Strength And Compaction Characteristics Of Bitumen-Stabilized Granular Soil

Olumide Moses Ogundipe

Abstract— This study investigates the stabilization of granular soil with bitumen. The strength and compaction characteristics of the natural and stabilized granular soil were determined. In the study, 2%, 4% and 6% bitumen content were considered. The results showed that the optimum binder content required in achieving the highest maximum dry density (MDD) and California bearing ratio (CBR) is 4%. It was discovered that when 6% bitumen was used, the MDD and the CBR decreased, although the values obtained were greater than those for unstabilized granular soil. The reduction in the MDD and CBR is probably due to the excess bitumen in the mix which filled the voids, thus resulting in slip and weakening the bond between the aggregates. Also, the relationship between the optimum moisture content and the bitumen content showed that the moisture content in the soil must be considered in the selection of the binder content that will give the best results. Generally, it was found that the properties of the granular soil improved when stabilized with cutback bitumen.

Index Terms— Stabilization, Granular soil, Bitumen, Maximum dry density, Optimum moisture content, California bearing ratio.

1 INTRODUCTION

Bituminous stabilization is the method of improving the properties of soil by admixing a bituminous material. Harris et al, [1] reported that bituminous stabilization for the construction of road bases has become increasingly used in developing countries in the last 30 years, particularly in areas characterized by cohesionless soils and which are poor in aggregate sources. Bituminous stabilization is generally accomplished using straight run bitumen, cutback, bitumen emulsion or foamed bitumen. This stabilization method not only improves the cohesion of the soil, but it also performs waterproofing function. For a coarse-grained non-plastic soil, the bituminous material adds cohesive strength, while for a cohesive soil, it waterproofs the soil and maintains its strength. According to USACE [2], the type of bitumen to be used depends upon the type of soil to be stabilized, methods of construction, and weather conditions. Kendall et al reported the successful use of foamed bitumen for soil stabilization. They attributed the success recorded in the use of foamed bitumen to its ease and speed of construction, its compatibility with a wide range of aggregate types and its relative immunity to the effects of weather. Bissada [3] investigated the ability of foamed-asphalt to stabilize local marginal sand aggregates for use as base and subbase materials in Kuwait. He found that the effectiveness of the foaming process was found to be more pronounced at pavement service temperatures above 30°C. In terms of subgrade deformation, he stated that the foamed-asphalt base and subbase layers under the assumed local curing conditions are superior to unbound materials such as sand-gravel mix. Harris et al [1] stabilized representative samples of subgrade sand with 80/100 penetration bitumen and found that only a small proportion of the samples achieved specified Marshall stability. They investigated further the effect of adding coarse sand to mixtures and discovered that the coarse sand improved density but not stability.

- *Dr. Ogundipe is currently a Senior Lecturer in Civil Engineering Department, Faculty of Engineering, Ekiti State University Ado-Ekiti, Nigeria*
- *E-mail: olumide.ogundipe@eksu.edu.ng*

The investigation showed that the required Marshall quotient would be satisfied by a mix containing, for example, 5% rapid curing (RC2) plus 5% water. In general, they found Marshall stability and compacted density increased with increasing total fluids content, thus demonstrating the importance of the fluid content. Aiban [4] reported that Al-Abdul Wahhab et al. investigated the use of blends of dune sand-crusher fines stablilized with emulsified asphalt in low volume roads in Saudi Arabia. They stated that .such road was weak and unstable, and that addition of crusher fines and Portland cement improved the mix properties significantly.Huan et al [5] carried out tests on the stabilization with foamed bitumen and lime. In their research, mix designs in which four different aggregate mixtures treated with three different foamed bitumen contents compacted with 1% hydrated Lime at 100% of optimum moisture content and cured for 7 days at room temperature were observed under laboratory conditions. Their indirect tensile strength test and unconfined compressive strength test showed that 75% Crushed Rock Base (CRB) and 25% Crushed Limestone (CLS) attained the highest values when treated with 3% foamed bitumen. The results of their resilient modulus test and permanent deformation test indicated that with an increased content of foamed bitumen, stiffness decreased and failure became serious, indicating that the optimum value of the foamed bitumen must be known to achieve suitable results.This study looks at the stabilization of granular soil with cutback bitumen. The impacts of the stabilization on the strength and compaction characteristics of granular soil were evaluated.

