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ORIGNAL ARTICLE

Study of the dominant physic-chemical properties of different clay species

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Abstract

Clay is some sort of dominantly using raw material for the industrial usages because of the specific attitudes of clays for those applications. The analysis of the fundamental physic-chemical and mechanical properties of three selected clay varieties was the expectations of the current research. The selected clays were named as anthill clay, brick clay and roof tile clay based on their primary usages and mode of occurrence. The natural moisture contents, acidities and sizes of the particles of raw clays and the water absorptions, bulk densities, splitting tensile strengths and compressive strengths of prepared bricks were investigated by following standard test methodologies and instruments. In addition, the microstructures of raw clays and prepared bricks were analyzed using an optical microscope. There were discovered relatively higher acidity from anthill clay, higher natural moisture content from roof tile clay, well graded grain arrangement in roof tile clay, poorly graded grain pattern from brick clay, gap graded grain pattern from anthill clay, higher portion of finer particles from roof tile clay accordingly with the results of both microscopic analysis and wet sieve analysis of raw clays, relatively higher water absorption from anthill clay brick, higher splitting tensile strength and compressive strength from roof tile clay bricks as the upshots of the existing research.

1. Introduction

Clay is an abundant earth material based on several locations on the earth and it is a special variety of soil because of the specific features of such clay that able to be distinguished from other general soil species. Due to those specifications such clays are industrially valuable as raw materials for different productions and processes as given in the below [1-6].

- Building materials (bricks, roof tiles etc.)
- Pottery (water and food containers)

According to the classifications of particle sizes of different soils, clay is a species of soil which is having relatively tiny particles. In the standard soil size classifications, clays were categorized as follows [4, 6-11].

When considering the textures of clays, it is fine grained cohesive material and it is gradually softening when adding of water. Usually those clays are occurred as the result of the weathering of sedimentary rocks transportation of debris and the deposition of such debris and fragments in some particular location while exposing against some different weather conditions. In general, the chemical composition of such clay might be an integration of the silicates, quartz, elements and organic components [8, 10, 12-18].

Also the chemical compositions and physic-chemical properties of clays are not remained constant at all occasions. Those characteristics of clays are depending on following factors. However, the relatively high porosity and less permeability are exhumed characteristics when comparing of such properties of another soil species.

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Table 1. Standard soil classifications

Standard classification system	Sizes of clay particles/mm
American society for testing and material (ASTM)	<0.005
British Standard (BS)	<0.002
United States Department of Agriculture (USDA)	<0.002
Unified Soil Classification System (USCS)	<0.075 (clay + silt)

When considering the textures of clays, it is fine grained cohesive material and it is gradually softening when adding of water. Usually those clays are occurred as the result of the weathering of sedimentary rocks transportation of debris and the deposition of such debris and fragments in some particular location while exposing against some different weather conditions. In general, the chemical composition of such clay might be an integration of the silicates, quartz, elements and organic components [8, 10, 12-18].
Also the chemical compositions and physic-chemical properties of clays are not remained constant at all occasions. Those characteristics of clays are depending on following factors. However, the relatively high porosity and less permeability are exhumed characteristics when comparing of such properties of another soil species.

- Origin or formation process of clay deposit
- Weathering and climatic conditions of the relevant area or region

Based on those specific properties, different clay varieties that found from various locations in the world have been developed for different advanced technological uses such as water treatment applications, ceramic industry, refractory materials, adsorption material and more advanced usages [1, 9, 11, 15].
In the progresses of clays during such applications are highly depending on the characteristics of selected clay such as the chemical composition, mineralogy, specific functional groups, porosity, permeability and firing temperature of bricks [9,12,14-17]. Some sort of clays can be further developed as the composites for more advanced Material Engineering applications such as the ceramic and refractory materials apart from their primary usages [15, 21-27].
Therefore, the investigation of the characteristics of some newly found clay species or already discovered clay species is an essential desideratum prior of the applications. According to the scope and objectives of the existing research, there were expected to investigate the physical characteristics, chemical characteristics and particle sizes analysis of three different types of clays which are available in Sri Lanka and some of them are already being used in the industries such as the building material manufacturing for the further development and enhancements of advanced industrial applications.

2. Materials and Methodology

In the selection of the materials for current research, three different clay types were selected and the samples were collected from the available locations in Sri Lanka as shown in the Fig.1.

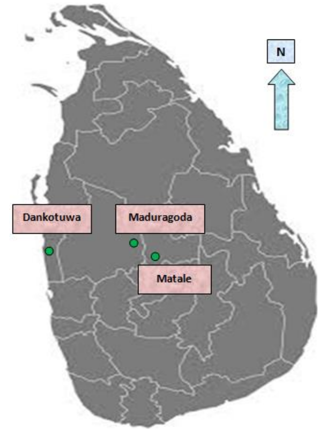

Figure 1. Sample collected areas (available locations of deposits)

In the collections of clay samples from the available locations, it was considered the complying with following precautions to maintain the accuracy of the experimental results.

- Avoiding of using corroded, contaminated or metallic tools in the collections of the samples
- Prevention of the exposing of such clay samples to the climatic variations
- Storage of the collected clay samples in polythene bags while protecting from direct sunlight

Based on the existing applications and mode of occurrences the clay types were known with some particular names as described in the below.

