Fundamental physico-chemical and mechanical analysis of different clay types

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Abstract. Clay plays an important role in the most of industries that related with water treatment and food stowage industries. The adequate physic-chemical properties are the most recognized factor for the wide range of applications. The investigation of the fundamental physico-chemical and some mechanical properties of such clay is an insistent task before the selection of some material for some specific role. The analysis of the fundamental physico-chemical and grain size analysis of grain sizes of three different types of selected clays were the aims and objectives of the existing research. Clay samples were collected from three different locations in Sri Lanka and they were stored well. The clay samples were named as anthill clay, brick clay and roof tile clay. Some potion from each clay sample was separated and such separated clay samples were oven dried for 24 hours under the temperature 110°C. Each of dried clay sample was separated again and the separated portions were prepared for the test of moisture content, dry sieve analysis and wet sieve analysis. As the major results of the experiment, especially there were obtained 14.49%, 21.45% and 25.97% moisture contents with respect to anthill, brick and roof tile clays, well-graded particle arrangement in roof tile clay, gap graded particle arrangement in anthill clay and uniformly graded particle arrangement in brick clays. In addition, according to the obtained results there were seen the finer particle weight percentages as 59.90%, 37.36% and 72.38% with respect to anthill clay, brick clay and roof tile clay.

1. Introduction
Clay is a specific earth resource among other natural resources because of the specific characteristics of clays when comparing with the usual characteristics of some other earth resources and synthetic materials. According to the most of standard soil classifications, clays are defined as the soil particles in the sizes of <0.002mm [1-7]. Therefore, the clay has gained the cohesiveness and it is a deformable material. As the chemical compositions of clay soils, usually there were found a series of clay minerals such as silicates. Based upon some specific characteristics of clays, they may have some advanced uses beyond the uses of typical clays. Some of the common uses of clays are given in the below [1-10].

- Pottery industry
- Building material (bricks and roof tiles)
- Raw material for ceramic industry
- Raw material for porcelain industry
The characteristics of clays would be varied from one clay deposit to another clay deposit because some of regional conditions and conditions of the available rock types play some important role in the variations of the characteristics of clays as mentioned in the below [5-12]:

- Climatic and weathering conditions (rainfall, wind, temperature etc.)
- Flora and fauna of the region
- Physic-chemical characterizes of mother rocks (chemical composition)
- Geomorphology of the region (slopes, hills etc.)

Therefore, it is possible to expect a series of different characteristics from different clay types that found in different regions including well-known characteristics and some unknown specific characteristics. Usually the clays are distinguished from other soils based upon following primary characteristics [2-13]:

- Consistence of finer particles
- Cohesive materials
- High water absorption
- Low percolation of water
- Ability of deformation and non-elasticity
- Smooth material

Based upon such characteristics, clays are selected for most of industrial applications and in the current modern world the clay has been become a widely using raw material since it is being investigated for innovations. According to the most of scientific investigations, there were observed the advanced applications of china clay, ball clay, red clay, lacustrine clay and fluvial clay, which are well-known clay species in the world. Among the modern developments and applications, the following points will be highlighted [1-13]:

- Water filters
- Manufacturing of composite materials
- Heat resistant materials (refractory)

Sri Lanka is a country that rich in different clay types including some large clay deposits. The physic-chemical analysis of some uncommon clay species and disclosing of their important characteristics are the expectations of the existing research.

2. Materials and methodology

According to the aims and objectives of the existing research, three different clay types were selected as the materials. Those clays were located in different places in Sri Lanka and a description regarding those clays has been given in the below.

- Anthill clay- clay which is using in the building of anthills by termites
- Brick clay- clay which is using in the manufacturing of bricks
- Roof tile clay- clay which is using in the manufacturing of roof tiles

When considering of the industrial applications of roof tile clay and brick clay, anthill clay is not much utilized for the remunerative applications because of the limited quantity at one location and the dissimilarities of the properties based upon the location.