2 MATERIALS AND METHODS

2.1 Materials

The materials used in the study are sand, cutback bitumen and water. The granular soil was collected along Iworoko-Ifaki Ekiti road, Ekiti state, Nigeria. Cutback bitumen, medium curing type (MC1) was used for the stabilization. The base binder in the MC1 was 60/70 bitumen. The MC1 was produced by blending 60% of the 60/70 bitumen with 40% dual purpose kerosene (DPK). The typical specification of the 60/70 bitumen is shown in Table 1. Water fit for drinking was used to ensure there were no deleterious substances.

Table1: Typical specifications for 60/70 bitumen

Characteristics	Test Method	Unit	Min.	Max.
Specific gravity @ 25^{o}C	ASTM D70	^{o}C	1.01	1.06
Penetration @ 25^{o}C	ASTM D5	mm	60	70
Drop in penetration after heating	ASTM D5	%		20
Solubility in Trichloroethylene	ASTM D2042	%	99	
Flash point	ASTM D92	^{o}C	230	
Softening point	ASTMD36	^{o}C	46	56
Loss on heating	ASTM D6	%		0.2
Ductility @ 25^{o}C	ASTM D113	cm	100	

2.2 Methods

The following tests were carried out on the natural soil sample: mechanical sieve analysis, specific gravity, moisture content and Atterberg limit test (Liquid limit, plastic limit and shrinkage limit) Also, the natural and the bitumen-stabilized samples were subjected to compaction and California bearing tests.

2.2.1 Mechanical sieve analysis

The sample was dried, weighed and sieved through a series of sieves. The portion retained on each sieve was weighed and the percentage passing each sieve was calculated. The method of dry sieving is detailed in BS 1377[6].

2.2.3 Specific gravity

The specific gravity was determined using the pyknometer method. The sample was oven-dried at 105^{o}C and was weighed in the pyknometer with and without water. The test was carried out in accordance with BS 1377 [6]. The specific gravity was calculated as shown in equation 1.

$$Gs = \frac{m2\text{-}m1}{(m4\text{-}m1)(m3\text{-}m2)} \quad (1)$$

Where m_1 = mass of container (g); m_2 = mass of the container and soil (g); m_3 = mass of container, soil and water (g) and m_4 = mass of container and water (g)

2.2.4 Moisture content

This test involves measuring the weight of the soil sample collected and sealed in the polythene to prevent the loss of moisture. Then, the soil was dried at 105^{o}C and the natural moisture content calculated as shown in equation 2. The test was carried out in accordance with BS 1377 [6].

$$\text{Moisture content, } w\,(\%) = \frac{M_w}{W_d} \quad (2)$$

(2)

Where, Ww = Weight of water and W_d = Weight of dry soil

2.2.5 Atterberg limit tests

The plastic limit is the moisture content at which the soil begins to crumble when rolled under the palm of the hand into 3mm thread. The liquid limit is the moisture content at which a soil passes from the liquid to plastic state [7]. This involves measuring the depths of penetration, after 5s, of an 80g standardized cone into a soil pat, at various moisture contents. The moisture content corresponding to a cone penetration of 20mm as determined from moisture content versus depth of penetration graph is taken as the liquid limit. The tests were conducted in accordance with BS 1377 [6].

2.2.6 Compaction test

The standard Proctor test was adopted for this study. This involves compacting air-dried soil sample into a cylindrical mould. With the standard Proctor test, a 50mm diameter, 2.5kg metal rammer was dropped through 300mm for 27 blows onto each of the three layers of soil in the mould. The mass of the soil was determined and its bulk and dry densities calculated as shown in equations 3 and 4, respectively. The process was repeated until the mass of the soil in the mould was less than the preceding measurement. The test procedure is described in BS 1377 [6].

$$\text{Bulk density, } \ell \text{ (kg/m}^3\text{)} = \frac{Ma - Mb}{\text{Volume of mould}} \quad (3)$$

Where, M_a = Weight of mould + compacted soil; and M_b = Weight of mould

$$\text{Dry density (kg/m}^3\text{)} = \frac{\ell}{1+w} \quad (4)$$

where ℓ = bulk density and w = moisture content

2.2.7 California bearing ratio (CBR) test

This test was used to assess the strength of the natural and bitumen-stabilized soil samples. The test involves compaction of the samples in the CBR moulds at the optimum moisture content determined from the compaction tests. The plunger of the CBR machine was made to penetrate the compacted soil at a rate of 1mm per minute. The penetration of the plunger was measured by a dial gauge and readings of the applied force were read at intervals of 0.25 mm to a total penetration not exceeding 7.5 mm. The CBR was calculated as shown in equation 5. The test procedure is detailed in BS 1377 [6].