- Anthill clay- Building materials for anthills of termites
- Brick clay- Raw material for the manufacturing of bricks (construction material)
- Roof tile clay - Raw material for the manufacturing of roof tiles

Brick clay and roof tile clays are already being used in the industrial applications especially in the constructions of building materials and anthill clay is not much popular in the industrial usages since it is a fine grained clay which is usually being used in the building of anthills by termites. The investigation of the physico-chemical properties and the suitability in the advanced industrial applications are the temporal requirement for the scientific aspects. The representative samples of such clays are shown in the Fig.2.

2.1 Natural moisture content

The water or moisture content of a soil or clay is an important parameter regarding the most of Engineering Applications because it is a drainage property of such clay or soil. Also it would be a factor for the regulations of the density, strength and hardness of such soil or clay. The natural moisture contents of raw clays were determined using the following equation [2, 6, 7, 25].

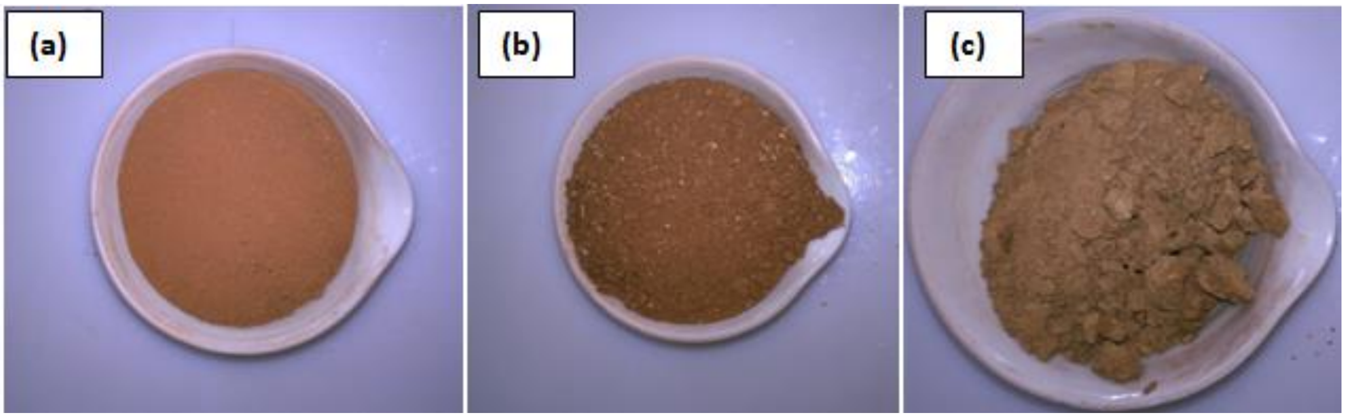

Figure 2. (a) Anthill clay, (b) brick clay and (c) roof tile clay samples

Natural moisture content = $\{(W_I - W_D)/ W_I\} *100\%$ (1)

W_I = Initial weight of raw clay sample
W_D = Dry weight of the same clay sample

2.2 Acidity

Acidity of a material is much considerable parameter especially in the selection of such material for some specific applications such as food industries, water treatment applications and some chemical processes [8, 16, 24, 28].
Under the requirements of the existing research, the acidities of three different clay types were tested. As the methodology, 5g of each clay sample was dissolved in 50ml of distilled water which is having a P^H of 7.00 (neutral conditions) under the temperature of 25.4^0C. The clay solutions were stirred well using a stirrer and the P^H values of each clay solution was measured using a digital P^H meter.

2.3 Dry sieve analysis

Dry sieve analysis is a methodology of analyzing the particle size distribution of some soil especially for coarse grain sizes. As the confirmation stage for the suitability of the dry sieve analysis method for the clayey soils, the existing experiment was performed.
According to the definitions of the standard methodology of ASTM D422 and some other references, the representative portions were selected from collected clay samples and those representative samples were oven dried under 110^0C until getting constant mass. After drying the dried clay bulks were crushed using a ceramic crucible until becoming free from colloids and clogs for 30 minutes [2,4-7,18,29-32].
The crushed clay samples were dropped on to a paper and the final representative samples were selected using the coning and quartering method as shown in the Fig.4.
According to the definitions and limitations of the coning and quartering method, the representative sample should be a combination of either quarter A and quarter C or quarter B and quarter D.
Approximately 50g clay samples were measured from each type of final representative samples of clays. The each selected clay sample was separately sieve analyzed for 10 minutes shaking time using a sieve shaker and set of sieve in the size range of 2mm- 0.037mm and pan (<0.037mm) as shown in the Fig.5.

Figure 3. Crushing of dried clay samples

The percentages of weight passed through each sieve were determined using following equations [7, 27, 30, 31 32].

Percentage of Weight Passed Through a Sieve (%) = $\{(100) - (W_R/W_T) *100\}$ % (2)

Where

W_R = Weight of the amount of clay that retaining in the relevant sieve (g)

W_T = Total weight of the clay sample (g)

After shaking period, the retaining mass of clays on each sieve was measured using an analytical balance and the particle size distribution curves were plotted for each clay type using the particle diameter (x-axis/independent parameter) and cumulative percentage of weight passed (y axis/ dependent parameter).
By observing the shape and order of the curves, following important readings were recorded from the particle size distribution curves that related with each type of clay.