The raw samples of such clay species are shown in Figure 1.
Some sort of sufficient quantities of clays were separated from each raw clay massive body. The separated clay samples were oven dried for 24 hours under the temperature of 110$^\circ$C using an oven. The dried clay samples were weighed for several times to confirm the removal of moisture from the bulk. The dried clay samples were crushed using a ceramic crucible until getting free from clogs.

The representative clay samples from each clay type were selected using an equitable sample selection method for solid samples, which is called as coning and quartering method that explained in Figure 3.

Figure 1. (a) Roof tile clay (b) brick clay and (c) ant hill clay

Figure 2. Drying oven
According to the definitions of the coning and quartering method, the representative samples should be a combination of either quarter A and quarter C or quarter B and quarter D.

Three representative dry clay samples were selected from those clay types using the coning and quartering method and the dry weights of each clay sample was measured using an analytical balance. Each clay sample was separately washed (finer portion) on the sieve of 0.075mm using distilled water and the remained portion (coarse portion) on the mesh was collected and oven dried for 24 hours under the temperature of 110°C and also the dry weight of that coarse portion was measured using an analytical balance.

The finer portion and coarse portion of each clay type were determined using the obtained data and following equations [1-5], [9].
Coarse portion = \((W_C/W_D) \times 100\%\) \hspace{1cm} (1)

Finer portion = \(\{(W_D - W_C)/W_D\} \times 100\%\) \hspace{1cm} (2)

where,

\(W_C\) = Dry weight of the coarse portion/g
\(W_D\) = Weight of dried initial clay sample/g

Using the same sample selection methodology three representative clay samples were selected from dried raw clay samples for the dry sieve analysis.

The initial weight of each dried clay sample was measured using an analytical balance. Each representative clay sample was dry sieve analyzed using a sieve set of 2mm, 0.5mm, 0.25mm, 0.149mm, 0.074mm, 0.037mm, pan (<0.037mm) and a sieve shaker for 10 minutes shaking period for each clay sample.

![Figure 5. Sieve set and sieve shaker](image)

The remaining clay weights of each sieve were measured using an analytical balance by considering the weight differences of both empty weight of each sieve and weight of sieve including clay. By considering the remaining weights of clays under different particle sizes, the particle size distribution curves were plotted in semi-logarithm sheet using particle diameter as the X-axis in logarithm scale and percent of weight pass through each sieve as the Y-axis in normal scale. After observing the shape of the particle size distribution curves, there important readings were recorded from particle size distribution curves as described in the below [1-9].

- \(D_{10}\) = 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

The following important parameters regarding the grain sizes and arrangement of clays/soils were determined using following definitions and equations:

\[
\text{Effective size} = D_{10}
\]
where

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

\[ C_u = \frac{D_{60}}{D_{10}} \]  \hspace{1cm} (4)

where

\[ C_u = \text{Uniformity coefficient} \]

\[ D_{60} = \text{Diameter corresponding to 60% finer percent in the particle size distribution curve} / \text{mm} \]

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

where

\[ C_c = \frac{(D_{30})^2}{D_{60} \times D_{10}} \]  \hspace{1cm} (5)

where

\[ C_c = \text{Coefficient of gradation} \]

\[ D_{60} = \text{Diameter corresponding to 60% finer percent in the particle size distribution curve} / \text{mm} \]

\[ D_{30} = \text{Diameter corresponding to 30% finer percent in the particle size distribution curve} / \text{mm} \]

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

where

\[ S_0 = \frac{D_{75}}{D_{25}}^{1/2} \]  \hspace{1cm} (6)

where

\[ S_0 = \text{Sorting coefficient} \]

\[ D_{75} = \text{Diameter corresponding to 75% finer percent in the particle size distribution curve} / \text{mm} \]

\[ D_{25} = \text{Diameter corresponding to 25% finer percent in the particle size distribution curve} / \text{mm} \]

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

where

\[ S_K = \frac{D_{25} \times D_{75}}{D_{50}} \]  \hspace{1cm} (8)

where

\[ S_K = \text{Skewness} \]

\[ D_{25} = \text{Diameter corresponding to 25% finer percent in the particle size distribution curve} / \text{mm} \]

\[ D_{75} = \text{Diameter corresponding to 75% finer percent in the particle size distribution curve} / \text{mm} \]

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

Apart from the mechanical particle size analysis of clays, the powdered clays were microscopically analyzed using an optical microscope.

