PHYSICAL PROPERTIES OF SUBGRADE SOILS FROM NIGERIAN HIGHWAY MASTER TEST SECTION 1 (KANO-KADUNA REGION)

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ABSTRACT
Subgrade materials from Master Test Section (MTS) 1 were tested to obtain their physical properties. Three samples each from the MTSs making a total eighteen (18) samples were obtained and subjected to laboratory test to determine their basic physical properties. Testing include particle size distribution, Atterberg limits and specific gravity tests. The samples were classified according to American Association of State Highway and Transportation Officials (AASHTO) and the Unified Soil Classification System (USCS). The AASHTO soil classification shows that the subgrade soil samples obtained from the MTS 1 were either clayey soil (A-6 and A-7-6) or silty soils (A-4, A-5 and A-2-4). The AASHTO soil classification generally showed that the subgrade samples were "Fair to Poor" in subgrade properties for use as construction materials. The USCS soil classification indicated that most of the samples were lean clay soil with gravel (CL) except few that were either clayey gravel (GC) or clayey sand (SC). This showed that the subgrade samples were mostly clay soil.

Keywords: *Soil Gradation, Atterberg Limits, Specific Gravity, Subgrade soils, Linear Shrinkage, Soil Classification.*

1.0 Introduction

Flexible Pavement is usually composed of several asphalt concrete layers, a granular base course and a soil subgrade (Smolen, 2003; AASHTO, 1993).

Pavements fail for different reasons; poor design, poor materials and poor construction methods are the most common. The pavement foundation (subgrade) represents one of the key elements in the pavement design; its behaviour will influence the overall pavement performance (Ibrahim, 2013).

Material characterization is vital to pavement analyses and has received increasing focus as it forms a critical component in recent improvements to engineering practices. Material characterization is a basic aspect of pavement engineering and is critical for analysis, performance prediction, design, construction, quality control/quality assurance, pavement management, and rehabilitation (Hossain, 2010; Rao, et al., 2012).

Subgrade characterization allows for the design of a proper foundational support for the pavement (Hossain, 2008). Physical properties of subgrade materials that identify the material response to external stimuli of traffic loading and environmental conditions are very import in characterization of subgrade materials using resilient modulus. The physical properties (fines content) of the subgrade material had been shown to have significant influence on the stress-deformation characteristics under short duration repeated loads (Sheng, 2010).

The primary objective of the laboratory experimental program was to evaluate the physical properties of the subgrade soil samples.

2.0 Materials and Method

2.1 Materials

The soils tested in this study to determine their basic physical properties were selected to provide a general representation of typical subgrade soils found in Kano-Kaduna region (MTS 1). Figure 1 shows the Master Test Section (MTS) 1. The MTS 1 consist of six sections. Three (3) samples each was obtained at 500mm depth from each of the six sections. A total of eighteen (18) subgrade soil samples was obtained and taken to the laboratory to determine their basic physical properties.

2.2 Methods

The primary objective of the laboratory experimental program was to evaluate the physical properties of the subgrade soil samples. To achieve the objective, samples of soil material were subjected to laboratory experimental program which includes the test materials and the engineering property analysis. The subgrade soil samples were subjected to standard laboratory tests using standard test procedures (AASHTO, 2003; BS 1377, 1990) to determine their physical properties. The soil properties determined in the laboratory include Atterberg limits, soil gradation and the specific gravity tests. The subgrade soil samples were then classified using Unified Soil Classification system and AASHTO Soil Classification system.

2.2.1 Atterberg Limits and Linear shrinkage of the Soil Samples

Atterberg limits were determined using the testing procedures (AASHTO T89, 2003; ASTM D 4318, 2000; BS 1377, 1990; AASHTO T90, 2003). The Liquid Limit was obtained by plotting the flow curve of the soil samples. The flow curve was made by plotting the individual moisture contents and the number of blows required to close the grooves, on a semi-logarithmic graph, for each of the points. A best-fit straight line was then drawn through the points. The moisture content corresponding to the intersection of the best-fit line with the 25-tap line was recorded as the Liquid Limit.