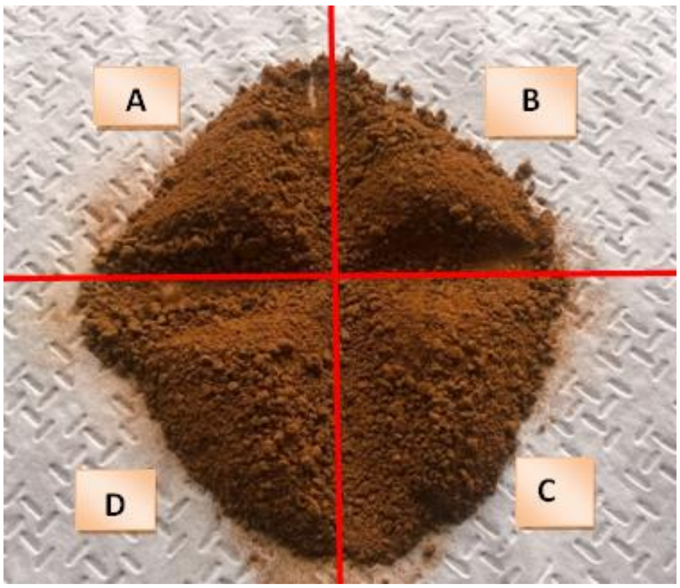

Figure 4. Coning and quartering method


Figure 5. Apparatus setup for sieve analysis

Table 2. Important readings from the particle size distributions curves and their definitions

Reading	Description
D_{10}	Diameter corresponding to 10% finer percent in the particle size distribution curve /mm
D_{25}	Diameter corresponding to 25% finer percent in the particle size distribution curve /mm
D_{30}	Diameter corresponding to 30% finer percent in the particle size distribution curve /mm
D_{50}	Diameter corresponding to 50% finer percent in the particle size distribution curve /mm
D_{60}	Diameter corresponding to 60% finer percent in the particle size distribution curve /mm
D_{75}	Diameter corresponding to 75% finer percent in the particle size distribution curve /mm

Based on the above important readings, the following important parameters for clays were determined using the following definitions and equations while observing the shape of the particle size distribution curves of each type of clay [6, 7, 27, 30, 31, 32].

$$\text{Effective size} = D_{10} \quad (3)$$

Where,

D_{10}= Diameter corresponding to 10% finer percent in the particle size distribution curve /mm

$$C_u = D_{60} / D_{10} \quad (4)$$

Where,

C_u = Uniformity coefficient
D_{60} = Diameter corresponding to 60% finer percent in the particle size distribution curve /mm
D_{10}= Diameter corresponding to 10% finer percent in the particle size distribution curve /mm

$$C_c = (D_{30})^2 / (D_{60} * D_{10}) \quad (5)$$

Where,

C_u = Coefficient of gradation
D_{60} = Diameter corresponding to 60% finer percent in the particle size distribution curve /mm
D_{30} = Diameter corresponding to 30% finer percent in the particle size distribution curve /mm
D_{10}= Diameter corresponding to 10% finer percent in the particle size distribution curve /mm

$$S_0 = (D_{75}/D_{25})^{1/2} \quad (6)$$

Where,

S_0 = Sorting coefficient

D_{25} = Diameter corresponding to 25% finer percent in the particle size distribution curve /mm
D_{75} = Diameter corresponding to 75% finer percent in the particle size distribution curve /mm

$$\text{Average grain size} = D_{50} \quad (7)$$

Where,

D_{50}= Diameter corresponding to 50% finer percent in the particle size distribution curve /mm

$$S_K = (D_{25} * D_{75}) / D_{50} \quad (8)$$

Where,

S_K = Skewness
D_{25} = Diameter corresponding to 25% finer percent in the particle size distribution curve /mm
D_{75} = Diameter corresponding to 75% finer percent in the particle size distribution curve /mm
D_{50} = Diameter corresponding to 50% finer percent in the particle size distribution curve /mm

2.4 Wet sieve analysis

Wet sieve analysis is a method of separating finer portion of particles (clay) and coarse portion of particles (sand, gravel etc.) in a mixture of soil with respect to some specific sieve size. In the current research the finer and coarse particles were separated with respect to the sieve size of 0.075mm.

Figure 6. Sieve of 0.075mm

As the methodology a representative clay sample was selected from each clay type and the selected clay samples were oven dried for 24 hours under the temperature of 110^0C. The weights of the dried clay samples were measured using an analytical balance. The dried clay samples were separately washed on a sieve of 0.075mm using a wash bottle which was filled with distilled water. The finer portion of particles (<0.075mm) was washed out through the mesh and the coarse portion of particles (>0.075mm) was retained on the mesh. The finer portion of particles (<0.075mm) was sent for the hydrometer analysis and the coarse portion of particles (>0.075mm) was collected and oven dried for 24 hours under the temperature of 110^0C. The final weight of the dried coarse particle portion was measured using an analytical balance and the finer percentages and coarse percentages of particles were determined using following definitions and equations [2, 3, 7, 30, 31, 32].

$$\text{Coarse percentage} = (W_C / W_I) * 100\% \quad (9)$$
$$\text{Finer percentage} = \{(W_I - W_C)/ W_I\} * 100\% \quad (10)$$

