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Plasticity, Strength and Permeability of Reclaimed Asphalt Pavement and Lateritic Soil Blends

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Abstract— This paper presents the results of laboratory evaluation of the effects of the addition of reclaimed asphalt pavement (RAP), to an A-2 lateritic soil, on the plasticity, strength and permeability of the soil. The natural soil was classified as A-2-6(1), according to AASHTO classification system. RAP was added to the soil in 0, 4, 8 and 12%, by dry weight of the soil. Specific gravity, Atterberg limits, compaction, California bearing ratio (CBR), unconfined compression and permeability tests were conducted on each of the soil-RAP blends. Results obtained show that as RAP content in the blend increased, the plasticity index, optimum moisture content, maximum dry unit weight, swell potential, unconfined compressive strength and permeability decreased while the specific gravity, soaked and unsoaked California bearing ratios increased. These results indicate that RAP effectively improved, especially, the plasticity and permeability of the soil. It also indicates that deformation should be a major design criterion while planning the use of lateritic soil-RAP blend as a road pavement layer material.

Index Terms— laterite, recycled asphalt, soil modification, subgrade, sub-base, tropical soil, unbound granular materials

1 Introduction

IN today's world, issues of reusing and recycling of non-renewable resources as a means of minimizing waste and environmental pollution; and for economic reasons are a priority to governments, organizations, researchers and the general public. The road construction industry, being a large consumer of non-renewable natural resources, is not left out. Solutions for reuse and recycle of wastes resulting from earthmoving, construction, rehabilitation and maintenance operations of road infrastructure are now being favoured [1].

The rehabilitation of hot mix asphalt (HMA) roadways that results into milling of the existing asphalt concrete surfacing and resurfacing of the roadway with new HMA accounts for a large quantity or stockpiling of reclaimed asphalt pavement (RAP) annually, worldwide. It is estimated that about 100 million tons of asphalt pavement is reclaimed each year in the United States [2]. Though some government agencies responsible for making policies that relate to highway and transportation permit a certain percentage of RAP to be recycled into new HMA, most of these stockpiling of milled asphalt ends up being disposed off as waste, especially in developing countries.

McGarrah [3] reported that transportation agencies of governments in the US received many request from road construction contractors seeking permission to use RAP as a base course and sub-base materials and this led to various research works and field testing [4], [5], [6], to investigate the properties and performance of wholly using RAP as a base course material. The properties of RAP made it worth considering for use as a pavement layer material [7], [8]. The use of RAP as a base material increases the rutting resistance and stability; and decreases temperature susceptibility of pavements [9]. However, Taha et al. [10] found out that blending of RAP with virgin aggregates gave more satisfactory results than wholly using RAP. Their results showed that the dry density and California bearing ratio (CBR) values decreased; the optimum moisture content (OMC) was unchanged; and the permeability increased, as the RAP in the blends increased. They recommended limiting the substitution of natural aggregate with RAP to 10% for road base applications. Taha et al. [11] discouraged the use of 100% RAP as a base material.

Bennert and Maher [12] investigated the effects of blending RAP with virgin aggregates on the mechanical properties of these blends for use as base course and sub-base materials. They found out that as RAP increased in the blend, the CBR and permeability of the RAP-virgin aggregate blends decreased.

In the tropics, lateritic soils occupy about 23 percent of the land surface and are the single most extensive kind of soil in this region [13]. Consequently, their selection for use as a construction material becomes an economically-viable choice. However, some of the lateritic soils are unsuitable for use as road construction materials because their properties do not comply with existing standard requirements. Some of these soils exhibit high plasticity, poor workability, low strength, high permeability, tendency to retain moisture and high natural moisture content [14].

Mustapha et al. [15] compared the CBR and unconfined compressive strength (UCS) of an A-6 lateritic soil and that of a mixture of the soil and 60% RAP, by weight of soil. These researchers found out that adding 60% RAP to the A-6 lateritic soil slightly increased its CBR and UCS. Edeh et al. [16] determined the plasticity and CBR of a ternary blend of a lateritic soil, RAP and Cement.

This paper presents the results of laboratory evaluation of the effects of adding RAP to an A-2 lateritic soil on its plasticity, strength and permeability.

