Enhancement of soil properties using bottom ash, fly ash and coconut ash – An application of waste to wealth

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Abstract. Abundant waste materials are being produced nowadays due to rapid commercialisation and urbanisation. Disposal of these waste materials is a challenging task since it causes both air and water pollution. Since the production of waste materials is inevitable, a suitable strategy has to adopted to convert this waste into wealth. In this study, the red soil was collected from the field and the same was composted with organic matter to enhance its organic carbon content. Further, bottom ash, fly ash and coconut waste ash (CWA) has been added to the composted soil in a ratio of 1:4. Subsequently, the organic carbon content and strength parameters of the mixtures were determined. Soil organic carbon content was determined using Walkley Black method while the strength parameters were determined using standard proctor compaction test (SPCT) and Vane shear test. The N, P and K of the original collected soil were 160 kg ha\(^{-1}\), 14 kg ha\(^{-1}\), and 139 kg ha\(^{-1}\) respectively. The soil organic carbon content is highest with 65% when composted soil is mixed with bottom ash. The maximum dry density of soil increased from 0.765 to 0.81 due to addition of bottom ash. The Shear strength increases gradually with the increase in percentage of Coconut Waste Ash (CWA) and torque of soil also attained the effective value.

Keywords: Bottom ash; Fly ash; Coconut waste ash; Soil organic carbon content; Maximum dry density

1. Introduction

Waste, either solid or liquid waste is inevitable in the society due to industrialisation and urbanisation. The type, amount and composition of the waste may vary with the type of activity which may be domestic, industrial or agricultural in nature. The volume of waste generated in the world has increased over the years. Improper handling of these waste materials creates air pollution, water pollution, soil pollution, etc. The best method to handle these waste materials is to adopt waste minimisation or recover valuable materials from them.
Farming sector, household tasks, residential and commercial activities, building construction in addition to several other sectors throughout the globe produces massive amount of solid waste, rice husk ash, coal ash, bottom ash, fly ash, coconut ash, liquid waste, building debris, etc [1]. Because of the presence of harmful or hazardous materials these wastes are dangerous in nature and also present a severe threat to the environment. To minimise these issues, some of these waste materials have been made use of in the field of geotechnical engineering such as landflling, stabilisation of soils, embankment construction, etc [2, 3]. Fly ash is a waste material that is being produced form the thermal power plant as a by-product of combustion of powdered coal. Rapid urbanisation has caused significant usage of power consumption resulting in huge quantities of fly ash is being generated in these plants. Fly ash particles are spherical in shape, grey in color and alkaline [4]. Fly ash is utilised in various infrastructure projects. Bottom ash is also a by-product of coal combustion at thermal power plants. The chemical composition of bottom ash is very much similar to the fly ash but the amount of carbon content is larger [5]. This ash has higher shear strength, permeability and low compressibility. Due to these features, the bottom ash is being used in the construction of huge infrastructures like dam.

Krithiga et al. [6] conducted studies on soil stabilisation using lime and fly ash. Nath et al. [7] studied the strength behaviour of organic soil stabilised with fly ash. Jafer et al. [8] conducted a study on the stabilisation of soft soil using binary blended high calcium fly ash and palm oil fuel ash. Lopez et al. [9] performed a study to analyse the feasibility of using bottom ash for embankments by mixing bottom ash with various types of soils. They reported that bottom ash can be used to enhance the bearing capacity of soils. Kim et al. [10] conducted a compressive investigation on weathered soil stabilised with ground bottom ash and red mud. They reported that the soil mixture with ground bottom ash and red mud proved environmentally safe. Prasanna and Kumar [11] performed a study on the reinforcement of sandy and loamy sand textured soils using coconut shell ash. They reported that stabilisation process enhanced the optimum moisture content, dry density, angle of friction and cohesion. Yusuf et al. [12] used coconut husk ash for the stabilisation of soils used for the roads. Popoola et al. [13] stabilised the laterite soil using coconut waste ash as a partial replacement for lime. Literature shows that ash produced as a byproduct of industrial processes have several applications in the field of geotechnical engineering. Although many products have been used for the stabilisation of the soil, investigation on the strength behaviour of composted soil mixed with these waste materials is yet to be explored.

In this study, the red soil was collected from the field and the same was composted with organic matter to enhance its organic carbon content. Further, bottom ash, fly ash and coconut waste ash (CWA) has been added to the composted soil in a ratio of 1:4. Subsequently, the organic carbon content and strength parameters of the mixture were determined. Soil organic carbon content was determined using Walkley Black method while the strength parameters were determined using SPCT and Vane shear test.

2. Study area and materials collection

The soil was taken from a coconut farm in Eripatty village near Anupparpalayam in Pollachi town located in Coimbatore, Tamil Nadu. The coordinates of these location is 10.6767° N, 77.0868° E. The geographic location of the field is shown in figure 1 below.
Fig. 1 Map of Anupparpalayam, Pollachi

The soil sample was taken from a particular vegetation field at every corner of the field. Soil samples were taken at the depth of 0.3 meter. The dimension of soil sampling was about 20 x 20 cm. The soil taken from the corners were mixed thoroughly and total mass was around 12 kg sample was taken from it. Then the soil samples were cleaned, dried and tested for its soil organic carbon content initially. Then some amount of soil was composted with various biodegradable materials such as tissue paper, paper ash, cow dung, egg shell and wooden power. The composted soil was frequently mixed well once in 4 days. The organic content like natural wastes especially cow dung, egg shells, tissue paper etc. when decomposed in the soil, the natural content of nutrients like nitrogen, phosphorus and potassium increases in the soil. Consequently the plants grow quickly, leaf texture improves, water holding capacity and germination also improves. Lack of nitrogen, potassium and phosphorus can result in poor growth of the plants. The coconut ash was collected from the burning of coconut shells in the agriculture area in the village named Thaasanayakkampatti near Dharapuram. Fly ash and bottom ash were collected from the nearby industries.

