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IMPROVEMENT OF CLAYEY SILTY SOIL LAYERS BELOW SUB BASE OF DELTA COUNTRY ROADS BY MIXING WITH PALM FRONDS

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ABSTRACT: The paper aims to minimize greenhouse gas emissions from cement and lime production while removing potential risks associated with inappropriate waste disposal techniques such as rice straw ash (RSA), sugarcane bagasse ash, crumb rubber, and palm frond ash, among others. Even in the face of heavy traffic and adverse weather, the subgrade must be strong and stable. Soil stabilization can be used to improve soil compressive strength and engineering properties of soil and, also weak subgrade layer in order to reduce pavement thickness and increase its lifetime. In this study, the stabilization materials were waste materials in the form of palm frond ash (PFA), which were collected from Beni Suef Governorate, Egypt. The tested soil is from Kafr Tohormos which is a residential area in Boulaq Al-Dakrour district, Giza Governorate, Egypt. The dry soil passing sieve No.40 was mixed with the palm frond ash, with 3%, 7%, 11%, and 15% from the dry weight of soil. Laboratory tests such as moisture content, sieve analysis, specific gravity, consistency limits, compaction test, unconfined compressive strength (UCS), and California Bearing Ratio (CBR) were carried out to identify the basic properties of a clayey silty soil. The findings of this study deduced decreasing in Atterberg limits with an increase in the stabilizing martial up to 11% then increased with more additives. Also, the specific gravity decreased with the increase of PFA percent with an amount of 3% to 15%. Maximum dry density decreased by 10% when adding 15% PFA, and the optimum moisture content increased by 25% when adding 15% PFA compared to their values without adding PFA. A significant change in CBR values which increased from 5% at natural soil conditions to a value of 31% when adding 15% PFA. Moreover, there is an increase in the unconfined compressive strength by 32% when adding 7% PFA.

Keywords: Stabilization; palm frond ash (PFA); Maximum Dry Density (MDD); Optimum Moisture Content (OMC); Unconfined compressive strength (qu); California Bearing Ratio (CBR)

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1. INTRODUCTION

The most typical method of stabilizing soft subgrades involves first removing the weak soil, which typically causes damage to the road surface [1]. Poor road surface conditions, such as potholes, rutting, shoving, and other flaws, caused discomfort and inconvenience to drivers. These defects lead to higher maintenance costs for pavements, so, it's important to provide a strong subgrade and implement soil improvement methods during the road construction process.

Weak and soft soils are common issues in civil engineering projects. Typically, the regular solution is to remove these weak soils and replace them with a stronger material [2].

The high replacement cost prompted researchers to explore alternative soil improvement methods. Soils containing significant contents of silt or clay have a change in their geotechnical characteristics as these contents swell and become plastic in the presence of water, shrink when dry, and expand when exposed to frost.

Soil stabilization is an engineering process that improves the quality of unusable soil [3]. Stabilization can be achieved through mechanical mixing of natural soil with stabilizing material, or by adding stabilizing material to an undisturbed soil deposit and allowing it to permeate through voids when soil and stabilizing agent are blended together. Soil stabilization is the process of adding stabilizing agents to soil in order to strengthen its properties [4]. These stabilizers are used in varying percentages with soil to determine how various parameters change in the soil when such an admixture is added.
The soil must have a high bearing capacity to support the structure's loads. Clay soil has a low California Bearing Ratio (CBR) value, which indicates that the soil's bearing capacity can be improved by mixing with stabilizing material [5].

PFA is a powder product generated by combusting palm frond ash waste and is considered more economical and environmentally friendly [6]. The proximity of PFA to open space, which causes environmental contamination. PFA has high pozzolanic properties, making it a siliceous or silica-aluminous material that divides finely. PFA has high pozzolanic properties, causing it to finely divide in the presence of moisture and react with calcium hydroxide at normal temperatures to form cementitious compounds [7], [8].

This study addresses the impact of PFA on clayey silt stabilization, with regard to fundamental physical characteristics such as specific gravity and Atterberg limit, furthermore soil strength characteristics such as undrained shear strength (qu), California bearing ratio (CBR), and looking for alternative construction materials that reduce the cost in addition to addressing pollution and disposal issues.

