM waste replacement are present as follows Eq. (1) - (4)

For 2.5 mm penetration depth

$$\frac{CBR_{improved}}{CBR_{natural}} = -0.0021CM^2 + 0.0780CM + 1 \quad (1)$$

For 5.0 mm penetration depth

$$\frac{CBR_{improved}}{CBR_{natural}} = -0.0027CM^2 + 0.1014CM + 1 \quad (2)$$

The predictive equations (Fig.8) for soaked CBR in term of CM waste replacement are present as follows:

For 2.5 mm penetration depth

$$\frac{CBR_{improved}}{CBR_{natural}} = 0.0001CM^2 + 0.0194CM + 1 \quad (3)$$

For 5.0 mm penetration depth

$$\frac{CBR_{improved}}{CBR_{natural}} = -0.0016CM^2 + 0.0582CM + 1 \quad (4)$$

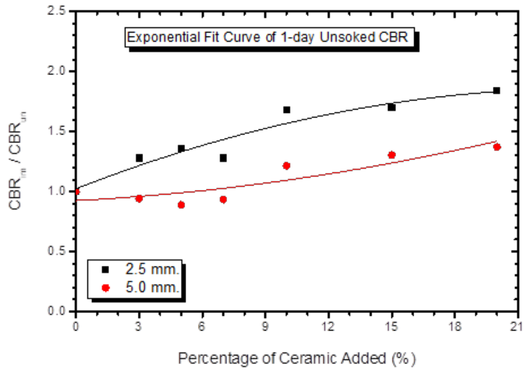

Fig.7 Relationship between normalized unsoaked CBR and CM replacement ratio.

These predictive equations are useful for predicting unsoaked and soaked CBR at different CM replacement ratio base on the values of lateritic soil without CM replacement. The coefficients of correlation of unsoaked equation are greater than 0.91, confirming the validity of this equation. While the coefficient of correlation of soaked equation is greater than 0.55 due to the uncertainty of water absorption of the CM waste.

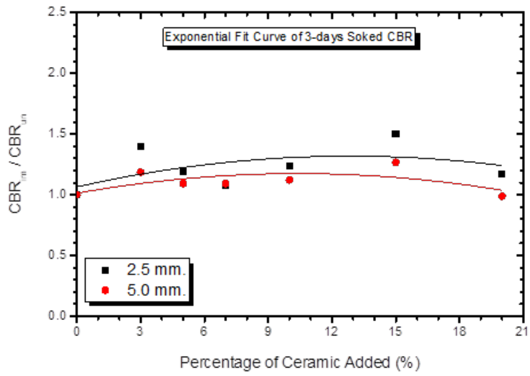

Fig.8 Relationship between normalized soaked CBR and CM replacement ratio.

3.6 Hydraulic Conductivity

The hydraulic conductivity of natural lateritic soil and natural soil blended with CM waste replacement was investigated. Specimens were prepared and tested for hydraulic conductivity in the laboratory under controlled conditions. The same procedure was used for each test to eliminate the ambiguity generated by testing variations. Increasing of CM waste content or the presence of more coarse aggregate generally means increasing of macropore size in the blended sample, which controls flow in compacted soil and higher hydraulic conductivity occurs as a consequence. The soil with low liquid limit and plasticity index generally contain a small number of clay minerals and/or lower clay content and usually exhibit higher hydraulic conductivity. Results of the hydraulic conductivity tests show that the hydraulic conductivity decrease as CM replacement ratio increase. The hydraulic conductivity of natural lateritic soil is 1.3×10^{-6} m/sec and gradually decreases as the CM replacement content increase in the range of 1.6×10^{-6} to 6.5×10^{-6} m/sec or 40 to 400%. However, the boundary of hydraulic conductivity for subbase material lied between 10^{-3} to 10^{-8} m/sec as shown in Fig.9.