Where,

W_C = Dry weight coarse particles (>0.075mm)/ g
W_I = Initial weight of dried raw clay sample/ g

2.5 Manufacturing of bricks

Regarding the manufacturing of bricks from the clays, much simple and conventional method was used. A separated portion of raw from each clay type was taken and the selected portion was seasoned while gradually adding water. The seasoned clays were laid into molds which were made by woods in similar sizes of 10cm*6cm*1.5cm. The upper surfaces of the wetted clay blocks were flattened while compacting the block into the mould. The clay blocks were allowed to dry under normal conditions without exposing to the sunlight after removing moulds after a few hours ago. After one-week time period, the solidified clay blocks were oven dried for a few hours under the temperature of 110^0C. The dried clay blocks were fired in the muffle furnace at the temperature of 800^0C for approximately seven hours and allowed to gently cool and taken out as the bricks [18-20, 22-25]. The relevant photographs of such procedure have been shown in the following figures.

Figure 7. Drying oven

Figure 8. Firing of bricks using a muffle furnace

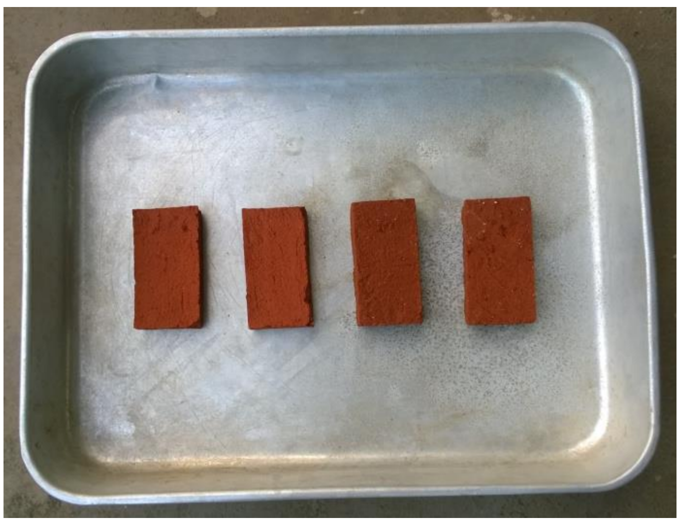

Figure 9. Manufactured bricks

2.6 Testing of compressive strengths and splitting tensile strengths of bricks

The manufactured bricks were sent for the testing of compressive load and splitting tensile load using universal tensile strength testing machine as shown in the following figures.

The compressive strengths and splitting tensile strengths of prepared bricks were determined using following obtained results from the universal strength testing machine, definitions and equations [19, 20, 22, 33].

$$\text{Compressive Strength} = P_C / A \quad (11)$$

Where,

P_C = Applied compressive load in the failure of the structure

A= Surface area of the bed surface of the brick (m^2)

$$\text{Splitting Tensile Strength} = 2P / (\pi * H * L) \quad (12)$$

Where,

P = Maximum applied load at the failure of the structure (N)
H = Distance between two edges (bridges) (m)
π = Constant (3.142)
L = Splitting length (m)

Figure 10. Universal tensile strength testing machine

Figure 11. Measuring of compressive load of bricks

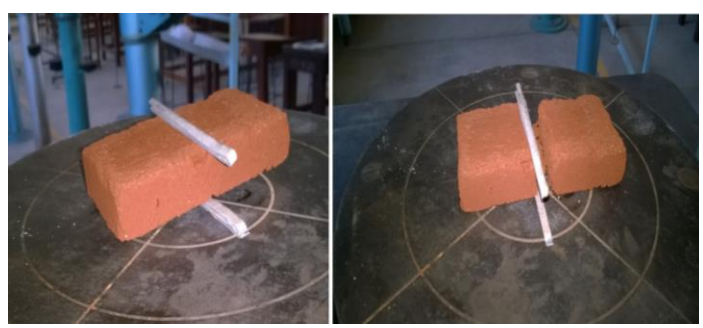

Figure 12. Measuring of splitting tensile load of bricks

2.7 Water absorptions of bricks

The water absorption is a useful parameter regarding the porosity and permeability of much material. However, the measurements of the water absorption of the raw clays were unsuccessful because of the inability of the remaining of the particular shape of the raw clay mass during the immersion in water. Therefore, the measurements of the water absorptions of the prepared bricks were used as the methodology of the testing of the water absorptions of clays. The prepared bricks were oven dried for 24 hours under the temperature of 110^0C until removing of the moisture and the dry weight of each brick was measured using an analytical balance. The moisture free bricks were entirely immersed in water for 24 hours under the normal atmospheric conditions and the wetted weight of each brick was measured using the same analytical balance after 24 hours' immersion period [19, 20, 22, 33].

Figure 13. Immersion of bricks in water

The water absorption of each brick was determined using the following equation [19, 20, 22, 33].

$$\text{Water absorption} = \{(W_W - W_D)/W_D\} * 100\% \qquad (13)$$

Where,

W_W = Wetted weigh of the brick
W_D = Dry weigh of the brick

2.8 Bulk Densities of bricks

Bulk densities of prepared bricks were determined using the weights of dried bricks and the dimensions of each brick which were measured using in order of an analytical balance and Vernier caliper. In the computation of the bulk densities of bricks following equation was used [17, 18, 25, 27].

$$\text{Bulk Density} = W_D / V \qquad (14)$$

Where,
W_D = Dried weight of the brick /g
V = Volume of the brick / cm^3

2.9 Microstructure Analysis of bricks

As the microstructure investigation stages of the bricks and raw clay samples, the powdered samples of prepared bricks and the dry powders of raw clay samples were observed using an optical microscope as shown in the Fig. 14 [17].