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2 Materials and Methods

2.1 Materials and Preparation

The RAP used for this research work was collected from a stockpile along Benin-Ore Road, during its roadway rehabilitation. Sieve analysis was performed to determine the gradation of the RAP. About 4% of its particles are finer than BS No. 200 Sieve (0.075 mm). The RAP sample contained an average bitumen content of 4.8% by weight of the mix. A typical bitumen content range for RAP obtained from wearing surface mixes is 4.5-6.0% [9].

The soil sample was collected, by method of bulk disturbed sampling, from Covenant University borrow pit (latitude 06°40′24″N and longitude 03° 09′12″E) behind the university student hostels. A top soil layer of 0.2 m was removed before digging to a depth of 0.5 m to collect the sample. Samples to be used for natural moisture content determination were stored in a watertight bag before this laboratory determination. The remaining samples were air-dried in the Soil Mechanics/Geotechnics laboratory of the Department of Civil Engineering, Covenant University, before carrying out the laboratory tests.

2.2 Methods

Gradation and specific gravity tests were conducted on the soil and RAP samples. The oxide composition of the soil sample was determined using atomic absorption spectrophotometer. RAP was added to the soil in 0, 4, 8 and 12%, by dry weight of the soil. Specific gravity, Atterberg limits, compaction, CBR, unconfined compression and permeability tests were conducted on each of the soil-RAP mixtures. The procedures for the various tests were carried out in accordance with BSI [17], [18].

Pearson's correlation coefficient (r) was used to identify the extent to which the values of each of these engineering properties are correlated with the increase in RAP content in the soil-RAP blends. The probability that the effects of changes in each of these engineering properties with the addition of RAP are not due to just chance alone was determined based on pre-specified probability threshold (p-value) to a significance level of 5% (0.05).

3 Results and Discussion

3.1 Some Concerned Oxide Composition of the Soil

In order to determine the level/extent of laterization of the soil used, the concentration of oxides of silica (SiO_2), iron (Fe_2O_3) and aluminum (Al_2O_3) in the soil was determined by atomic absorption spectroscopy. A ternary or tri-plot of this composition is shown in Fig. 1. The soil contains a higher silica content than iron oxide content. This suggests that this soil was formed from laterite on an acidic rock and it contains some quartz. The soil also contains a higher proportion of sesquioxide of aluminum than the sesquioxide of iron. Thus, the soil is bauxitic. The ratio of silica-sesquioxides was determined to be 1.35. Thus, confirming that the soil is lateritic. According to the Schellmann [19] scheme of classification of weathering products, this soil sample was classified as being taken from a kaolinized profile.

3.2 Natural Soil

The summary of the result of the geotechnical properties of the natural soil is presented in the Table 1.

