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GEOTECHNICAL CHARACTERISTICS OF SYNTHETIC MUNICIPAL SOLID WASTE FOR EFFECTIVE LANDFILL DESIGN

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ABSTRACT: This paper presents the results of laboratory investigation performed to determine the geotechnical characteristics of synthetic municipal solid waste (SMSW); simulating typical composition of municipal solid waste (MSW) generated in Akure metropolis, south-western Nigeria. It was generally observed that the unit weight, specific gravity and shear strength of the SMSW increased with increase in compactive effort. Direct shear tests gave cohesion value of 7.6kN/m^3 for both Modified AASHTO and 4x Modified AASHTO compaction methods, while angle of shearing resistance for Modified AASHTO compaction method was 42.4^0, and 48.5^0 for 4x Modified AASHTO compaction. In design of landfills the least shear strength failure envelope should be used for effective design. The hydraulic conductivity for both compactive efforts were within the same order of magnitude indicating that the Modified AASHTO compaction was a good approximation of field compaction for the municipal solid wastes. Compressibility test on SMSW gave compression ratio of 0.20 with total compression of 33.0% under maximum load of 224kN/m^2. this complies with the results reported in literature. Compression index (c_c) was 0.4, initial compression ratio (r_0) was 0.19, primary compression ratio (r_p) was 0.71 and secondary compression ratio (r_s) was 0.10. These provide the necessary information needed for the computation of expected settlement in the landfill.

Keywords: Synthetic municipal solid waste, Geotechnical characteristics, Shear strength, Hydraulic conductivity, Compactive effort.

1. INTRODUCTION

Municipal solid wastes (MSW) as waste materials typically consist of food wastes, garden wastes, paper products, plastic, textiles, woods, metal, construction demolition wastes and soil, However, the composition of MSW varies from region to region and it depends upon lifestyle, demographic features and legislation [1].The disposal of municipal solid waste (MSW) in the world is a problem that continues to grow with the growth of population and the development of nations. Since the beginning of the time people have needed to find a way of disposing their refuse. As far back as 18th century in England and France, Carters were paid by individuals to carry refuse and discard it in the outskirts of cities. Disposal of waste in open pit became a routine and Benjamin Franklin initiated the first municipal cleaning program in Philadelphia in 1757 [2].

The methods of waste disposal have continued to change with development and advancement of industrialized nations. In recent time wastes are not simply dumped into an open pit, due to health hazard posed by them and adverse environmental impact; hence, modern methods of disposing MSW were generally adopted. Sanitary landfill is the most common method of MSW disposal and probably accounts for 54% of United States MSW disposal, though it has been proven to be responsible for contamination of portable water in certain areas [3]. It is the most cost effective method of waste disposal adopted by most nations of the world compared to other waste management techniques, such as incineration and composting. Although, waste management authorities advocate recycling and reuse of waste material, many countries worldwide prefer land filling of MSW as an economic option [1]. However, in Nigeria the most populous black nation in the world, sanitary landfill design and construction is not yet embraced as expected. This modern form of waste management technique should be considered in view of the deleterious environmental effects of open waste dumping on the geo-environment especially the surface water and underground water resources. It must be stressed that open dumping is still prevalent in most parts of Nigeria with the concomitant health consequences of this poor environmental management technique.

Integrity, sustainability and potential for future land reclamation of closed landfills depend upon the geotechnical characteristics of MSW stemming from the engineering properties of its constituents/elements. Though the failure of sanitary landfill may not be rampant, it does occur in different parts of the world. Modes of failure associated with; landfill sub-grade, waste and lining system was reported by [4]. Table 1 shows the engineering properties of MSW required for effective design of sanitary landfill.

Table 1 Engineering properties of MSW required for design [4]

Design case	Unit weight	Vertical compressibility	Shear strength	Horizontal in-situ stress	Hydraulic conductivity
Sub-grade stability	X		X	X	
Sub-grade integrity	X		X	X	
Waste slope stability	X	X	X		X
Shallow slope linear stability	X		X	X	X
Shallow slope linear integrity	X	X	X	X	
Steep slope linear stability	X		X	X	X
Steep slope linear integrity	X	X	X	X	
Cover system integrity	X	X	X		
Drainage system integrity	X			X	
Leachate/gas well integrity	X	X	X	X	X

2. MATERIALS AND METHODS

2.1 Study Area

MSW generated within Akure was selected for this study. Akure is a growing urban area within latitudes 7° 10'N and 7° 20'N and between longitudes 5^o 07'E and 5^o 17'E in Ondo State, Nigeria. The mean annual temperature ranges between 24^oC -27^oC, while the annual rainfall, varies between 1500mm and 3500mm.