2. MATERIALS AND METHODS

2.1. Soil

Disturbed samples of clayey silt soil were collected from the Kafr Tohormos which is a residential area in Boulaq Al-Dakrour district, Giza Governorate, Egypt. The soil was obtained at a depth varying from 1m to 2m below existing ground surface, which considers the pavement's surface of the residential building conducted in the area. To determine the basic soil properties, Atterberg limit tests, sieve analysis, and the hydrometer analysis, based on the result obtained from the basic soil tests. The selected clayey silt soil samples were classified as A-7-6 and MH according to AASHTO and USCS classification systems, indicating that it is fair to poor for road construction purposes. Soil properties are given in **Error! Reference source not found.**, and the particle size distribution curve of the soil is shown in

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Table 1: Soil physical properties

Physical Properties	
Specific Gravity	2.60
Moisture Content, (%)	14.9
Liquid Limit, (%)	46
Plastic Limit, (%)	24
Plasticity Index, (%)	22
Unified soil classification system (USCS)	MH
Soil samples ingredients	
% Sand	15
% Clay	32
% Silt	53

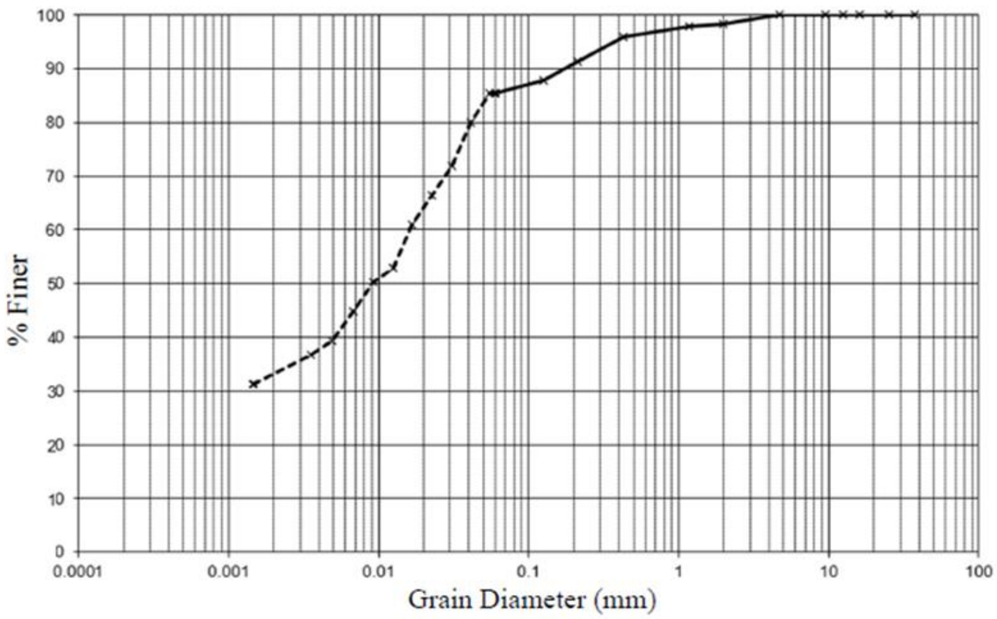

Figure 1: Particle size distribution of the clayey silt soil

2.2. Palm frond ash

Palm fronds (PF) were collected from locations in Beni-Suef City, Egypt. After collection, PF was air dried and then being burned by heating in the furnace for 2 hours at a temperature between 800-825°C to remove unburned carbon and to increase the pozzolanic properties at the Faculty of Agriculture laboratory, El-Azhar University. **Figure 2** depicts a sample of palm frond ash.

Figure 2: Raw palm frond ash (PFA)

2.3. XRF (X–ray fluorescence analysis) method

Chemical analysis was conducted using the XRF (X–ray fluorescence analysis) method, which shows the principal pozzolanic oxide compounds (Fe_2O_3, $Al_2 O_3$, and SiO_2) in the Palm frond ash.