**Figure 6.** Optical microscope
3. Results and discussion
The obtained results for the dry sieve analysis of three different clay types are shown in following tables.

| Table 1. Particle size distribution of anthill clay |
|-----------------------------------------------|
| **Sieve Size (mm)** | **Weight retained on each sieve (g)** | **Percentage of weight retained (%)** | **Cumulative percentage of weight retained (%)** | **Percent Finer (%)** |
|---------------------|--------------------------------------|----------------------------------------|-----------------------------------------------|----------------------|
| 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                 |
| Pan                 | 0.75                                 | 1.47                                   | 100                                           | 0.00                 |
| **Total**           | **50.88**                            | **100**                                |                                               |                      |

| Table 2. Particle size distribution of brick clay |
|-----------------------------------------------|
| **Sieve Size (mm)** | **Weight retained on each sieve (g)** | **Percentage of weight retained (%)** | **Cumulative percentage of weight retained (%)** | **Percent Finer (%)** |
|---------------------|--------------------------------------|----------------------------------------|-----------------------------------------------|----------------------|
| 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                 |
| Pan                 | 0.73                                 | 1.42                                   | 100                                           | 0.00                 |
| **Total**           | **51.27**                            | **100**                                |                                               |                      |
Table 3. 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 (%) | Percent Finer (%) |
|----------------|---------------------------------|-----------------------------------|---------------------------------------------|-------------------|
| 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              |
| Pan            | 1.12                            | 2.20                              | 100                                         | 0.00              |
| Total          | 50.93                           | 100                               | 100                                         | 0.00              |

The particle size distribution curves of three different clay types are shown in Figure 7.

Figure 7. Particle size distribution curves for three different clays

When comparing the general shapes of the particle size distribution curves of three different clays, it can be seen the well graded arrangement of particles in roof tile clay, poorly graded (uniformly graded) arrangement of particles and gap graded arrangement of particles in anthill clay. The shape of the particle size distribution curve is an important indicator based on followings [1-5], [9].
• Detection of the grain size distribution of the curve
• Indicator for some physical characteristics of clays foremost of the porosity and permeability
• Indicator for the mechanical strengths of the clay structure or some alternative structure of that clay such as the mechanical strengths of bricks

Usually in well-graded soils/clays, it is found the presence of particle as a sequence according to the size and a symmetrically balanced distribution of particles. In poorly graded soils/clays, it is found some as a sequence of particles in size although asymmetrically balanced distribution of particles. In the case of gap-graded soils/clays, it is unable to observe any sequence of the particles sizes and the particles size distribution would be either symmetrical or asymmetrical [2-9].

Apart from the particle sizes, the particle shapes play an important role on the causing of physical characteristics such as the strengths, porosity and permeability. The important readings were recorded from the particle size distribution curves as shown in Table 4.

**Table 4. Important observations from particle size distribution curves regarding the particle sizes of clays**

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

According to the above data, the important characteristics of such soils were determined and interpreted in following graphs.

![Effective Size/ D10 (mm)](image-url)

**Figure 8.** Effective sizes (D10) of clay particles
The maximum effective sizes ($D_{10}$) value was observed from brick clay since the lowest effective sizes ($D_{10}$) was observing from anthill clay. The effective size ($D_{10}$) of a clay/soil is considered as a critical parameter to indicate the permeability of such soil/clay. The lower values for effective sizes ($D_{10}$) indicate lower permeability. Therefore, the anthill clay may have the lowest permeability among these clay types [1-5], [7], [9].