Figure 1: Map showing roads in Master Test Section 1 of Nigeria

The plastic limit was determined by alternately pressing together and rolling into a 3.2-mm diameter thread a small portion of plastic soil until its water content was reduced to a point at which the thread crumbles and can no longer be pressed together and re-rolled. The water content of the soil at this point was reported as the plastic limit.

The plasticity index was calculated as the difference between the liquid limit and the plastic limit. The PL and PI are to be reported to the nearest whole number. The plasticity index of the subgrade soil samples was calculated using Equation (1):

$$PI = LL - PL \qquad (1)$$

The linear shrinkage was determined in accordance with the testing procedures (AASHTO T92, 2003; BS 1377, 1990; ASTM D 427, 1999). On cooling, the length of the soil samples was measured with a ruler and the linear shrinkage was calculated using Equation (2):

$$Linear\ Shrinkage = \frac{(Initial\ length - Dried\ length)}{Initial\ length} \times 100 \quad (2)$$

2.2.2 Particle Size Distribution of the Soil Samples

The analysis of soils by particle size provides a useful engineering classification system from which a considerable amount of empirical data can be obtained. Soil gradation was conducted on the soil samples in accordance with testing procedures (AASHTO T88, 2003; BS 1377, 1990; ASTM D 422, 1998).

2.2.3 Specific Gravity of the Soil Samples

The specific gravity tests was conducted on the s soil samples in accordance with testing procedures (AASHTO T100-03, 2004; BS 1377, 1990; ASTM D 854, 2000). The specific gravity is calculated using Equation (3):

$$G_s = \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_1)} \qquad (3)$$

2.2.4 Soil Classification of the Soil Samples

The soil samples was classified using Unified Soil Classification System (USCS) and AASHTO Soil Classification. The USCS was in accordance with American Society for Testing and Materials (ASTM) standard (ASTM D 2487-98, 2000). The AASHTO Soil Classification system was in accordance with AASHTO M145 (AASHTO M145-91, 2004).

3.0 Results and Discussion

3.1 Determination of Atterberg Limits and Linear shrinkage of the Soil Samples

Table 1 show the summary of Atterberg limits and linear shrinkage test results of the soil samples. As shown in Table 1, the liquid limit of the soil samples ranged from 29 to 45 with plasticity index ranging from 8 to 19. Table 1 indicated that most of the soil samples were materials with a high liquid limit and plasticity index. This provide an indication of the presence of clay in the soil samples and thereby will be unsuitable for many construction applications.

Table 1: Summary of Atterberg Limits and Linear shrinkage Test Results of the Soil Samples

Master Test Section	Liquid Limit (LL) (%)	Plastic Limit (PL) (%)	Plasticity Index (PI) (%)	Linear Shrinkage (%)
MTS 1-1	37	20	17	10.00
	39	24	15	8.57
	33	20	13	11.43
MTS 1-2	36	24	12	10.00
	29	21	8	8.57
	37	18	19	9.29
MTS 1-3	39	25	14	10.71
	36	26	10	7.14
	31	18	13	9.29
MTS 1-4	45	29	16	8.57
	42	25	17	10.71
	32	22	10	9.29
MTS 1-5	42	28	14	7.86
	41	31	10	8.57
	41	27	14	7.14
MTS 1-6	30	20	10	8.57
	35	21	14	8.57
	39	23	16	10.71

3.2 Determination of Particle Size Distribution of the Soil Samples

Figures 2 through 7 show the particle size distribution curve for the soil samples. Table 2 showed the summary of sieve analyses tests results of the soil samples.