Table 2: Chemical composition of palm frond ash

Main Constituents (wt. %)	Results (%)
SiO_2	61.46
TiO_2	0.33
Al_2O_3	1.58
$Fe_2O_3^{tot.}$	2.43
MgO	1.86
CaO	10.14
Na_2O	1.09
K_2O	2.43
P_2O_5	2.54
SO_3	3.00
Cl	2.16
LOI	10.70
MnO	0.175
ZnO	0.040
SrO	0.079
Rb_2O	0.008
Br	--

3. Mix Design and Preparation of samples

To identify the geotechnical properties of clayey silt soil, a series of lab experiments had been performed such as Atterberg limits, specific gravity, organic content, modified proctor test, California bearing ratio (CBR), and unconfined compressive strength. Four different percentages of palm frond ash were added to the soil in the proportion of 3%, 7%, 11%, and 15% in terms of the percentage of its dry weight. The soil without palm frond ash (0%) was considered as a reference sample throughout this study.

The tests in the following sections were conducted, in accordance with ASTM Standards, on the prepared soil/PFA mixtures.

3.1. Atterberg limits

The liquid limit test was conducted out via the Cassagrand apparatus in accordance with ASTM D423, while the plastic limit test was carried out in accordance with ASTM D424-59. These tests were performed to investigate the effect of adding palm frond ash on the consistency limits.

3.2. Specific Gravity Tests

The specific gravity of soils was determined in accordance with the Density and Specific Gravity ASTM D792, using the density bottle of 50 ml capacity.

3.3. Compaction test

The modified proctor compaction test was carried out to determine the moisture content–dry density relationship according to ASTM D 1557 for natural soil and soil with PFA in percentages (3%, 7%, 11%, and 15%) of soil dry weight. The test was carried out using a mold with a 101.6mm internal diameter and 116.4mm effective height, with a 4.6 kg hammer of a 450 mm free fall is used to compact the entire soil sample in five layers with 25 blows. The compaction tests were aimed to determine the compaction properties of the natural soil and treated soil.

3.4. Unconfined compressive strength (UCS)

The purpose of the Unconfined Compressive Strength (UCS) test is to evaluate the sample's strength. Remolded soil samples were “destructured,” and then formed back into a cylindrical shape. The disturbed sample was prepared in the mold and compacted manually to achieve a natural density of soil. The test was performed on the natural soil samples and to the same soil samples mixed with the PFA in percentages of 3%, 7%, 11%, and 15% of soil dry weight.

3.5. California bearing ratio (CBR)

The California Bearing Ratio (CBR) test is commonly used to determine the strength of subgrade soil for road and airfield pavement design. In order to achieve the objective of this study, the CBR test is carried out to evaluate the strength of subgrade soil at ratio of the load sustained by the specimen at 2.5- or 5.0-mm penetration. The internal diameter of the CBR mold is 152 mm, and it includes a detachable normal or perforated baseplate as well as a removable extension collar. For compaction, a 4.5 kg hammer with a drop height of 450 mm is used. California Bearing ratio test was carried out on natural soil and treated soil with palm ash in percentages of 3%, 7%, 11%, and 15 % of soil dry weight.

CBR was performed in accordance with Standard (BS 1377: Part 4:199) for soaked (4 days) conditions. The value of moisture content added to the sample is adopted from the compaction test that was conducted before.

4. Results and Discussion

4.1. Atterberg limits tests

The results showed that the liquid limit and plastic limit had decreased from percentage 3% up to percentage 11 % then it increased, this improvement may be attributed to the replacement of part of the fine particles of the clayey silt soil with the PFA with its pozzolana effect on soil consistency [9]. Furthermore, the plasticity index decreased from a percentage of 3% up to a percentage of 11 % then it started to rise for the same causes. As shown in Figure 4.1