Figure 14. Optical microscope

3. Results and Discussion

Based on the performed experiments and the order of the obtaining of the results, the interpretations and discussions have been sub categorized as follows.

3.1 Acidity

The experimental results for the acidities of clays are given in the Table 3.

Table 3. Acidities of clays

Clay Type	P^H
Anthill Clay	5.56
Brick Clay	6.57
Roof Tile Clay	5.68

When considering the obtained results for the acidities of clays, the lowest value was observed from anthill clay and the highest value was observed from brick clay. In the considerations of the critical values of the acid-base limitations all of obtained values were appeared less than 7 which is known as the critical point for the acids and bases [8, 16, 24, 28, 34]. However, those clays should be considered as weak acidic compounds because the all of P^H values were found in the range of 5.5-7.0. Therefore, those clays are not much harmful in the food science applications and water treatment applications. Apart from that the acidity of a particular type of clay deposit may not be remained in a constant value and those conditions are possible to be varied based upon following external cases [24, 34].

- Acid rain
- Vegetation and cultivation
- Chemical composition such as the composing of alkaline metals
- Decomposition of rocks and minerals

3.2 Moisture Content

The natural moisture contents of three different clays have been given in the Table 4.

Table 4. Natural moisture contents of clays

Clay Type	Moisture Content (%)
Anthill Clay	15.49
Brick Clay	21.45
Roof Tile Clay	25.97

According to the moisture content results of the raw clay samples, the optimal natural moisture content was found from roof tile clay while the minimum value was observing from anthill clay. The natural moisture content of a clay/soil is a primary indicator even though it is depending on several environmental factors as well. The following environmental factors play a dominant role in the regulations of the natural moisture content apart from the qualities and properties of the relevant material [2, 6, 7, 25].

- Climatic conditions of the area/ region
- Flora disseminations
- Geological features

When comparing those criteria, the water absorption of the dried raw clays or clay bricks under similar conditions is possible to be emphasized as an even handed indicator regarding the other physical properties of clays such as the porosity and bulk density.

3.3 Water Absorption

The obtained results for the analysis of water absorption of bricks were given in the Table 5 based on the important assumption that the all bricks were saturated with the water content within 24 hours.
According to those results the maximum water absorption was discovered from roof tile clay bricks while the maximum water absorption was recording from anthill clay bricks. The water absorption of brick or some other material is depending on following factors [19, 22, 23, 33].

- Grain/ particle sizes of the clay/material
- Shapes of the grains/ particles
- Number of pores/ voids existing in the body
- Chemical compositions of the clay/ material such as the mineralogy of clay

Table 5. Water absorption of bricks

Clay Type of the Brick	Anthill Clay	Brick Clay	Roof Tile Clay
Water Absorption (%)	24.93	19.88	17.30

The absorption of water is really important in the describing of the strengths of the structure of the brick because the bondages between particles are the preliminary concepts regarding the explanations of both water absorption and strengths of the structure [30].
Therefore, the water absorption is a primary indicator for the most of advanced mechanical properties of those clays/ materials such as the strength and hardness. The correlations between the water absorption of the bricks and the important mechanical properties of those bricks were deliberated in the following sub sections [4, 30].

3.4 Bulk Density

According to the determinations of the bulk densities of bricks, the results were interpreted in the Table 6.

Table 6. Bulk densities of bricks

Clay Type of the Brick	Anthill Clay	Brick Clay	Roof Tile Clay
Bulk Density (g/cm^3)	2.62	3.15	2.00

As the reconciliation of the obtained results for the bulk densities of bricks, the maximum bulk density was observed from brick clay and the minimum bulk density was observed from roof tile clay. According to the theoretical explanation of the density difference, the brick samples were composed with higher amount of coarse particles/heavy particles such as sand and gravels which are having higher specific gravities. In the consideration of the particle sizes of roof tile clay, the majority of roof tile clay sample was composed with lighter particles such as clay, silt and finer clay with lower specific gravities. Also the densities of natural/ raw clay would be slightly varied because of the variations in the porosity [17, 18, 25, 27].

3.5 Compressive Strength

The determined values of compressive strengths of the bricks were listed in the Table 7.

Table 7. Compressive strengths of bricks

Clay of the Brick	Initial Cracking Load (lb)	Maximum Load (lb)	Compressive Strength (MPa)
Anthill Clay	17500	19250	20.88
Brick Clay	15400	15900	17.25
Roof Tile Clay	-	29200	>31.68

When considering those results, there were mainly observed the relatively lower compressive strength from the bricks which were manufactured using brick clays and the huge compressive strength from roof tile clay brick because the roof tile clay brick was not cracked even though the maximum applied compressive load was 29200lb. Then the compressive strength of the roof tile clay brick must be greater than 31.68MPa.