2.2 Municipal Solid Wastes Composition

MSW sampled from various parts of Akure contain approximately the following components by weight: 10% paper and cardboard, 54.0% food and other putrescible materials, 12.5% plastic, nylon and rubber, 4.3% metal and aluminium, 2.0% glass, 6.0% wood, 5.2% textiles and leather and 6.0% of soil like waste. Some previous studies have used synthetic municipal solid wastes (SMSW) to investigate the engineering properties of MSW [1], [5], [6] and [7]. Various components were further grouped into biodegradable and non biodegradable components according to [8]. These components were used for preparation of SMSW used in this study. The maximum aggregate size of the components was limited to 15mm to facilitate the use of conventional geotechnical testing equipments. Table 2 shows the SMSW composition used for this study.

Table 2 SMSW composition of Akure metropolis

Compositions	%	Material used
Non biodegradable	30	Gravelly lateritic soil
Biodegradable		
Garden waste	20	Grass clipping
Vegetable waste	15	Green leaves
Cellulose non paper	14	White bread
Paper waste	16	Shredded paper
Meat	5	Ground pork meat

3. METHODOLOGY

Various tests carried out on SMSW samples are; moisture content, specific gravity, particle size distribution, compaction, compressibility and shear strength.

Moisture content

The moisture content of SMSW was determined according to Part 2:3 of [9]. The SMSW was oven dried with the oven temperature being maintained at 60^0 c to avoid combustion of volatile material.

3.1 Specific Gravity

The specific gravity of prepared SMSW was determined according to Part 2:8 of [9]. The specific gravity test was carried out on both fresh and dis-aggregated compacted SMSW to investigate their variation as reported by [10].

3.2 Particle size distribution

The grain size distribution of SMSW was determined using BS standard, according to Part 2:9 of [9]. The test was carried out on wet basis. The materials was washed using sieve No 200 (0.075mm), oven dried and sieved using BS set of sieves. After vigorous shaking for 10 minutes the material was allowed to settle down for 2 minutes and the weight of material retained on each sieve was recorded against it, and the percentage finer was determined. The sieve size was plotted against the percentage passing, on semi logarithm scale.

3.3 Compaction test

Compaction tests were conducted on prepared SMSW samples. The tests were conducted according to Part 4:3 of [9]. The two compactive efforts used are the Modified AASHTO and four times (4X) Modified AASHTO to simulate higher compactive effort needed for field compaction of MSW while still maintaining the framework of a standard test method as reported by [10]. Factors affecting compaction were investigated during the tests. The method used in addition of water is non pre-wetted method (NPW), where only the first water added to the loose sample of SMSW was allowed to hydrate it for 18 hours. Subsequent water added, for higher target moisture content was compacted immediately, without further hydration time.

3.4 Compressibility Test

Compressibility test was conducted on prepared SMSW samples with bulk unit weight of $8.2kN/m^3$ and moisture content of 50.3% in accordance with Part 5:3 of [9]. The oedometer used in this study was floating ring type with a circular brass ring of 60mm diameter and 20mm thickness, the specimen was compacted into the brass ring with porous stone at the top and bottom of the sample; compaction was done to get the initial bulk unit weight of the sample and the specimen was subjected to vertical load ranging from 0.01kN-0.64kN. Loading was done at 24 hours interval.

3.5 Direct shear test

The shear strength parameter of prepared SMSW was determined by conducting direct shear tests on specimens from each SMSW unit weight variation. The test was conducted in accordance with Part 7:5 of [9]. Shear box used in this research was square type. SMSW was compacted into shear box having 60mm lengths and 20mm height. SMSW specimens were tested under different normal stress conditions. Initial wet unit weights are $8.2kN/m^3$ and $11.1kN/m^3$; with moisture contents of 50.3% and 35% respectively from compaction result. Porous stones were place on the top and bottom of the sample content; vertical stress was applied to the sample and then sheared at a constant strain rate of 0.5mm/min.