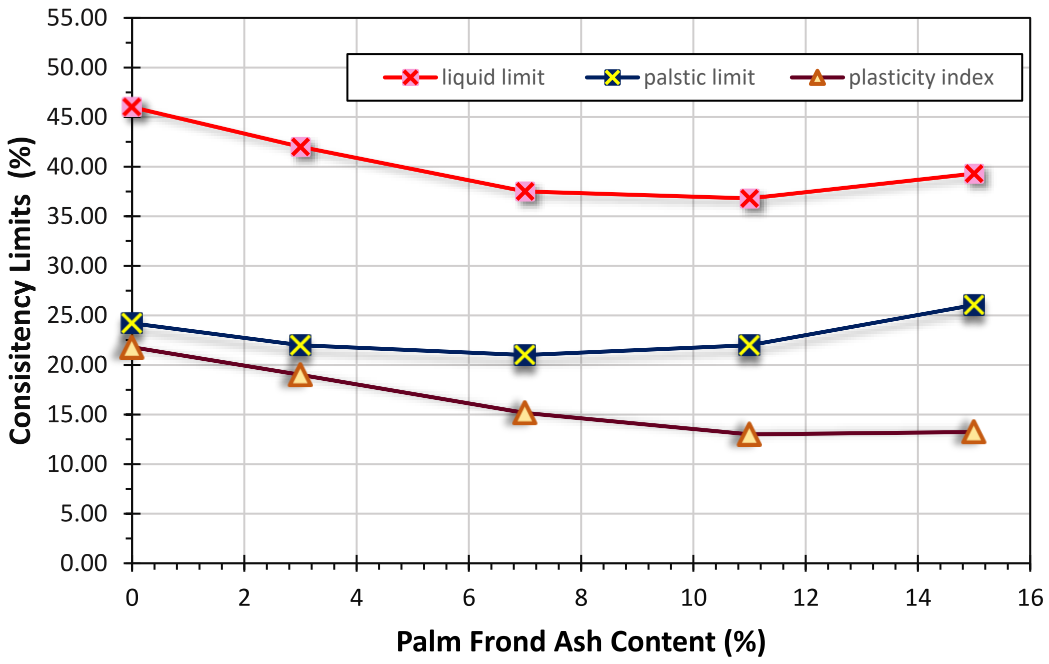

Figure 3: Effect of palm frond ash content on consistency limits on clayey silt soil

4.2. specific gravity

Figure 4 represents the specific gravity test results for natural soil and the soil mixed with different percentages of PFA. The specific gravity of natural soil gave the peak value without any additives, and after mixing the soil with different percentages of PFA of its dry weight, the specific gravity had been decreased with an increase in the percentage of PFA.

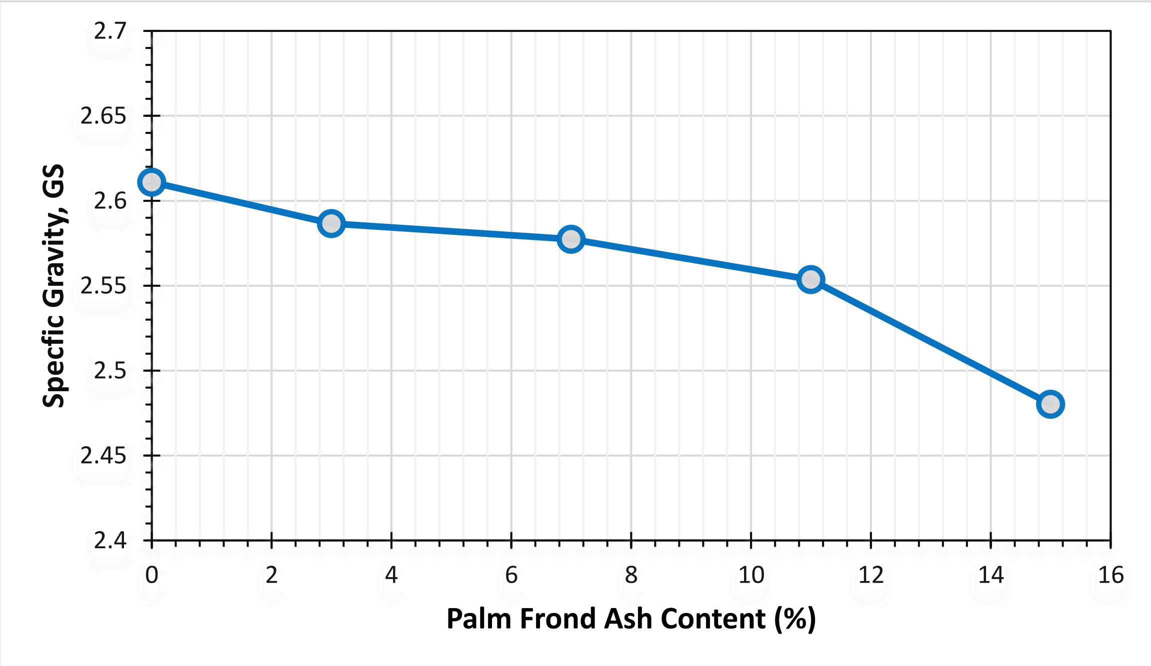

Figure 4: Effect of PFA content on specific gravity of clayey silt soil

4.3. Modified proctor compaction test

The results of max dry density (MDD) and optimum moisture content (OMC) of clayey silt soil are shown in