$$CBR = \frac{Test\,load}{S\tan dard\,load} \times 100\% \quad (5)$$

3 RESULTS AND DISCUSSIONS

The result of the sieve analysis (see Figure 1) shows that about 1.89% of the sample passes the sieve number 200 (75 μm sieve). This shows that the soil contains small amount of silt or clay. The Atterberg limit tests show that the soil is non-plastic, indicating that the fine portion of the soil is silt. The AASHTO classification system shows that the soil belongs to group A-1 and sub group A-1-b as the percentage of the sample passing sieves No 40 (0.425mm) and No 200 (0.075mm) are within the specification of 50 maximum and 25 maximum, respectively. This indicates that the soil with a coefficient of uniformity of 7.5 can be classified as well graded and it is rated as excellent subgrade material. The result of the specific gravity test of the soil sample is as shown in Table 2. The specific gravity for the soil was found to be 2.78.

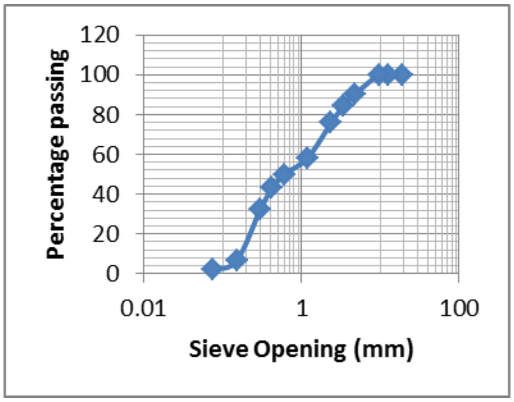

Figure 1: Particle size distribution curve of the soil sample

Table 2: Specific Gravity of Natural Soil

Sample	A	B
Weight of density bottle, m_1(g)	23.5	23.5
Weight of density bottle + soil, m_2(g)	527.5	535
Weight of density bottle + soil +water, m_3(g)	1136.8	1145
Weight of density + water (full), m_4(g)	816.3	816
Specific gravity	2.75	2.80
Average specific gravity	2.78	

The moisture content results of the soil are shown in Table 3. The average value of 21.2% is very high for a granular soil (sand) which is known for poor water retention. The high value could be because the sample was collected during the raining season. Figure 2 shows the relationship between the maximum dry density (MDD), optimum moisture content (OMC) and bitumen content. It shows that the OMC required in achieving the MDD increases with decreasing bitumen content. This implies that the amount of moisture in the soil is an important consideration in getting the optimum fluid content (water and bitumen) required to achieve the best results. Also, Figure 2 shows that the MDD increases with addition of 2% and 4% bitumen content but decreases with the addition of 6% of bitumen, which is thought to be because of the excess fluid content. This is in agreement with the findings of Huan et al [5] that excess bitumen will result in the reduction of stiffness of the mixture. The highest MDD was achieved with the addition of 4% bitumen content. It can also be seen that the addition of 6% bitumen required less OMC while addition of 2% and 4% bitumen required more OMC than the natural soil.

Table 3: Moisture Content of the natural soil sample

Sample No	A	B	C
Container no (cup)	3	33	1
Mass of cup + wet soil	153.1	127.2	118.6
Mass of cup + dry soil	127.6	108	100.6
Mass of cup	16.3	10.3	16.5
Mass of dry soil, M_s	111.4	97.7	84.15
Moisture content, w%	22.8	19.6	19.7
Average Moisture content, w%	21.2%		

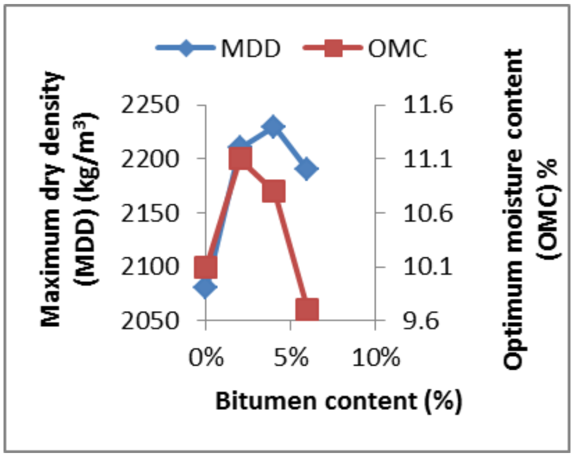

Figure 2: The relationship between maximum dry density, optimum moisture content and bitumen content