In the comparison of both water absorption capacities and compressive strengths of bricks of three clay bricks, the greatest compressive strength was observed from roof tile clay brick even though having least water absorption. Apart from such observations, in the considerations of those two properties in both bricks which were prepared using brick clay and anthill clay, the above relationship was inversely shifted because the greatest water absorption was observed from anthill clay brick and also some intermediate compressive strength was observed from such anthill clay brick even though some lower compressive strength and lower water absorption were observing from bricks which are prepared using brick clay [19,20,22,33]. The suggestions and conclusions will be discussed in following sub sections forever.

3.6 Splitting Tensile Strength

The determined values for the splitting tensile strengths of bricks were given in the Table 8.

Table 8. Splitting tensile strengths of bricks

Clay of the Brick	Splitting Load (lb)	Splitting Tensile Strength (MPa)
Anthill Clay	155	0.44
Brick Clay	110	0.31
Roof Tile Clay	460	1.30

The results of the splitting tensile strengths of the bricks were similarly varied with the variations of the compressive strengths of bricks according to the clay type. The maximum splitting strength was found from roof tile clay brick while observing the minimum splitting tensile strength from brick which is prepared using brick clay as usual. The discussion would be same as the discussion of the compressive strength of same bricks in the previous sub section [33]. But in gap graded soil/ clay such as anthill clay, the linkage between the porosity and water absorption could not be seen as defined. Therefore, it can be further concluded some suggestions of affecting factors on the mechanical strengths of bricks apart from the porosity and permeability as given in the below [7,33].

- Chemical compositions, functional groups (electrostatic forces)
- Shapes of particles
- Firing temperature of bricks

3.7 Microstructures of Bricks

According to the microscopic analysis of the dry powdered raw clay samples and the powdered brick samples, the observed microstructures of those materials were shown in the following figures.

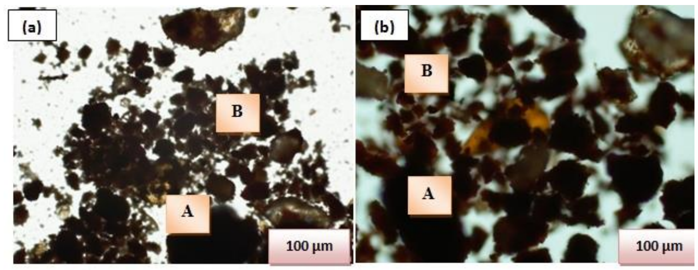

Figure 15. Microstructures of (a) raw anthill clay and (b) powdered bricks of anthill clay

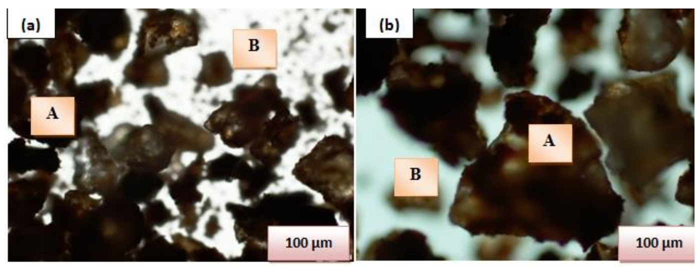

Figure 16. Microstructures of (a) raw brick clay and (b) powdered bricks of brick clay

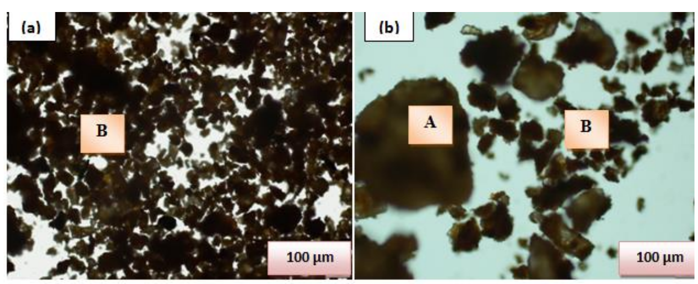

Figure 17. Microstructures of (a) raw roof tile clay and (b) powdered bricks of roof tile clay

- A- Coarse particles
- B- Finer particles

The microstructures of bricks showed the large amount of relatively finer particles in roof tile clay, large amount of coarse particles in brick clay as the observations. When comparing of the microstructures of raw clays with the microstructures of their bricks, the reddish color was formed in brick particles and clusters of particles/ banded particles (clogs) were observed in brick particles. The shapes of particles will be considered in the sorting type, grain size distribution of a clay and characterization of the mechanical properties such as porosity, permeability and mechanical strengths [14, 17].

3.8 Particle/ Grain Size Distribution

Particle size distributions of clays according to sieve sizes have been interpreted in following tables 9-11.

Table 9. Particle size distribution of anthill clay

Sieve Size (mm)	Weight retained on each sieve (g)	Percentage of weight retained (%)	Cumulative percentage of weight retained (%)	Cumulative percentage of weight passed (%)
2	0.02	0.04	0.04	99.96
0.5	10.34	20.32	20.36	79.64
0.25	15.61	30.68	51.04	48.96
0.149	12.39	24.35	75.39	24.61
0.074	3.91	7.68	83.08	16.92
0.037	7.86	15.45	98.53	1.47
<0.037 (pan)	0.75	1.47	100	0.00