Figure 5. The variations of MDD and OMC with different percentages of PFA content are shown in Figures 6 and 7 respectively. The findings presented that the more adding of PFA, the more decreasing MDD for all varying percentages of PFA and this is owing to the low specific gravity of PFA in comparison with clayey silt soil and the flocculated and agglomerated clay particles occupying larger spaces leading to a corresponding decrease in dry density according to [9]. Also, there is an increase in the optimum moisture content for all different percentages, due to cations exchange between soil and PFA which leads to attracting and holding positively charged ions and molecules like calcium, sodium and water. Furthermore, PFA is a pozzolanic material that need more water for hydration process and it works as a lubricant agent to disperse between clay plates and grains making it absorb more water.

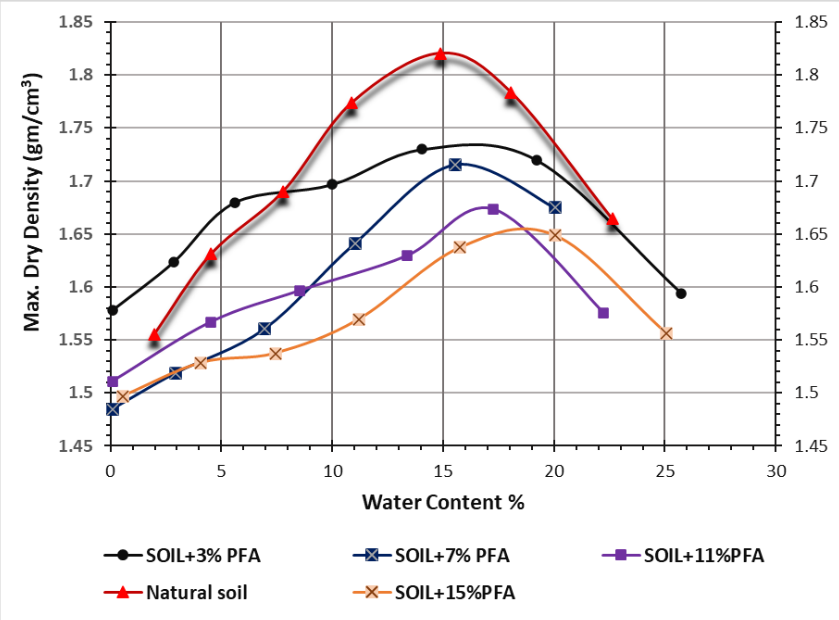

Figure 5: Compaction tests graphs of natural soil and the mixing soil with palm frond ash

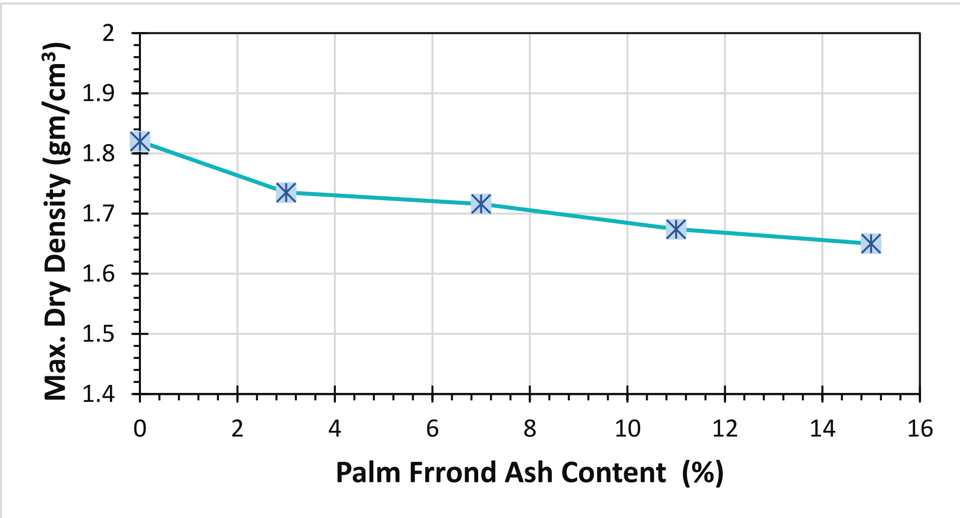

Figure 6: Variation of max dry density (MDD) at different percentages PFA content