![Figure 9. Uniformity coefficients (Cu) of clays](image1)

The uniformity coefficient ($C_u$) of clays/soils is an important descriptive parameter regarding the grading of such clay/soil as much as the observations of particle size distribution curve. Usually for well grading soils/clays the uniformity coefficient ($C_u$) is appeared as $4 < C_u < 6$. According to the current results, the poorly graded characteristics were observed from brick clay same as the graph because $C_u < 4$ and well graded properties were observed from anthill clay and roof tile clay because $C_u \approx 6$ and $C_u \approx 4.5$ [1], [2], [4], [5], [9].

![Figure 10. Coefficients of gradations (Cc) of clays](image2)
The coefficient of gradation (Cc) of clays/soils indicates the arrangement of grains in the bulk of clay/soil. Usually for well grading soils/clays, the coefficient of gradation (Cc) is approaches to 1. The obtained results showed the well arrangement of grains in roof tile clay and poor arrangement of anthill clay [2-6], [9].

![Figure 1: Sorting coefficients (S0) of clays](image1)

Figure 11. Sorting coefficients (S0) of clays

The sorting coefficient (S0) of clays/soils is an indicator regarding the sorting of particles and the highest values indicate the more sorted clays/soils. When comparing of the above results, it is possible to identify some well sorting from roof tile clay while observing some poor sorting in brick clay [2], [4], [5], [7], [9], [10].

![Figure 2: Average grain sizes (D50) of clays](image2)

Figure 12. Average grain sizes (D50) of clays
Average grain size ($D_{50}$) of a soil/clay is a statistical parameter regarding the grain sizes of clays/soils. Furthermore, it can be used to categorize the soil whether it is clay or some other type of soil. In addition, the average grain size ($D_{50}$) would be a representative value regarding the sizes of particles. In the categorization, the average grain size ($D_{50}$) could be compared with the well-defined standards [1-6].

Skewness (Sk) of the particle size distributions of clays is a statistical parameter regarding the distribution of particle sizes in the bulk. According to above results, it is possible to find a symmetrical distribution of particles/grains because those obtained values were appeared in the domain of 0.10-0.30 also with the positive sign [1-7]. The wet sieve analysis results are shown in Figure 14.

![Figure 13. Skewness (Sk) of the particle size distributions of clays](image1.png)

![Figure 14. Finer and coarse particle percentages of clays (according to the weight)](image2.png)
According to those results, the maximum finer portion was found from roof tile clay while observing maximum coarse portion from brick clays according to the weight. When comparing of the clay portion and grading of clay materials, it is possible to find some well grading arrangement of grains in clay types which are having large portion of finer particles such as clay, silt and ultra finer clay [1-10].

The following images show the microstructures of three different clay types.

![Figure 15. Microstructure of anthill clay](image1)

![Figure 16. Microstructure of brick clay](image2)
Figure 17. Microstructure of roof tile clay

The important observations if the microstructures of clays are mentioned in the below:

- A- Coarse particles
- B- Finer particles
- C- Angular and sub angular particles
- D- Rounded and sub rounded particles
- E- Irregular shaped particles

When observing the microstructures of clays the following important points could be summarized:

- Poorly grading of grains with large sizes
- Well grading of grains with finer sizes
- Well grading of grains in the shapes of sub-rounded and rounded
- Poorly grading of grains in the shapes of angular, sub angular and irregular

4. **Conclusion and recommendations for future research works**

According to the obtained results, it is possible to conclude the presence of large finer portion in roof tile clays, large coarse portion in brick clay, well grading particle arrangement in roof tile clays, poorly grading particle arrangement in brick clays and gap grading particle arrangement in anthill clay. As the further recommendations for future research works, the following aspects will be highlighted:

- Investigation and comparison of the porosity and permeability with the obtained results for the grain size analysis
- Investigation of the geotechnical parameters of these clays such as the plastic limit, shrinkage limit etc.

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