As shown in Table 2, the percent of silt content in the soil samples ranged from 13.76% to 48.16% and the percent of clay content in the soil samples ranged from 8.48% to 69.28%. Also, Table 2 showed that most of the soil samples had more than 50% finer materials with smaller fraction of sand present and have particle sizes smaller than 75 μm. This indicate that the soil samples contains more of clay and silty materials than gravel and/or sand. This provides a useful information for the engineering classification of the soil.

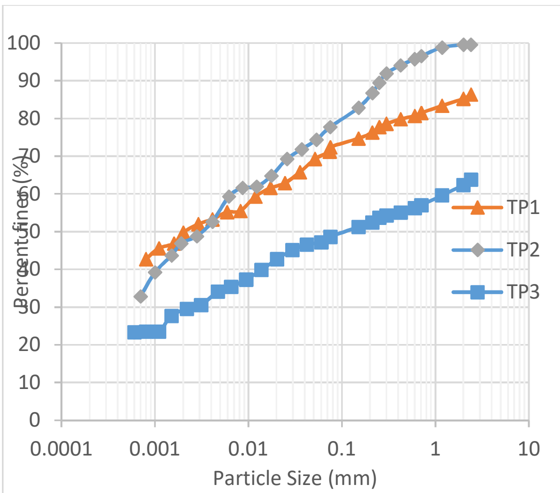

Figure 2: Particle Size Distribution Curve for MTS 1-1 Soil Samples

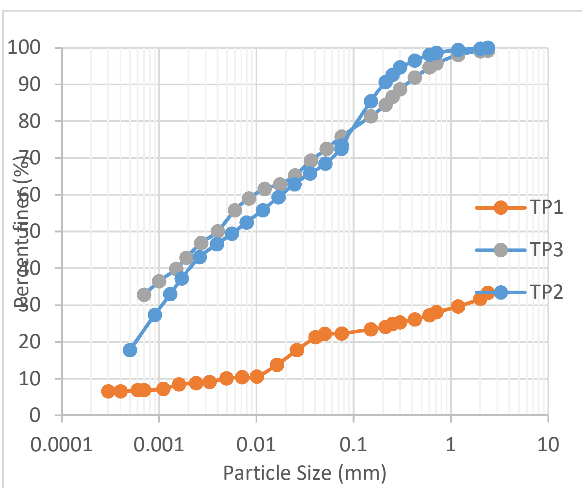

Figure 3: Particle Size Distribution Curve for MTS 1-2 Soil Samples

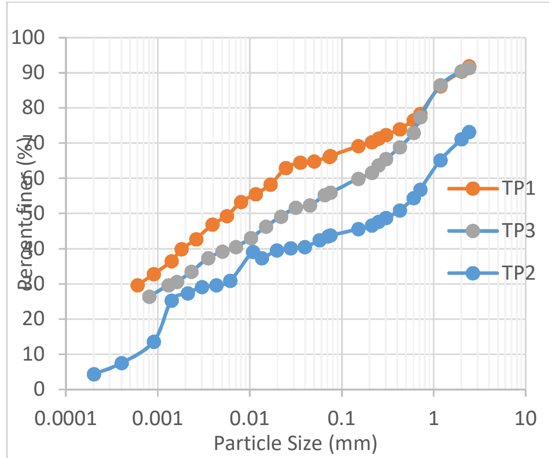

Figure 4: Particle Size Distribution Curve for MTS 1-3 Soil Samples

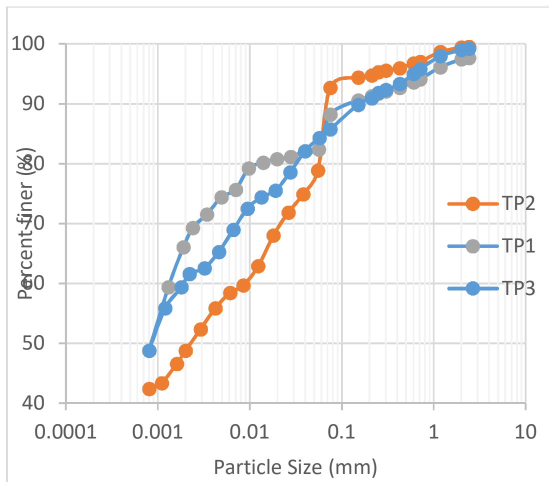

Figure 5: Particle Size Distribution Curve for MTS 1-4 Soil Samples

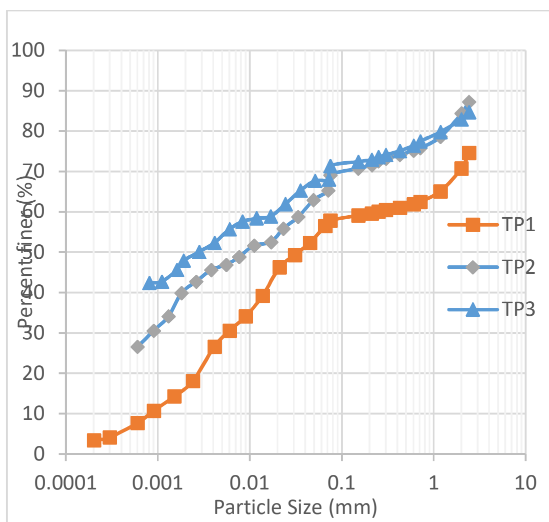

Figure 6: Particle Size Distribution Curve for MTS 1-5 Soil Samples

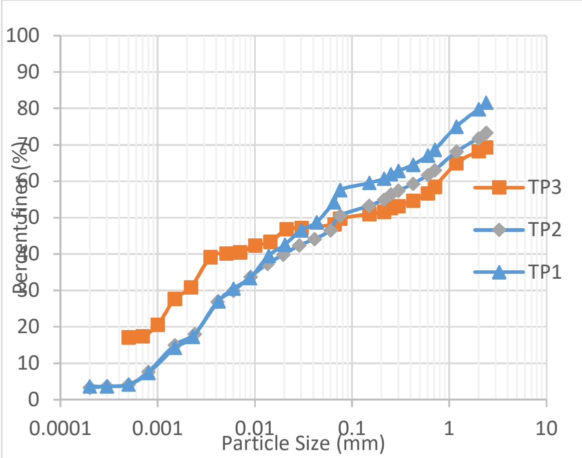

Figure 7: Particle Size Distribution Curve for MTS 1-6 Soil Samples

Table 2: Summary of Sieve Analyses Tests Results of the Soil Samples