3.6 Hydraulic conductivity

Hydraulic conductivity test was conducted on two sets of prepared SMSW samples with three samples from each set, based on the two unit weight variation from compaction tests. The test was conducted in accordance with BS 1377 Part 5:5 of [9]. The initial bulk/wet unit weights of the samples were arrived at by compaction of the SMSW samples in permeameter cell with tamping rod.

4. RESULTS AND DISCUSSION

4.1 SMSW Moisture Content

The average value of moisture content taken from SMSW was found to be 31.5%, this fall within the range (25%-70%) reported in literature [1], [3], and [11]. However, the oven temperature was maintained at 60^0c during oven drying to avoid combustion of volatile materials. Moisture content of waste depends on waste composition, climatic condition of the area, amount of organic content present in the waste and rate of decomposition. Therefore, higher moisture content is expected from older waste than for fresh waste; especially during decomposition process.

4.2 SMSW Specific Gravity

The specific gravity of SMSW determined ranged between 1.39 and 1.53. These comply with the range of values reported in published paper for fresh waste [10]. However It is noteworthy to know that, the value of specific gravity is a function of compactive effort, the percentage of soil like material present in MSW and degree of decomposition of the waste; hence the higher boundary of the range would be expected for waste subjected to higher compactive effort, with higher percentage of soil like material or waste which decomposition process have commenced.

4.3 SMSW Particle Size Distribution

The result of particles size distribution of SMSW shows that, approximately 30% of the sample was retained on 10mm sieve and remaining constituents are of sizes less than 10mm diameter. In addition to that, some of the materials used in generating synthetic waste are two dimensional; their sizes will not adversely affect the test results due to their relatively small thickness. Hence, SMSW used in this research would not over influence the results obtained using conventional equipment from soil mechanics laboratory. Figure 1 shows the graph of SMSW particles size distribution.