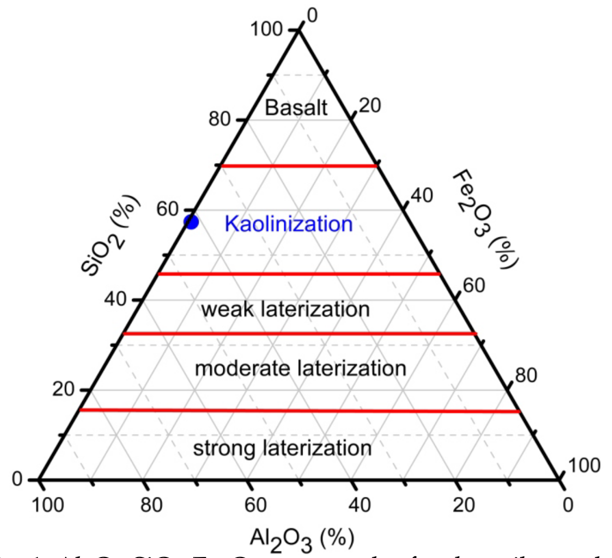

Fig. 1. Al_2O_3-SiO_2-Fe_2O_3 ternary plot for the soil sample

Table. Geotechnical Properties of Natural Soil

	Properties	Quantity / Description
Gradation / Classification	Gravel (>4.75 mm), %	12.5
	Sand (0.075 - 4.75 mm), %	58.4
	Silt and Clay (<0.075 mm), %	29.1
	AASHTO Soil Classification System	A-2-6 (1)
	Unified Soil Classification System	SC - Clayey Sand
Physical	Colour	Brown
	Natural Moisture Content (%)	15.7
	Specific Gravity	2.54
	Liquid Limit (%)	29.0
	Plastic Limit (%)	10.8
	Plasticity Index (%)	18.2
	Linear Shrinkage (%)	4.0
	Maximum Dry Unit weight (kN/m^3)	17.5
	Optimum Moisture Content (%)	14.7
	Permeability (cm/s)	8.58×10^{-5}
	Swell Potential (%)	0.287
Strength	Unsoaked CBR (%)	56
	Soaked CBR (%)	29
	Unconfined Compressive Strength (kN/m^2)	130.4

The soil has a natural moisture content of 15.7% and it is classified as A-2-6(1), according to the AASHTO soil classification system. The particle size distribution curves for the soil and RAP aggregate are shown in Fig. 2.

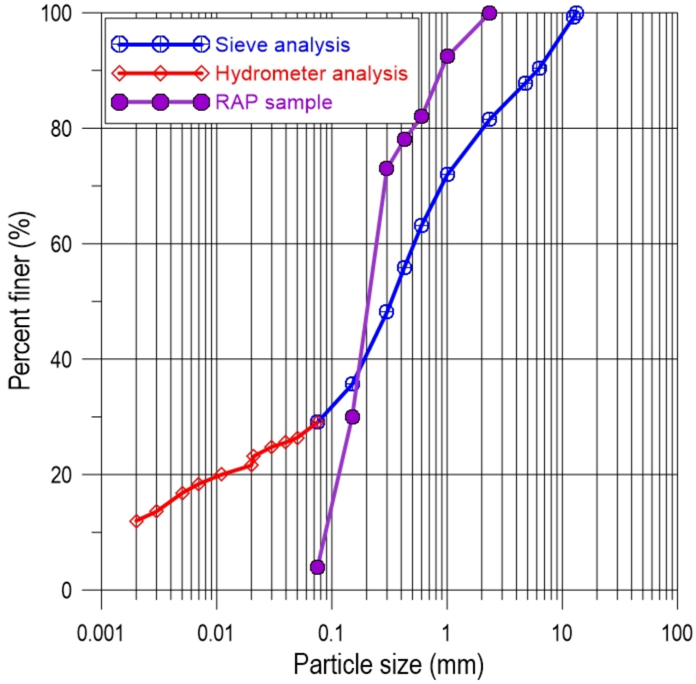

Fig. 2. Particle size distribution of natural soil and RAP

It showed that the percentage passing BS No. 200 sieve (0.075 mm) is 29.1% and according to AASHTO, it is a granular soil since it is less than 35%. Since this fine content is 29.1%, it indicates that it considerably influenced the properties of the soil. The soil was in its plastic state at the time of collection. Its plasticity index was found to be greater than 11% and thus according to AASHTO, the fines are clayey. The activity of the soil was determined to be 1.08 and using the table for activity of clay-rich soils provided by [20], this soil can be described as normal.

3.3 Effects of Adding RAP to the Natural Soil

The specific gravity of the soil sample and RAP is 2.54 and 2.93, respectively. Variation of the specific gravity of soil with RAP content is presented in Fig. 3. There is a positive correlation between the percent of RAP added to the soil and the specific gravity of the blend.

The specific gravity of the natural soil increased by 3.9% after adding 12% RAP to the soil. The increase in specific gravities of the soil-RAP blends as the RAP content increased was strongly correlated, $r = 0.983$, $p = 0.017$. The p-value obtained indicates that there is moderate evidence against the null hypothesis (no difference between the specific gravity of the natural soil and those of the soil-RAP blends).

The changes in the liquid, plastic and shrinkage limits; and the plasticity index of the lateritic soil sample, as various percentages of RAP were blended with it, are presented in Fig. 4. There is a negative correlation between the plasticity indices of the soil-RAP blends and the addition of RAP to the soil.

The plasticity index of the natural soil decreased by 42.3% after adding 12% RAP to the soil. This decrease in the plasticity indices of the soil-RAP blends with increasing RAP content was strongly correlated, $r = -0.976$, $p = 0.024$.