Master Test Section	Passing #200 (%)	Passing #40 (%)	Passing #4 (%)	Clay (%)	Silt (%)
MTS 1-1	72.42	79.86	86.38	49.76	22.72
	77.76	94.12	99.64	46.88	30.88
	48.66	55.08	63.78	29.60	19.04
MTS 1-2	22.32	26.14	33.30	8.48	13.76
	73.38	96.42	99.94	37.28	36.16
	75.84	91.84	99.16	42.88	32.96
MTS 1-3	66.34	73.96	91.86	39.84	26.56
	43.76	50.88	73.14	27.36	16.48
	55.94	68.82	91.38	33.44	22.40
MTS 1-4	88.22	92.70	97.64	69.28	18.88
	92.70	95.96	99.52	48.80	48.16
	85.76	93.32	99.22	61.60	24.16
MTS 1-5	57.82	61.06	74.62	18.08	39.68
	69.08	74.10	87.20	42.72	26.40
	71.36	75.08	84.68	50.08	21.28
MTS 1-6	57.60	64.54	81.58	17.28	40.32
	50.48	59.34	73.32	18.08	32.32
	49.76	54.70	69.32	30.88	18.88

3.3 Determination of Specific Gravity of the Soil Samples

Specific gravity tests were conducted on the soil samples and the results were summarized in Table 3. As shown in Table 3, the specific gravity for A-4 group ranged from 2.46 to 3.31. The specific gravity for A-2-4 and A-5 groups were 2.57 and 2.50 respectively. The specific gravity for A-6 group ranged between 2.44 to 2.51. In the case of A-7-6 group, the specific gravity ranged from 2.53 to 2.58. Table 3 showed that the specific gravity of the soil samples are greater than one, thereby do not require special treatment.