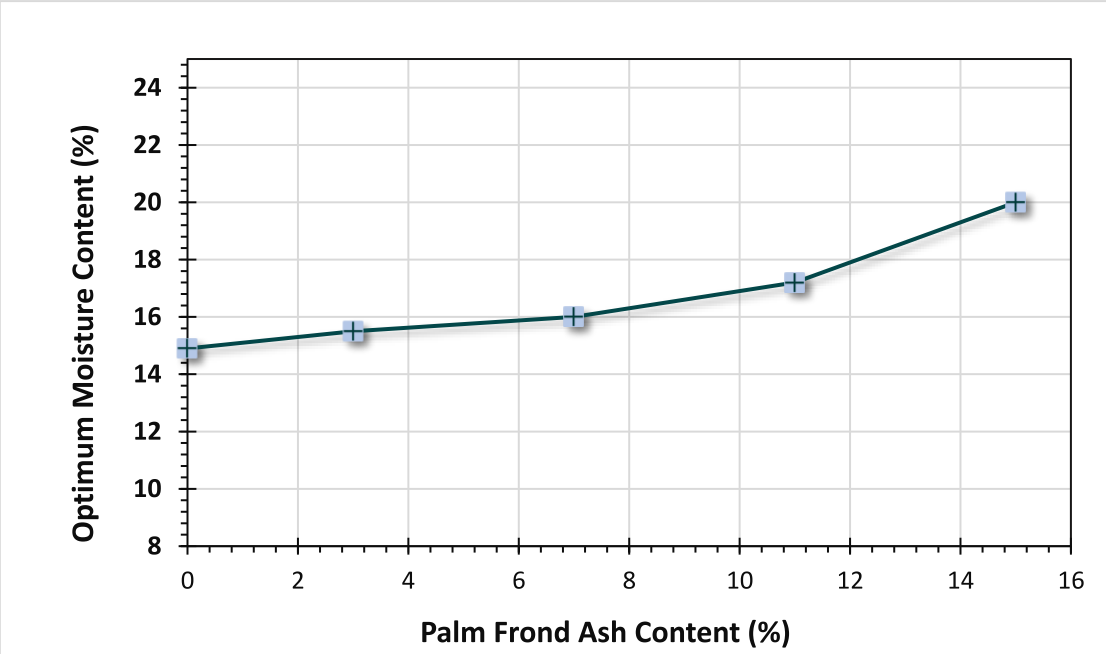

Figure 7: Variation of OMC at different percentages PFA content.

4.4. California Bearing Ratio:

In order to assess the strength of the road subgrade and subbase for pavement thickness design, the CBR test was carried out to verify the bearing value. CBR tests were conducted in this study under soaked conditions for 96 hours. The purpose of soaked CBR is to simulate the worst possible road pavement condition. The test results of clayey silt soil and soil mixed with different percentages of PFA are shown in Figure 8 and Figure 9.

The results indicate that there is a significant increase in CBR values. The CBR value increased with the increase in the amount of PFA content. The CBR value of the natural soil was the minimum value of 5% and the peak value when soil mixed with 15% of PFA. The maximum value reached to 30%.
Increasing of CBR value means high strength, stiffness, and cohesiveness to subgrade soil. The rise in CBR values is attributed to PFA when finely divided and exposed to water, it reacts with Ca (OH)2 to form cementation compounds via hydration and pozzolanic reactions.