The California bearing ratio (CBR) results for the natural granular soil and the bitumen-stabilized granular soil is shown in Figure 3. The CBR of the natural soil was 88%, confirming the classification of the soil, which shows that it is a well graded and rated as excellent for use as subgrade material. Also, this indicates that the soil is good in his natural state as either a subbase or base material. However, the results show that the CBR of the soil increases with addition of bitumen. The maximum CBR was obtained with the addition of 4% bitumen, while a reduction in strength was observed when 6% bitumen content was added, although the strength was greater than that measured in the natural soil. This further confirms that excess bitumen impacts negatively on the properties of the stabilized soil. The addition of 4% bitumen resulted in almost 100% increase in strength. This will have a significant effect on the design of the asphalt pavement. It may be possible to make substantial savings in the surfacing by reducing its thickness because of the improved properties of the lower layers.

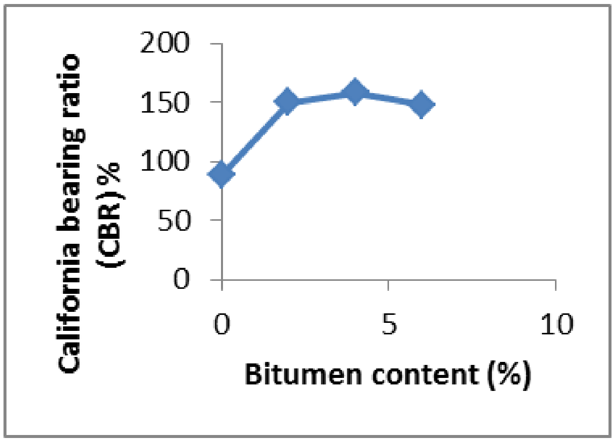

Figure 3: California bearing ratio results

4 CONCLUSIONS

The strength and compaction properties of granular soil stabilized with cutback bitumen were investigated. The results of the study showed that the properties were improved with the addition of bitumen. The maximum dry density (MDD) and the California bearing ratio (CBR) increased with increasing bitumen content with the best results obtained when 4% bitumen content was used. It was found that excess bitumen caused reduction in the MDD and CBR of the stabilized soil. This is attributed to the fact that a low but adequate (optimum) binder is needed for a mixture with good load bearing capacity and resistance to permanent deformation. Excess bitumen in the stabilized soil will fill the void, reducing the air voids. Under load, this leads to deformation because unlike air the binder cannot change in volume, therefore carrying more load than it can sustain. It is also important to consider the moisture content of the soil before it is stabilized with bitumen. Further studies (finite element modeling) are being carried out to evaluate the impact the improvement in MDD and CBR could have in terms of savings from the reduction in thickness of pavement surfacing material.

REFERENCES

[1] Harris, V. A. P., Hitch L.S. and J.M. Jowett, Bituminous stabilization of fine sands: construction of the Baiomori-Gashua road, Nigeria. Proc. Institution of Civil Engineers Part 1, 74 (1983), 270-300.

[2] USACE, Stabilization with Bitumen. United States Army Corps of Engineers. EM 1110-3-137, 1984.

[3] Bissada A.F, Structural Response of Foamed-Asphalt-Sand Mixtures in Hot Environments. Transportation Research Record 1115, 1999.

[4] Aiban S.A., A study of Sand Stabilization in Eastern Saudi Arabia. Engineering Geology, 38 (1994), 65-79.

[5] Huan Y., Siripun K., Jitsangiam P. and H. Nikraz, A preliminary study on foamed bitumen stabilisation for Western Australian pavements. Scientific Research and Essays 5(23), (2010) 3687-3700.

[6] BS 1377, Method of Test for Soils for Civil Engineering Purposes, British Standard Institution, London, 1990.

[7] O'Flaherty C.A,, Highways: The Location, Design, Construction and Maintenance of Pavements. 4th Edition, Butterworth-Heinemann, Oxford, United Kingdom, 2002.