3.4 Determination of Soil Classification of the Soil Samples

The soil samples was classified using USCS and AASHTO Soil Classification. Table 4 summarized the USCS and the AASHTO Classification of the soil. According to USCS and the AASHTO Soil Classification system, the soil type for each of the soil sample was identified on the basis of the results of Atterberg limit, and particle size distribution tests (see Table 1 and Figures 2 through 7). For the USCS, most of the soil samples belongs to the group of CL (low plasticity clay). The USCS identifies that the soil samples are fine-grained soils and mostly clay. The AASHTO soil classification shows that the soil samples belongs to Clay (A-6 and A-7-6) or silty soils (A-4, A-5 and A-2-4) group.

Table 3: Summary of Specific Gravity Tests Results of the Soil Samples

MTS	Specific Gravity	Soil Type
MTS 1-1	2.51	A-6
	2.44	A-6
	2.49	A-6
MTS 1-2	2.57	A-2-4
	2.46	A-4
	2.51	A-4
MTS 1-3	2.46	A-4
	3.31	A-4
	2.51	A-6
MTS 1-4	2.54	A-7-6
	2.55	A-7-6
	2.55	A-4
MTS 1-5	2.58	A-7-6
	2.50	A-5
	2.53	A-7-6
MTS 1-6	2.58	A-4
	2.46	A-6
	2.47	A-4

Table 4: The USCS and the AASHTO Classification Results of the Soil Samples

Master Test Section	USCS	AASHTO
MTS 1-1	CL (Lean clay with gravel)	A-6 (clayed soils)
	CL (Lean clay with gravel)	A-6 (clayed soils)
	GC (Clayed Gravel)	A-6 (clayed soils)
MTS 1-2	GC (Clayed Gravel)	A-2-4 (Silty or clayed gravel sand)
	CL (Lean clay with gravel)	A-4 (Silty soils)
	CL (Lean clay with gravel)	A-4 (Silty soils)
MTS 1-3	CL (Gravelly lean clay)	A-4 (Silty soils)
	SC (Clayed Sand)	A-4 (Silty soils)
	CL (Gravelly lean clay)	A-6 (clayed soils)
MTS 1-4	CL (Lean clay)	A-7-6 (clayed soils)
	CL (Lean clay)	A-7-6 (clayed soils)
	CL (Lean clay)	A-4 (Silty soils)
MTS 1-5	CL (Gravelly lean clay)	A-7-6 (clayed soils)
	CL (Gravelly lean clay)	A-5 (Silty soils)
	CL (Lean clay with gravel)	A-7-6 (clayed soils)
MTS 1-6	CL (Gravelly lean clay)	A-4 (Silty soils)
	CL (Gravelly lean clay)	A-6 (clayed soils)
	GC (Clayed Gravel)	A-4 (Silty soils)

4.0 Conclusions

Based on the results of this study, the following conclusions were reached:

1. The soil samples were materials with a high liquid limit and plasticity index. This provide an indication of the presence of clay in the soil samples and thereby will be unsuitable for many construction applications.

2. The soil samples had more than 50% finer materials with smaller fraction of sand present and have particle sizes smaller than 75 µm. This indicate that the soil samples contains more of clayed and silty materials than gravel and/or sand.
3. The AASHTO soil classification shows that the soil samples belongs to Clayed soil (A-6 and A-7-6) or silty soils (A-4, A-5 and A-2-4) group. This showed that the subgrade soil samples were "Fair to Poor" in subgrade properties.
4. For the USCS, most of the soil samples belongs to the group of CL (low plasticity clay). This identifies that the soil samples are fine-grained soils and mostly clay.

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