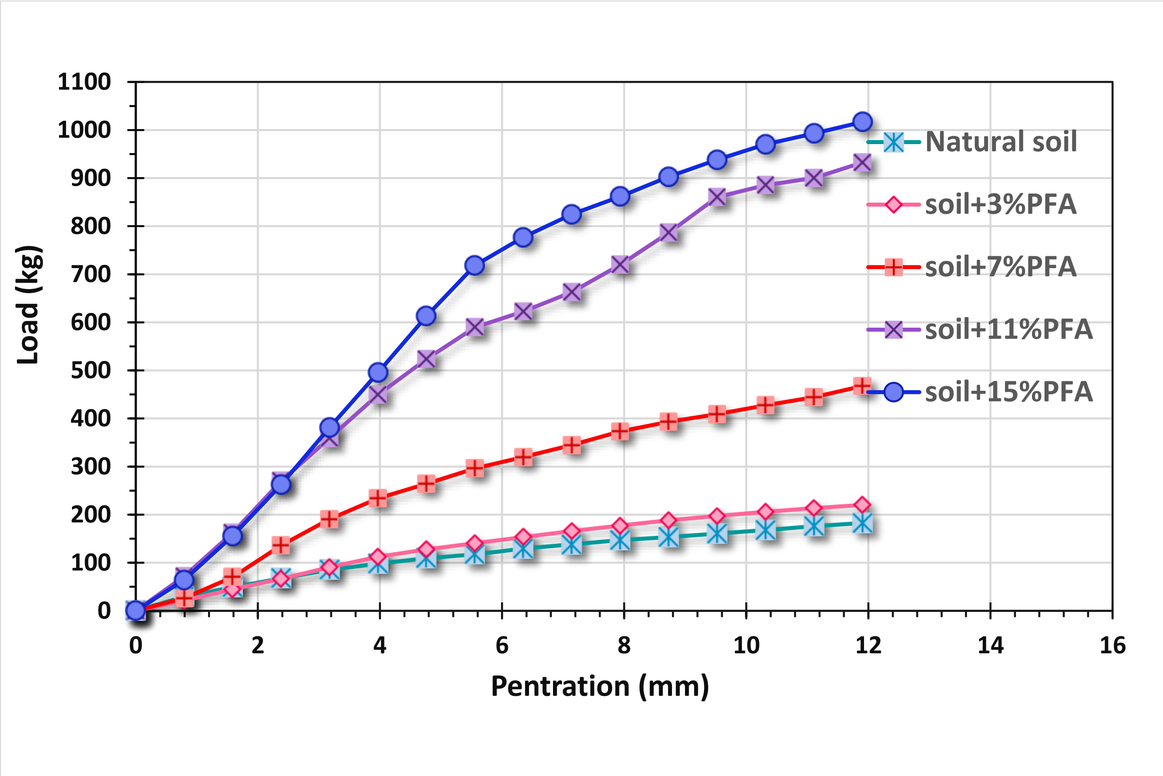

Figure 8: Results of soaked CBR for natural soil and soil with PFA.

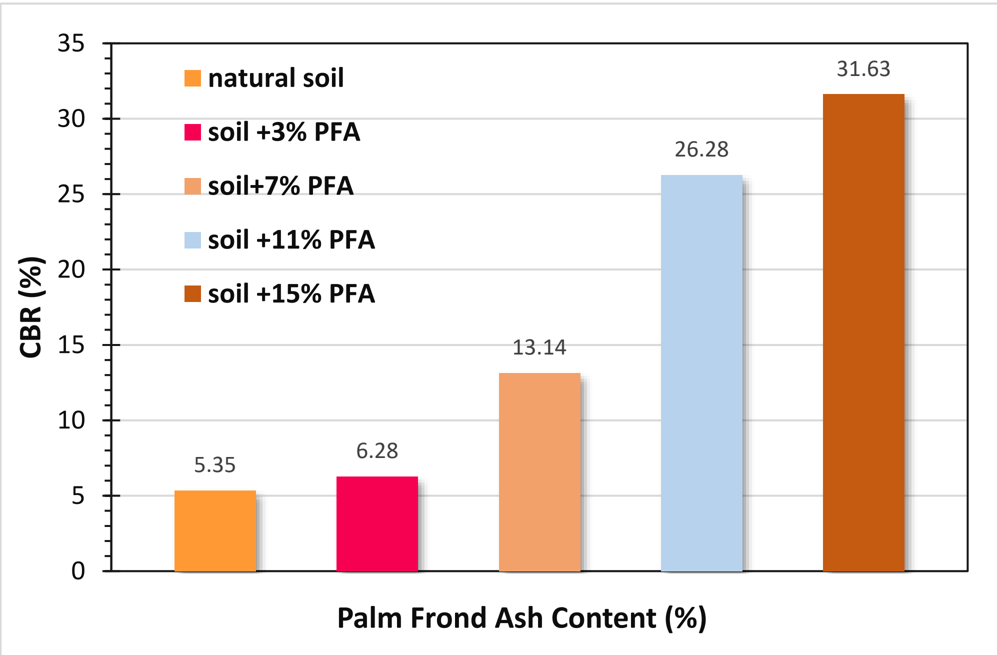

Figure 9: CBR values with 0%, 3%, 7%, 11% and 15% of PFA content.