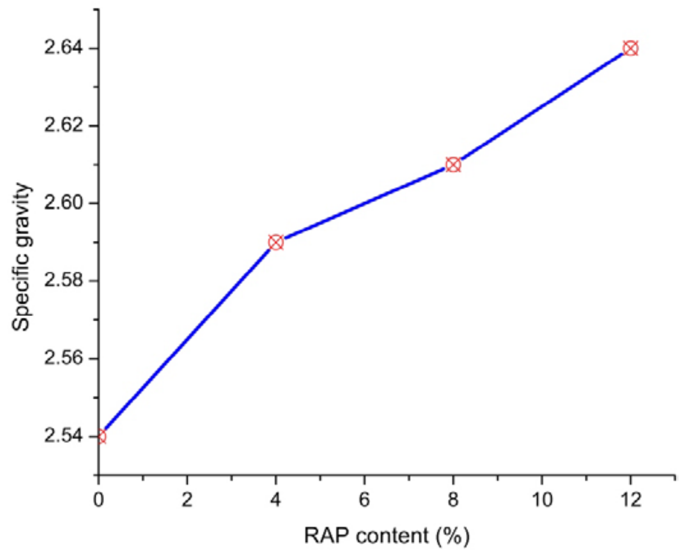

Fig. 3. Variation of specific gravity with RAP content

The p-value obtained indicates that there is moderate evidence against the null hypothesis (no difference between the plasticity index of the natural soil and those of the soil-RAP blends). This decrease in the plasticity index makes the soil-RAP blend more workable. After the addition of 12% RAP, the linear shrinkage of the natural soil increased by 95%. This shows that deformation of the soil increases with increasing RAP content in the soil.

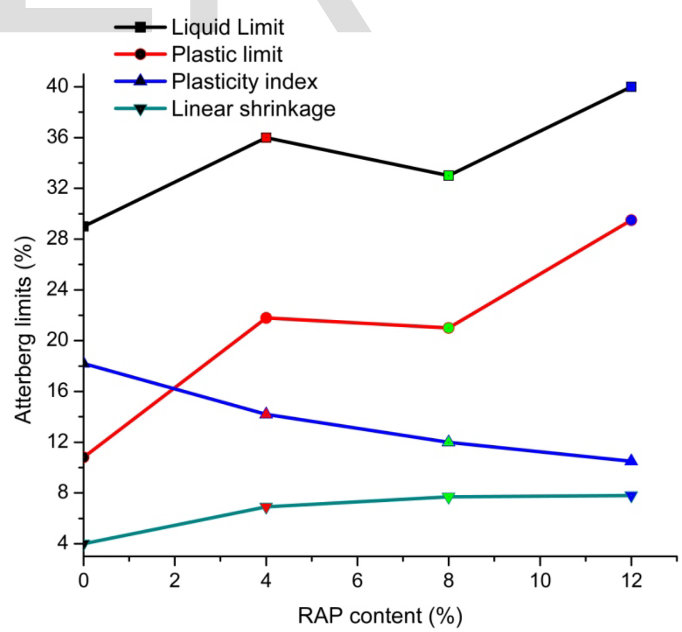

Fig. 4. Variation of Atterberg limits with RAP content

Fig. 5 is the plasticity chart showing the variation of plasticity index with liquid limit. It shows that the natural soil progressively changed from being clay of low plasticity (CL) to silt of low plasticity (ML). This change is attributed to the ag-

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glomeration of clay particles facilitated by the bituminous (binder) content of the RAP.