3. Methodology

The organic carbon content test has been conducted by Walkley Black Chromic Wet Acid Oxidation method by using chemicals such as Potassium dichromate, Orthophosphoric acid, H₂SO₄, Distilled water and Ferrous Ammonium Sulphate. The strength parameters like maximum dry density (MDD) and optimum moisture content (OMC) was determined using SPCT and shear strength was vane shear test. The NPK test was conducted on the original soil collected from the field to estimate its nutrient content. The various ash materials were mixed with the composted soil with 1:4 ratio.

4. Results and discussion

The laboratory tests revealed that the soil type is reddish brown, the soil texture is loamy sand and the lime content is calcareous. The NPK test results have been provided in table 1 below.
Table 1. Results of the NPK test of the soil collected from the field

| Parameter        | Value | Unit     | Comments   | Prescribed limit |
|------------------|-------|----------|------------|------------------|
| Organic Carbon   | -     | %        | -          |                  |
| pH               | 8.15  |          | Slightly Alkaline |                  |
| EC               | 0.08  | dS m⁻¹   | Non Saline |                  |
| Available N      | 160   | Kg ha⁻¹  | Low        | 280 - 450 kg/ha  |
| Available P (Olsen's) | 14.0 | Kg ha⁻¹  | Medium     | 11 - 22 kg/ha    |
| Available K      | 139   | Kg ha⁻¹  | Medium     | 118 - 280 kg/ha  |

The above table indicates that the nitrogen content of the collected soil is low, while the potassium and phosphorus content are within the prescribed limits. The specific gravity of the red soil was determined to be 2.38 which is within the prescribed limits. The results of the soil organic carbon content are provided in Table 2 below.

Table 2. Soil organic carbon content of co-composted soil

| S.No | Soil type                  | % organic carbon |
|------|----------------------------|------------------|
| 1    | Plain soil                 | 0.34             |
| 2    | Soil with Bottom Ash       | 0.22             |
| 3    | Soil with Fly ash          | 0.42             |
| 4    | Soil with CWA              | 0.35             |
| 5    | Composted soil             | 0.44             |
| 6    | Composted soil with Bottom Ash | 0.65       |
| 7    | Composted soil with Fly Ash| 0.36             |
| 8    | Composted soil with CWA    | 0.33             |

It is observed from Table 2 that the original soil has only 0.34% organic carbon content. The organic carbon content increases significantly when the soil is mixed with fly ash. The composted soil possesses more organic carbon content when compared to the original soil due to the composting process. The same composted soil mixed with bottom ash has the maximum organic carbon content when compared to composted soil mixed with other types of ash. The results obtained from the SPCT is presented in Table 3 below and the results of the Vane shear test is provided in Table 4.

Table 3. Optimum moisture content and maximum dry density

| S. No | Soil type    | OMC (%) | MDD (g/cm³) |
|-------|--------------|---------|-------------|
| 1     | Normal soil  | 15      | 0.765       |
| 2     | Soil with Fly Ash | 12      | 0.69        |
From table 3 it is observed that the optimum moisture content is higher for original soil when compared to the soil mixed with different types of ash content. Maximum dry density is obtained for the soil mixed with bottom ash. The addition of lime (CaO) to the soil increases the optimum moisture content quickly and decreases the corresponding dry density of soil. Since the dry density of soil purely depends upon the degree of compaction and by addition of appropriate moisture content. From table 2, we conclude that generally lime (CaO) is rich in calcium hydroxide and it enormously releases large amount of heat when coming in contact with water. Adding of bottom coal ash with soil improves the mechanical strength of soil and reduces the swell and shrink of soil. By the addition of 12% of bottom ash, the value of maximum density of soil increases by 5% of the total weight compared to the conventional case. Further, from table 3 it can be noticed that the soil with Coconut Waste Ash (CWA) have attained the maximum dry density at early stage by the addition of 8% of CWA. This may be due to presence of CWA in the soil, which also increases the shear strength of soil by 0.025kg/cm². The addition of CWA has also increased the Maximum Dry Density (MDD) by 8% when compared to soil with bottom ash. From the SPC, we can conclude that the soil with bottom ash of 12% gives good mechanical behaviour and also has better results compared to other type soil-ash combinations and conventional type of soil.

From table 4, results of the shear strength of soil determined using Vane shear test is compared. The results show that the addition of bottom ash gives higher shear strength and torque. Coconut Waste Ash (CWA) is categorized as pozzolana materials with silica of about 60-70%, 4.9% of aluminium and 0.95% of iron oxides [14]. Presence of Silica together with Aluminium and iron oxides are the contributors of increased strength of soil.

5. Conclusion

In this study, the soil organic carbon content and strength parameters of composted soil mixed with fly ash, bottom ash and CWA was determined. The N, P and K of the original collected soil are 160 kg ha⁻¹, 14 kg ha⁻¹, and 139 kg ha⁻¹ respectively. The soil organic carbon content is highest with 65% when composted soil is mixed with bottom ash. The maximum dry density of soil increases from 0.765 to 0.81 due to addition of bottom ash. This indicates 12% addition of moisture content is enough to attain the effective Maximum Dry Density (MDD) because minimum OMC was also recorded at this percentage. The Shear strength increases gradually with the increase in percentage of Coconut Waste Ash (CWA) and torque of soil also attained the effective value.

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