4.5. Unconfined compressive strength

Unconfined compressive strength (UCS) is the most widely used and versatile method for assessing the strength of stabilized soils. Figure 10 shows UCS variations with PFA increases from 0% to 7%. UCS values increase with PFA content; peaking at 6-8% PFA and then dropping at 11% PFA. The increase in UCS can be attributed to the formation of cementitious compounds between soil $CaOH_2$ and PFA, as well as pozzolans in PFA. The decrease in UCS values after adding 11% PFA could be attributed to weak bonds between the soil and cementitious compounds due to insufficient water content needed to hydration process.

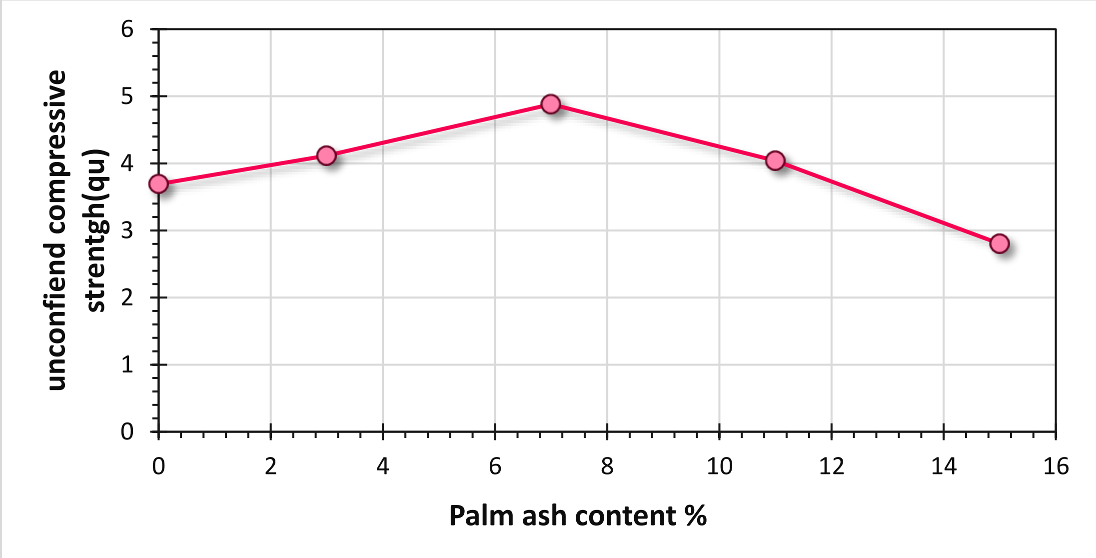

Figure 10: Variation of unconfined compressive strength with PFA content.

5. CONCLUSIONS

A clayey silt soil was classified as A-7-6 and MH by the AASHTO and USCS classification systems, confirming it's fair to poor for road construction purposes. So, it needs improvement to be valid for road construction by adding it with different percentages of palm frond ash (PFA). The effect of PFA on the geotechnical properties of subgrade soil is investigated and analyzed and the main conclusion of this study is as follows:

- The liquid limit and plastic limit decreased as the PFA content increased up to 11%, after which they increased, and the plasticity index decreased up to 11% of PFA content before increasing.
- Specific gravity of the tested samples decreased with the increase of PFA content.
- The maximum dry density values decreased with the increase of the percentage of PFA. In contrast, the optimum moisture content increases with increasing palm ash content.
- The results indicate that the presence of PFA effected the increasing of subgrade soil CBR value. The CBR results for natural soil had fulfilled the minimum value of 5%, and the maximum value had occurred at 15% of PFA which contributed the highest CBR value of 30%.
- Added PFA to the soil increased the unconfined compressive strength by 32% with increasing PFA content from 3% to 7%, and then the unconfined compressive strength decreased with 11% of PFA.

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