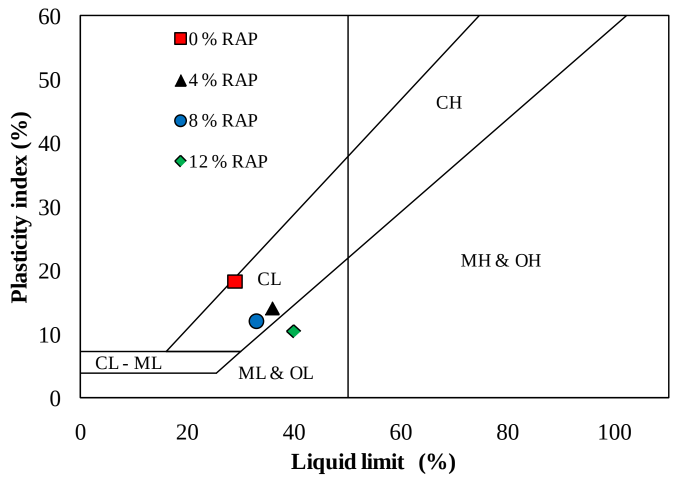

Fig. 5. Plasticity chart showing the variation of the soil plasticity with its RAP content

Variation of OMC and maximum dry unit weight with the addition of RAP to the soil is shown in Fig. 6. After adding 12% RAP to the soil, its maximum dry unit weight and OMC decreased by 2.5% and 10.3%, respectively. The negative correlations of each of the maximum dry unit weight and OMC with the addition of RAP to the soil were strong, r = −0.961, p = 0.039; and r = −0.933, p = 0.067, respectively.

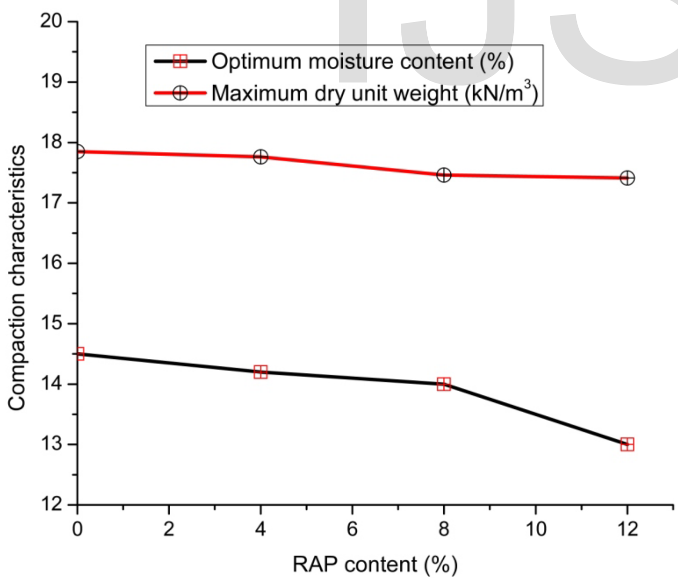

Fig. 6. Variation of compaction characteristics with RAP content

The p-value for the maximum dry unit weight indicates that there is moderate evidence against the null hypothesis (no difference between the maximum dry unit weight of the natural soil and those of the soil-RAP blends) while that for the OMC indicates that there is weak evidence against the null hypothesis (no difference between the OMC of the natural soil and those of the soil-RAP blends).

The decrease in OMC may also be resulting from the clumping-together of clay particles, which reduce the surface area of the soil and its water-holding capacity. The clumped clay particles begin to behave like silt-sized particles; which is corroborated by Fig. 5. The coarser the grain of a soil becomes, the lesser the water it requires to reach optimum [21], [22], [23].

Variation of unsoaked and soaked CBR with the addition of RAP to the soil is shown in Fig. 7. There is a positive correlation between the unsoaked CBR value and the percent of RAP added to the soil. This positive correlation was found to be strong, r = 0.996, p= 0.004. The p-value obtained indicates that there is strong evidence against the null hypothesis (no difference between the unsoaked CBR of the natural soil and those of the soil-RAP blends). After the addition of 12% RAP to the soil, the unsoaked CBR of the soil increased by 14.3%. This increase is slight. Thus, the unsoaked CBR of the soil is generally low.