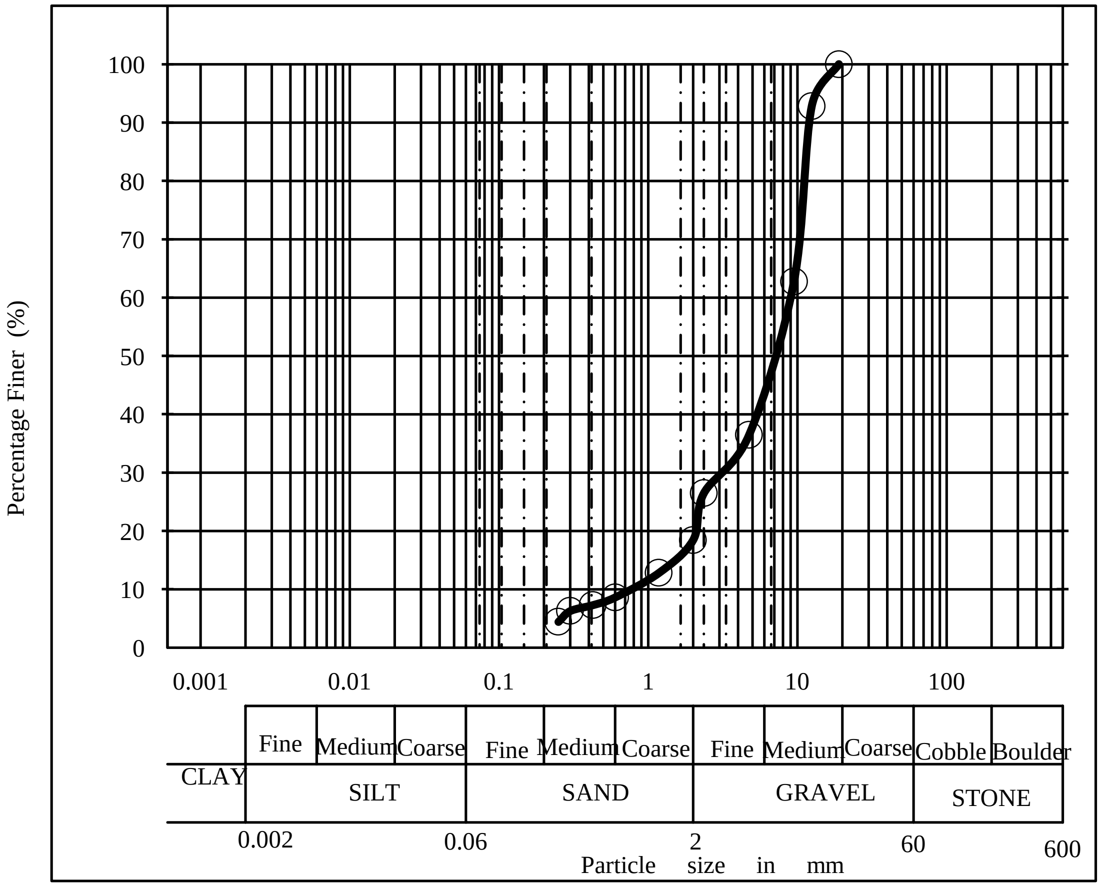

Fig. 1 SMSW particle size distribution curve

4.4 SMSW Compaction

The maximum dry unit weight for Modified AASHTO was 8.1kN/m^3, while that of 4X Modified AASHTO was 10.9kN/m^3; optimum moisture content for Modified AASHTO and 4X Modified AASHTO were 50.3% and 35% respectively. These values fall within the range of values reported in literature [10]. The curves for both methods are presented in Fig. 2.

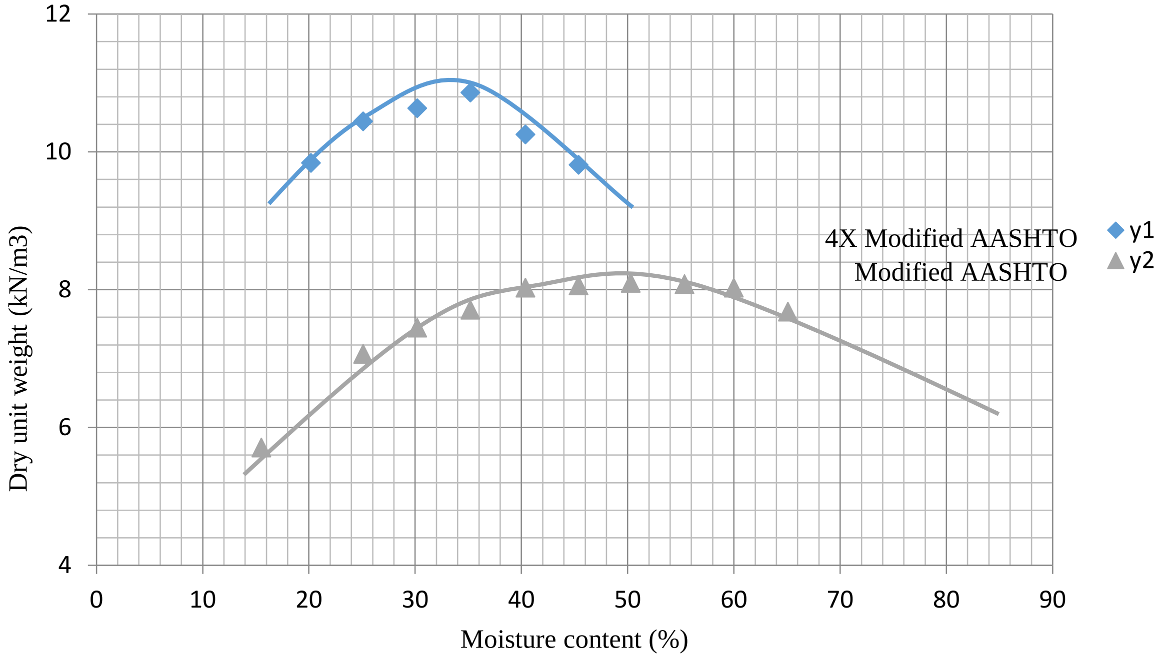

Fig. 2 SMSW compaction curve

The general shape of the compaction curves obtained for SMSW in the laboratory was consistent with the shape of compaction curves commonly obtained for soils. Dry unit weights increased with moisture content to a maximum value and then decreased with further increases in moisture content. Similar to soils, the additional solids content per unit volume was attributed to the lubrication of the particles from water addition, resulting in a denser packing arrangement. The water addition also produced a softening of the solid materials in wastes, increasing compressibility and decreasing rebound (significant for wastes) in response to compaction forces. The effectiveness of the moisture addition diminished at wet of optimum conditions as indicated by the decreasing dry unit weight (γ_d) due to the replacement of solids with water. In general, the relative locations of the compaction curves for low and high effort were similar to those for soils. However, the decrease in dry unit weight at high moisture content for wastes is not as prominent as that of soils because, the relative difference between unit weight of water and unit weight of solids is lower for wastes than for soils.