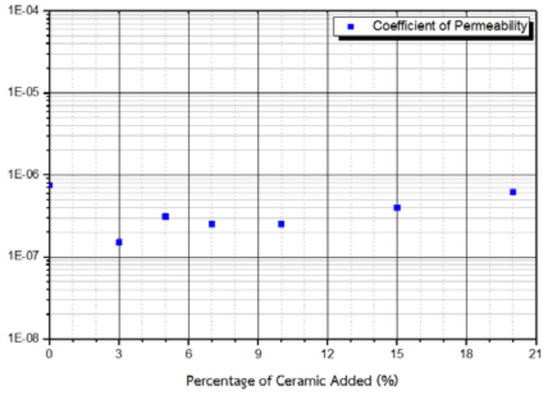

Fig.9 Relationship between hydraulic conductivity and CM replacement ratio

3.7 Los Angeles Abrasion Tests

Due to the movement of traffic, the aggregate used in the surface course of the highway pavements are subjected to wearing. As the vehicle moves along the road, particles of soil between the pneumatic tire and the road surface cause abrasion of road aggregates. The steel reamed wheels of animal-driven vehicles also cause a great deal of abrasion on the road surface. Therefore, the road aggregates should be hard enough to resist abrasion. Resistance to abrasion of aggregate is determined in the laboratory by Los Angeles test machine. The principle of Los Angeles abrasion test is to produce abrasive action by use of standard steel balls which when mixed with aggregates and rotated in a drum with a specific number of rotation cycles also causes an impact on aggregates. The gross percentage wear of the aggregates due to rubbing with steel balls is determined and is defined as Los Angeles Abrasion Value. In this study, the Los Angeles abrasion test of natural lateritic soil is 63% while the abrasion of natural soil with CM replacement is found to vary from 53% to 58%. The lowest abrasion is found for 5% of CM replacement. All the blended material exhibited Los Angeles Abrasion Value less than the type specified value as in [11] of 60% as shown in Fig.10.

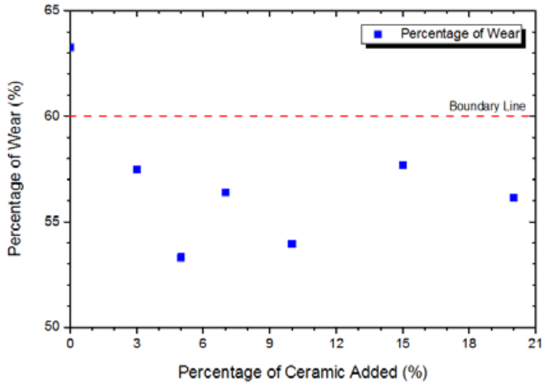

Fig.10 Relationship between Los Angeles Abrasion Value and CM replacement ratio

4. CONCLUSIONS

This research aims to improve the engineering properties of locally available lateritic with CM waste as subbase material. The soil samples were collected from a borrow pit in Chachoengsao province, Thailand. According to the unified soil classification system, the lateritic soil is classified as clayey sand (SC). The lateritic soil meets the requirement in term of grain size distribution but it does not meet the requirements of CBR [11] as defined by the Department of Rural Roads (DRR). Therefore, this lateritic soil needs to be blended with a higher quality material such as CM waste to meet the CBR requirement of subbase material.

The lateritic soil and CM was blended with lateritic soil: CM ratios of 97:3, 95:5, 93:7, 90:10, 85:15, 80;20. The replacement of CM waste led to a reduction of the liquid limit, plastic limit and plasticity index. This reduction is achieved by reducing the thickness of the double layer of soil particles present in the laterite soil, as a result of cation exchange reaction, which causes an increase in the attraction force leading to a flocculation of the particles. As the CM fraction increased, the PL does not change significantly. The average PI was 8%, less than 8% as in [11].

Based on the test results of modified compaction test of the blended lateritic soil:CM ratios of 97:3, 95:5, 93:7, 90:10, 85:15, 80:20; the moisture content of the blended lateritic soil and CM waste is likely to decrease as the amount of CM waste increased due to the CM waste used in this study was incinerated at 1200°C and does not absorb water [20,21]. The maximum dry density (Modified Proctor Density) and the optimum water content of the natural studied soil were 1.95 g/cm^3 and 10% respectively. The maximum MDD and OMC obtained from the specimen with lateritic soil: CM ratios of 90:10 are 2.23 kN/m^3 and 8%, respectively.

The unsoaked CBR was conducted immediately after compaction and the test results show that CBR values gradually increased as the amount of added ceramic waste increased. It was noted that the CBR values of the blended sample were higher than those of the plain soil due to the addition of CM waste aggregate. The minimum soaked CBR value of lateritic soil replaced by 7% of CM waste was found to be 33% and 45% at a penetration depth of 2.5 and 5.0 mm, respectively, which is higher than the subbase standard [11]. The swelling percent value of the natural studied soil used the CBR-instrument was 0.069%. The addition of CM waste led to a decrease in these values from 0.069 to 0.040% which much lower than the boundary line of 4% for subbase material [11].

The hydraulic conductivity test results show that the higher the CM replacement ratio, the lower the hydraulic conductivity. The hydraulic conductivity of natural lateritic soil is $1.3x10^{-6}$ m/sec and gradually decreases as the CM content increase in the range of $1.6x10^{-6}$ to $6.5x10^{-6}$ m/sec or 40 to 400%. The boundary of hydraulic conductivity for subbase material lied between 10^{-3} to 10-8 m/sec.

The Los Angeles abrasion test of natural lateritic soil is 63% while the abrasion of natural soil with CM replacement is found form 53% to 58%. The lowest abrasion is found for 7% of CM replacement. All the blended material exhibited Los Angeles Abrasion Value less than the type specified value as in [11] of 60%.

5. ACKNOWLEDGMENTS

This work was financially supported by the higher education research promotion and national research university project of Thailand, Office of Higher Education Commission Grant No. KMUTNB-NRU-58-23. The financial support and facilities that were provided by King Mongkut’s University of Technology North Bangkok are very much appreciated.

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