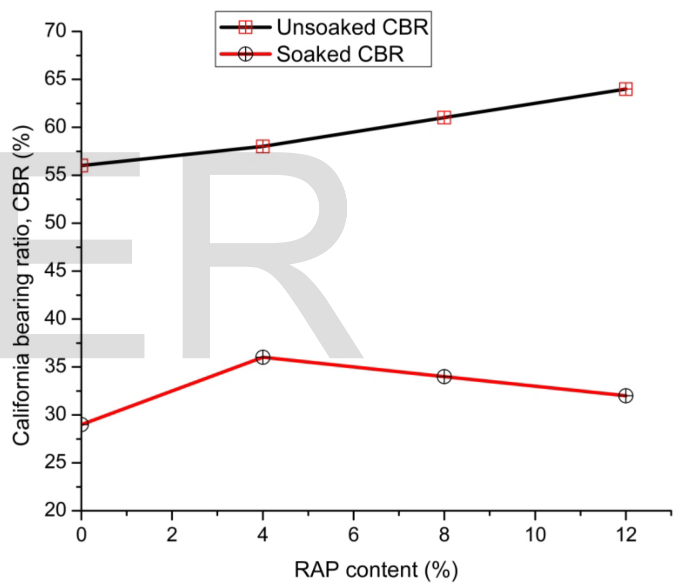

Fig. 7. Variation of CBR with RAP content

The increase in soaked CBR of the soil-RAP blends as the RAP content increased was moderately correlated, r = 0.303, p = 0.697. The p-value obtained indicates that there is no evidence against the null hypothesis (no difference between the soaked CBR of the natural soil and those of the soil-RAP blends). This means that the soaked CBR results appear to be consistent with the null hypothesis. After the addition of 12% RAP to the soil, the soaked CBR of the soil increased by 10.3%. Though the addition of RAP did not appreciably increase the soaked CBR of the natural soil, which is less than 30%, the soaked CBR became greater than 30% for all the blends. Consequently, the natural soil that only met TRL [24] requirements for use as a subgrade material became suitable for use as a sub-base material.

The swell potential of the natural soil decreased with increase in RAP content, as can be seen in Fig. 8. The decrease in swell potential of the soil-RAP blends as the RAP con-

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tent increased was strongly correlated, r = −0.954, p=0.046. The p-value obtained indicates that there is moderate evidence against the null hypothesis (no difference between the swell potential of the natural soil and those of the soil-RAP blends). After the addition of 12% RAP to the soil, it decreased by 44.6%. The swell potential of the soil was generally low suggesting that kaolinite is the predominant clay mineral in the soil and this is in alignment with its classification in Fig. 1.

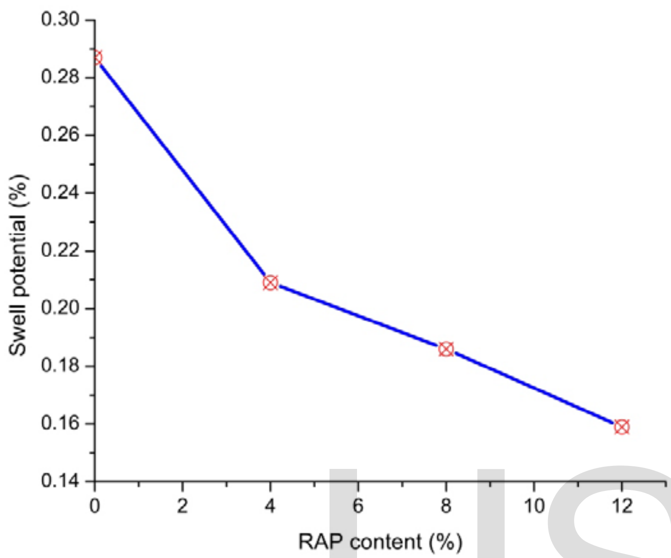

Fig. 8. Variation of swell potential with RAP content

The unconfined compressive strength (UCS) of the soil and that of the soil-RAP blends are presented in Fig. 9. The decrease in UCS of the soil with an increase in its RAP content was strongly correlated, r = −0.881, p = 0.119. The p-value obtained indicates that there is no significant evidence against the null hypothesis (no difference between the UCS of the natural soil and those of the soil-RAP blend). The UCS of the soil decreased by 88.4% after adding 12% RAP to the soil. This result affirms that increasing RAP content in lateritic soil-RAP blends can cause substantial irrecoverable deformation. Bennert and Maher (2005) also found out that high RAP content in RAP-virgin aggregate blends caused large permanent deformation.