4.5 SMSW Compressibility

Compressibility test on SMSW resulted in compression ratio of 0.20 with total compression of 33.0% under maximum load of 224kN/m^2. This complies with the result reported in literature for fresh SMSW [1], [3], [5], and [7]. Compression index (Cc) was 0.4, initial compression ratio (r_0) was 0.19, primary compression ratio (r_p) was 0.71 and secondary compression ratio (r_s) was 0.10. These provide the necessary information needed for the computation of expected settlement in the landfill. However the effect of degradation due to decomposition of waste should be properly investigated as it may influence the amount of ultimate settlement.

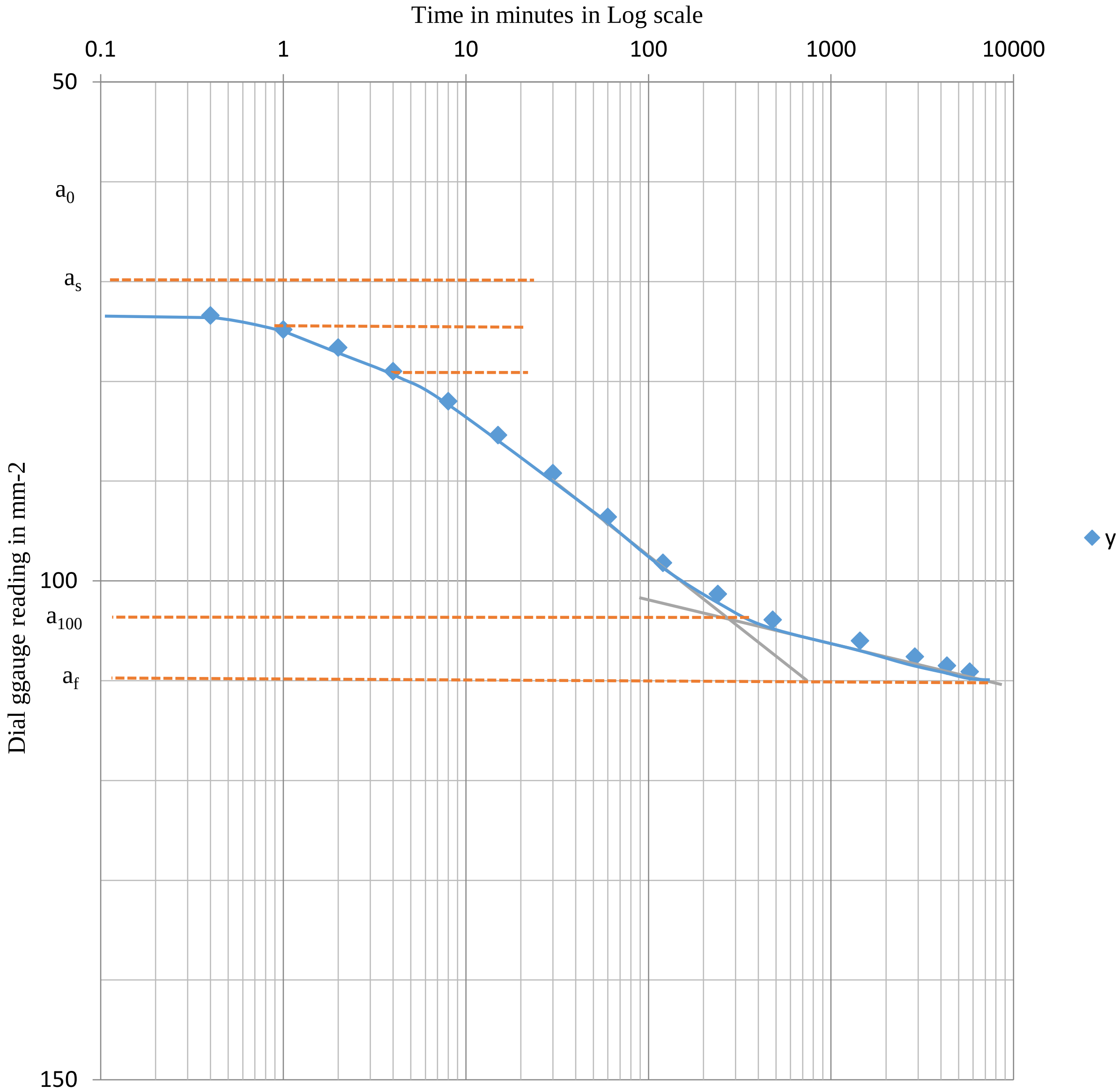

Fig. 3 SMSW Compression curve using Cassagrande's method

The initial compression ratio was calculated according to the following equations by [12].

$$r_o = \frac{a_o - a_s}{a_o - a_f} \quad (1)$$

Where r_o is the initial compression ratio; a_o is the start of compression process; a_s is the start of consolidation process and a_f is the limit of secondary consolidation process. The primary compression ratio can be expressed according to Eq. (2) shows below.

$$r_p = \frac{a_s - a_{100}}{a_o - a_f} \quad (2)$$

Also, r_p is the primary compression ratio; a_o , a_s and a_f are as defined in Eq. (1) while a_{100} is the limit of primary consolidation process. Equation (3) represents the expression for secondary compression (r_s), while r_o and r_p are as in Eq. (1) and Eq. (2).

$$r_s = 1 - (r_o + r_p) \quad (3)$$

4.6 Shear Strength

Direct shear tests resulted in cohesion of 7.6kN/m^3 for both Modified AASHTO and 4X Modified AASHTO compaction methods, while frictional angle for Modified AASHTO compaction method was 42.4^0, and frictional angle for 4X Modified AASHTO compaction method was 48.5^o as indicated in Figure 4. The shear strength failure envelope for the two compaction variation is shown in Figure 4. Cohesion is within the range of results reported in literature for fresh wastes, however the angle of internal friction for sample compacted using 4X Modified AASHTO (i.e. with $11.1 kN/m^3$ wet unit weight) was found to be slightly above the range reported in literature [13], [14], and [15]. This may be as a result of higher proportion of reinforcing component. Thus, in design of landfill the least shear strength failure envelope should be considered for effective design. The shear stress versus shear displacement plots for the two variants of compactive efforts hence degree of densification (indicated by bulk unit weight [γ_b]) for three normal stresses $13.9 kN/m^2$, $27.8 kN/m^2$ and $41.7 kN/m^2$ used for the direct shear test are presented in Figure 5. Shear stress versus horizontal displacement graph indicates a general bilinear plot for all normal stress values within the elastic zone. Plastic softening occurs close to the critical shear value, and the slope of shear stress versus horizontal displacement tends to flatten in the plastic zone.