Table 10. Particle size distribution of brick clay

Sieve Size (mm)	Weight retained on each sieve (g)	Percentage of weight retained (%)	Cumulative percentage of weight retained (%)	Cumulative percentage of weight passed (%)
2	0.01	0.02	0.02	99.98
0.5	10.41	20.30	20.32	79.68
0.25	17.13	33.41	53.74	46.26
0.149	13.43	26.19	79.93	20.07
0.074	7.09	13.83	93.76	6.24
0.037	2.47	4.82	98.58	1.42
<0.037 (pan)	0.73	1.42	100	0.00

Table 11. Particle size distribution of roof tile clay

Sieve Size (mm)	Weight retained on each sieve (g)	Percentage of weight retained (%)	Cumulative percentage of weight retained (%)	Cumulative percentage of weight passed (%)
2	0.16	0.31	0.31	99.69
0.5	11.8	23.17	23.48	76.52
0.25	7.97	15.65	39.13	60.87
0.149	11.71	22.99	62.12	37.88
0.074	11.12	21.83	83.96	16.04
0.037	7.05	13.84	97.80	2.20
<0.037 (pan)	1.12	2.20	100	0.00

As the graphical representation of the particle size distributions in such clays, the particle size distribution curves of three different types of clays are shown in the Figure 18.

In the consideration of the particle size distribution curves of three clays while comparing the standard curve shapes, there were observed the well graded grain arrangement from roof tile clay since anthill clay was showing gap graded grain arrangement and brick clay was showing uniformly graded grain arrangement. According to the further explanation of such patterns, well grading of grain the presence of particles symmetrically in the bulk accordingly with an order such as a sequence in sizes, uniformly grading is asymmetrically presence of particle in various sizes although disordered in sizes and the gap grading is a presence of particles since creating a gap in the range of particle sizes [7, 27, 30, 31, 32].

By referring the patterns and shapes of the particle size distribution curves the following important readings were recorded with respect to each clay type as shortlisted in the Table 12. Consequently, with above readings and the definitions of some important parameters regarding the grain/ particles distributions of clays were determined and interpreted in the Table 13.

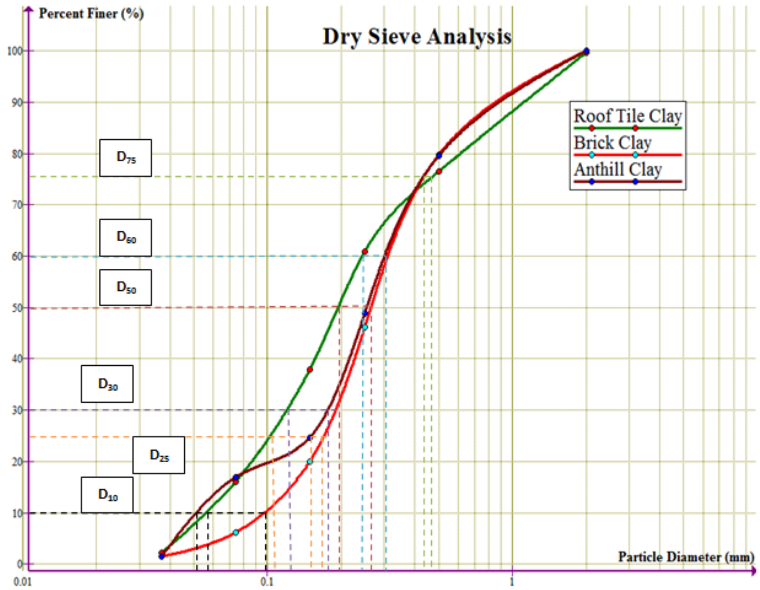

Figure 18. Particle size distribution curves of clays

Table 12. Important readings from the graphs

Type of Clay	D_{10}(mm)	D_{25} (mm)	D_{30} (mm)	D_{50} (mm)	D_{60}(mm)	D_{75} (mm)
Anthill Clay	0.051	0.146	0.175	0.25	0.295	0.425
Brick Clay	0.096	0.170	0.192	0.27	0.310	0.433
Roof Tile Clay	0.055	0.103	0.119	0.19	0.245	0.470

Table 13. Important parameters of particle sizes of clays

Type of Clay	Effective Size/ D_{10} (mm)	Uniformity Coefficient /C_u	Coefficient of Gradation/C_c	Sorting Coefficient/ S_0	Average Grain Size/ D_{50} (mm)	Skewness/ S_K (mm)
Anthill Clay	0.051	5.78	2.04	1.71	0.25	0.248
Brick Clay	0.096	3.23	1.24	1.60	0.27	0.273
Roof Tile Clay	0.055	4.45	1.05	2.12	0.19	0.255

According to the measurements of effective size (D_{10}) such clays, the lowest value was obtained from anthill clay and the highest value was obtained from brick clay. The Effective Size (D_{10}) is a critical parameter in the consideration of the permeability/ hydraulic conductivity of such clay/soil and the permeability is directly correlated with the effective size (D_{10}). Therefore, the permeability/ hydraulic conductivity of anthill clay would be relatively less than the permeability/ hydraulic conductivity of other clays [7, 27].

Regarding the uniformity coefficients of three clay types, it was found poorly grading of brick clay because the uniformity coefficient is less than 4 (C_u<4) when comparing with the C_u values of other clays. If some clay/ soil is having a C_u value of large minor deviation from 4, such soil/ clay would be more poorly graded [7, 27].