The variation of permeability with the addition of RAP to the soil is shown in Fig. 10. There is a negative correlation between the percent of RAP added to the soil and the permeability of the soil. The decrease in permeability of the soil with an increase in its RAP content was strongly correlated, r = −1.000, p < 0.001. The p-value obtained indicates that there is very strong evidence against the null hypothesis (no difference between the permeability of the natural soil and those of the soil-RAP blends). Using the results of specific gravity and compaction characteristics, the void ratio and porosity of the natural soil and soil-RAP mixtures were calculated. The results obtained showed that the void ratio and porosity both progressively decreased with increasing RAP content. This decrease in void ratio and porosity may be attributed to the clogging of the pores within the soil by the bituminous content of the RAP. This may be responsible for the decrease in permeability with increasing RAP content in the soil.

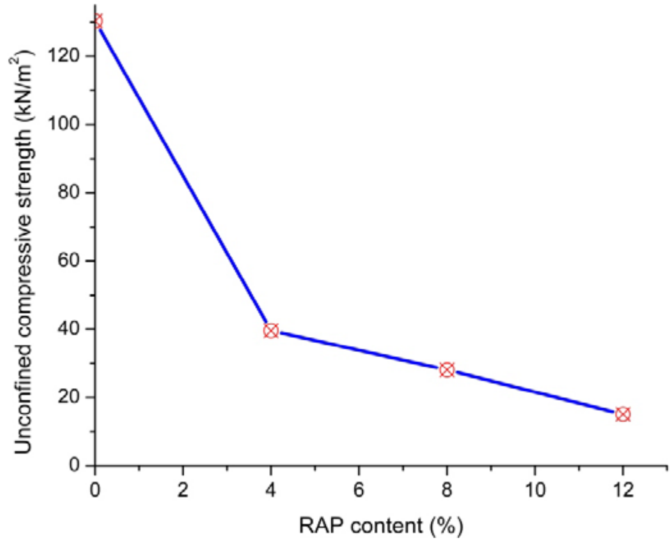

Fig. 9. Variation of UCS with RAP content

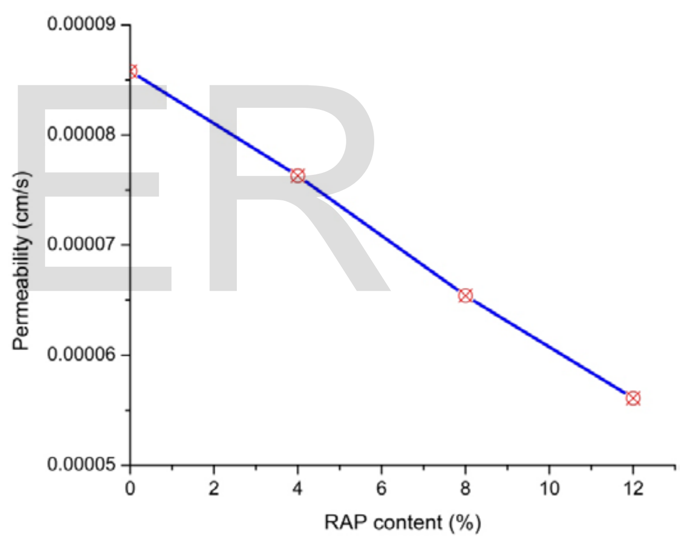

Fig. 10. Variation of permeability with RAP content

4 Conclusions

From the results obtained, the following conclusions were made:

(i) RAP, when added to a lateritic soil, can be used to reduce the plasticity and swell potential of its clay fraction. Thus, making the soil more workable.

(ii) The addition of RAP to the lateritic soil did not significantly improve its strength.

(iii) The addition of RAP to the lateritic soil reduced the ease with which water permeates the soil and its moisture-holding capacity. This makes it suitable for reducing the permeability of soils to be used as road pavement layer material and earth dam material.

(iv) Deformation should be a major design criterion while planning the use of lateritic soil-RAP blend for use as a pavement layer material.

(v) The natural soil, prior to application of RAP, was only suitable for use as subgrade/fill material for flexible pavement construction, according to TRL [24]. This is because its plasticity index is greater than 12% and its soaked CBR is less than 30%. However, upon application of 4, 8, and 12% RAP, the plasticity index and soaked CBR became less than 12% and greater than 30%, respectively; making the lateritic soil-RAP blends suitable for use as sub-base material.

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