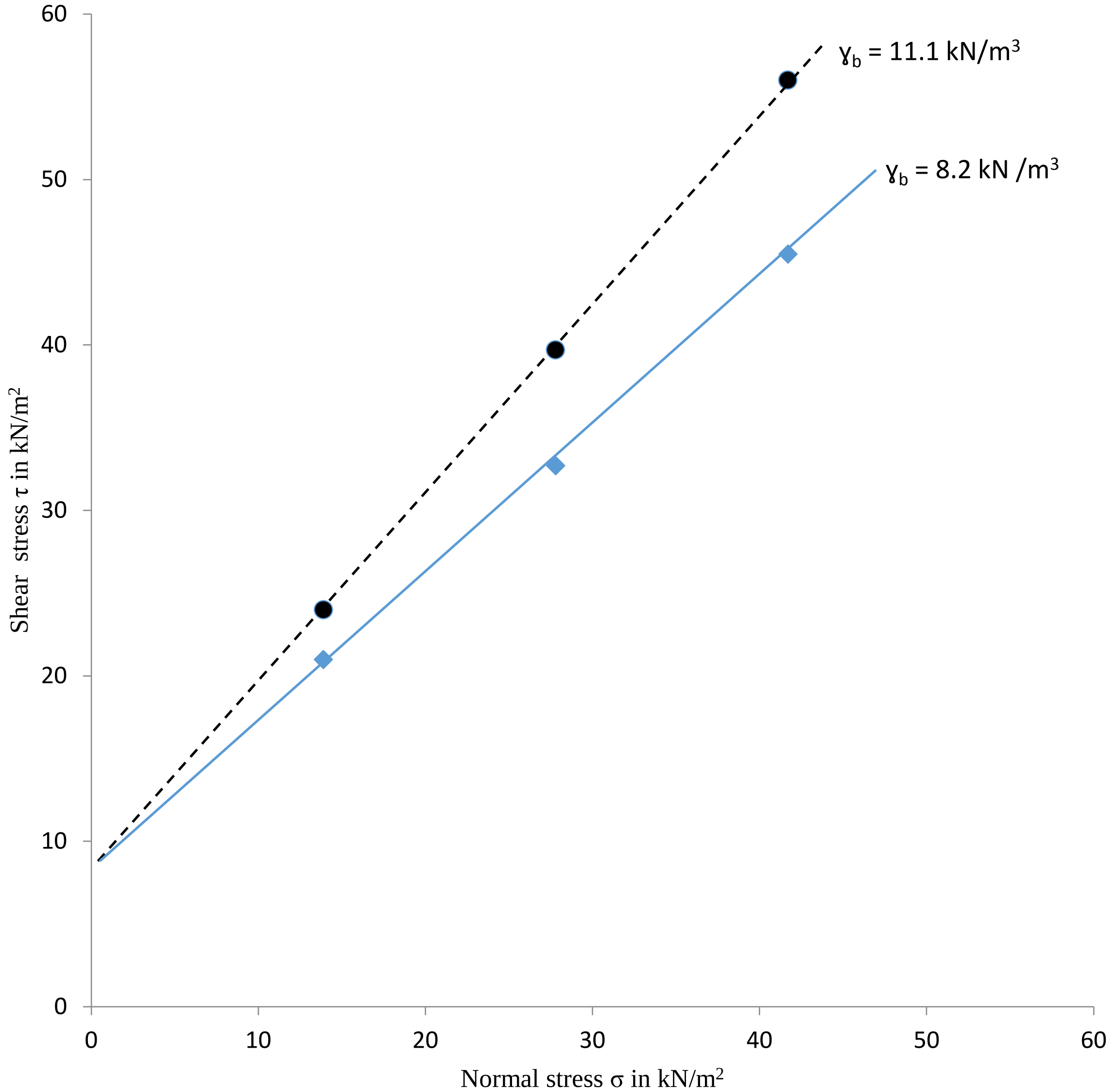

Fig. 4 SMSW shear strength failure envelope

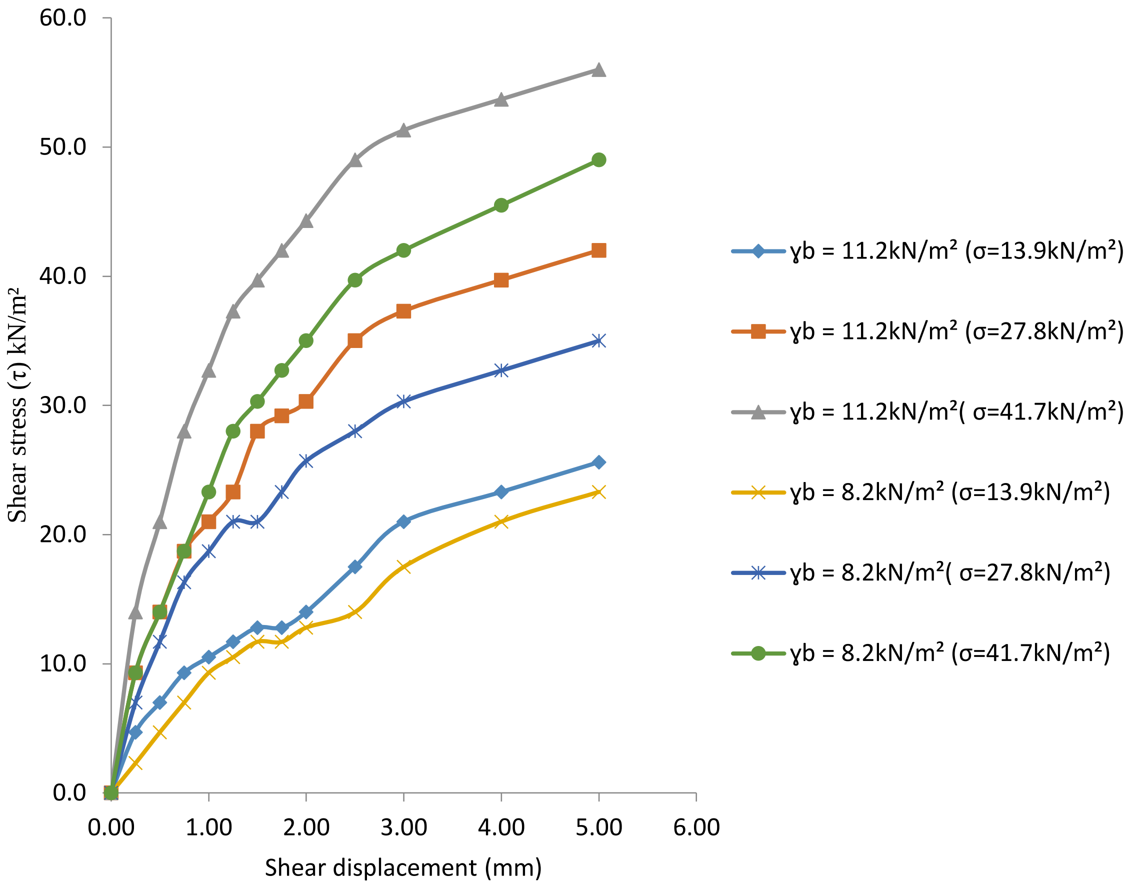

Fig. 5 SMSW shear stress curves

4.7 Hydraulic Conductivity

Municipal Solid Waste hydraulic conductivity is important to landfill designers because of the influence it has on Leachate pressure distributions in the waste body and hence on the magnitude and distribution of effective stresses and, therefore, on shear strength [16]. Since shear strength is inversely proportional to compressibility/compression, the combined effect of hydraulic conductivity and compression is simulated by the SMSW.

Average hydraulic conductivity value in this research was 2.16×10^{-6}m/s for samples with wet unit weight of 11.1kN/m^3 and, 2.04×10^{-6}m/s for samples with wet unit weight of 8.2kN/m^3. This shows that hydraulic conductivity values are relatively high, also only minimal variation in hydraulic conductivity was observed due to density change of the samples. Hydraulic conductivity of gravelly lateritic soil used to represent non biodegradable component of SMSW may be the reason for this behaviour. However, the results were within the range of hydraulic conductivity values as reported by [3], [17], [18] and [19]. A comprehensive report on waste hydraulic conductivity was given by [20].

5. CONCLUSION

This article presents the geotechnical characteristics of SMSW of Akure metropolis South-western Nigeria. The wide spread of indiscriminate dumping of MSW all over Akure metropolis has lead to environmental degradation and poses a great threat to public health. In finding a permanent solution to this menace, proper waste management technique is needed, hence the need for construction of a sanitary landfill. In construction of a stable sanitary landfill three most important factors are considered, the stability of the lining system, the stability of sub-grade and the stability of the waste materials itself. The strength characteristics of SMSW simulating typical composition of MSW generated in Akure metropolis was determined in this work.

Knowledge of unit weight of MSW is required for all aspects of landfill design as reported in the literature. Initially the unit weight of waste is dependent on waste composition, the daily cover and the degree of compaction during placement. Mechanisms resulting in settlement of waste include physical compression and creep, raveling, and decomposition due to biodegradation of organic components. For simplicity, the total settlement of a landfill can be taken as the combination of initial, primary and secondary compression. Initial compression includes reduction in voids due to removal of air. Primary compression includes the physical compression of components and consolidation. Secondary compression includes all creep effects and those relating to degradation. Knowledge of shear strength is required in order to assess the waste slope stability. Laboratory methods have been used widely but results from such studies should be interpreted carefully due to their association with disturbed samples. Out of the methods available, the direct shear box used in this work has been adjudged to produce the most reliable information. From the results of various test carried out on the SMSW the following conclusions could be drawn.

1) The unit weight of SMSW increased by 35% with 300% increase in compactive effort and specific gravity increased with 14%.
2) Shear strength of SMSW increases with increased unit weight (as a result of compaction), due to densification of the solids and increase in cohesion of wastes materials.
3) Compressibility of SMSW material is high; hence the expected settlement would be high.
4) Only minimal variation in hydraulic conductivity was observed due to density change of the samples.

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