When comparing the coefficient of gradation (C_c), the well grading of roof tile clay was observed because the coefficient of grading is more approximated to 1 (C_c ~1). The value of coefficient of gradation (C_c) of anthill clay is unexpectedly deviated from 1 since the coefficient of gradation (C_c) of poorly graded brick clay was appearing moderately proximate to 1 [6].

There were observed some higher sorting coefficient (S_0) from roof tile clay while observing a lower sorting coefficient (S_0) from brick clay. The observations confirm that the well grading of roof tile clay and poorly grading/ uniformly grading of brick clay forever. This is highly considerable measurement regarding the sorting and grading of soils in geological and engineering purposes [6, 7, 27].

Average grain size is an optional measurement with respect to the particle size distribution of some soil/ clay even through it can be used as a representative value when comparing the particle size distribution of a series of clays/ soils with each other because it is similar to the mean value of the sizes of different particles of some particulate clay/soil. According to the existing analysis, the brick clay particles are relatively larger than the particles of other clay types [6, 7, 27, 31, 32].

According to the skewness values of three different clay types, all of such clay types are categorized as the fine skewed clays/soils because those values are appearing in the range of 0.30-0.10 with the (+) sign. In the comparison of the deviation of skewness values from 0.00, some more symmetrical particle size distribution was found from anthill clay.

As the overall prognosis of three different types of clays, it can be concluded the well grading and sorting of grains from roof tile clays, poorly grading of particles from brick clays and unusual variations of the important parameters of anthill clay. According to the grain sizes and sorting of clays, brick clay would be more applicable in water treatment applications because of the lower permeability/ hydraulic conductivity.

According to the wet sieve analysis of three clay species, the obtained results for the coarse and finer particle percentages of clays with respect to their weights were graphically represented in the Figure 19.

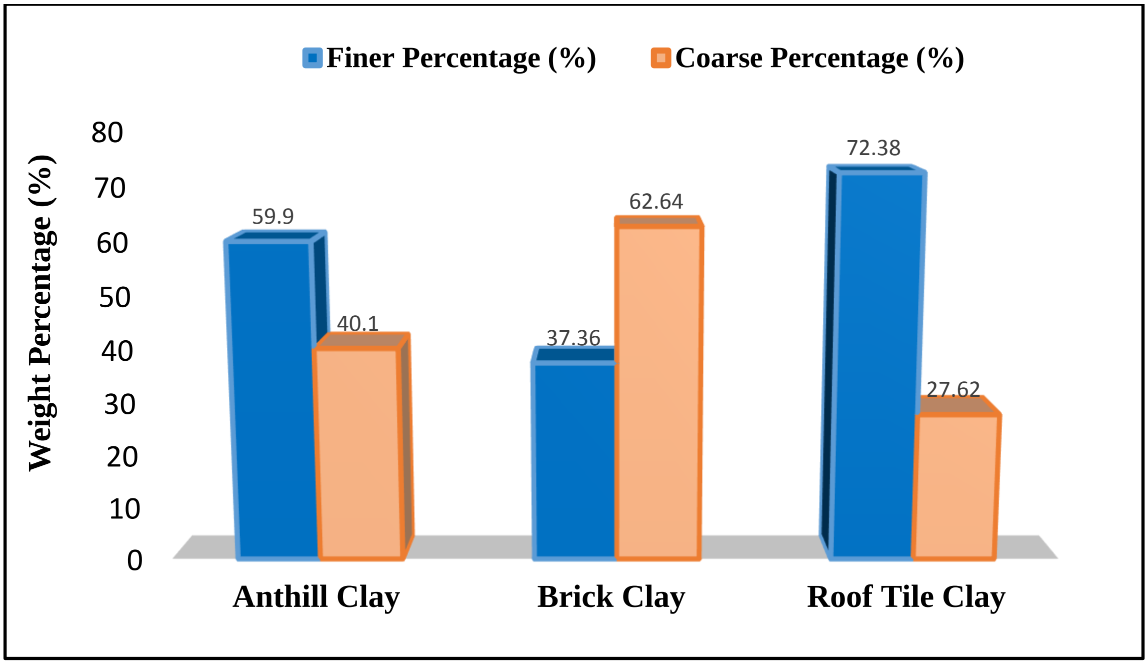

Figure 19. Coarse and finer particles percentages of clays with respect to the weight

The above results showed a relatively higher finer particle (<0.075mm) percentage in roof tile clay while some higher coarse particle (>0.075mm) percentage was observing from brick clay according to the weight. When considering the types of particles, roof clay was composed with tiny particles while slightly including coarse particles such as the sand particles and the brick clay was composed with coarse particles which are relatively large in size and also with less cohesiveness [15]. As the overall comparison of the particles sizes and some mechanical properties of clays and their bricks, the clays/soils with larger finer portions may have some massive strengths.

4. Conclusions

The roof tile clay is fine grained clay with well graded grain size distribution including less bulk density and water absorption of bricks although having more strengthen structure against both splitting tensile and compressive loads. The brick clay is uniformly graded clay while having higher permeability (effective size), intermediate water absorption and relatively weaker both compressive and splitting tensile strengths. According to those behaviors, the roof tile clay would be much applicable in hard materials such as the ceramic and composites, brick clay is suitable for water treatment applications because of higher permeability and the anthill clay could be further developed in a series of various advanced applications because of the unusual characterizations of such clay.

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