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Mechanical Properties of Municipal Solid Waste in Lagos Metropolis, a Case Study of Ikeja

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Abstract

Studying the mechanical behavior of Municipal Solid Waste (MSW) is accompanied by many complications. This work attempts at studying some properties of municipal waste recovered from Ikeja Municipal Area in Lagos, Nigeria. Knowledge of the likely ranges of mechanical properties of waste is required to assess potential modes of failure and hence to design the landfill, as the stability of waste mass is one of the major concerns associated with the design of landfill expansion in Lagos. Mechanical properties such as green compression, permeability, bulk density, porosity and shear strength were determined experimentally for three different waste samples A, B and C at different moisture contents. The values of the experimental results for the different moisture contents are given as follows: green compression: Maximum 65 N/m^2, minimum 24 N/m^2; permeability: maximum 209.56cm/sec., minimum 73.17 cm/sec.; bulk density: maximum 2.364 g/cm3, minimum 0.6514 g/cm^3; porosity: maximum 204.09, minimum 83.19 and shear strength: maximum 85 N/m^2, minimum 45 N/m^2. The results obtained showed that green compression, shear strength, permeability, bulk density, and porosity all have varying values dependent on the constituents of the wastes. The results also showed that sample C has both the highest and lowest porosities. On a plot of experimental values obtained, all the sample wastes converge at the same point of moisture content of 25%. This shows that shear strength property becomes similar as moisture content increases. It can also be concluded that different moisture contents influence the mechanical properties of solid waste.

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1. Introduction

Ikeja is the capital of Lagos state, Nigeria and is located 10.5 miles (17km) northwest of Lagos, southwestern Nigeria. Its coordinates, Latitude: 6^{0}34’60’’N, Longitude: 3^{0}20’00’’E. Ikeja is an outer-ring suburb of the city of Lagos. Ikeja comprises of major areas such as Ojodu Berger, Omole, Alausa, Agidingbi, Ogba-Aguda, Computer Village, Oregun, Onigbongbo, Ikeja G.R.A, Oke-Ira, Opebi, Allen Avenue etc.

In the early days, Ikeja was a well–planned, clean and quiet residential environment with shopping malls, pharmacies and government reservation areas but with significant growth in population and economy had led to establishment of various industries. This growth had resulted in a rapid increase in the quantity of Municipal Solid Waste (MSW). At present the per-capita generation of MSW in Lagos has reached 0.5kg/day, and the annual total generation is approximately 85 million tons. Table 1 depicts mean percentage by weight composition of refuse from three social classes in Ikeja, namely, government reservation, middle class and old town areas.

Table 1: Composition of refuse from three social classes in Ikeja (Mean percentage by weight)

COMPONENTS	GOVERNMENT RESERVATION AREA	MIDDLE CLASS AREA	OLD TOWN AREA
PAPER	10.2	11.3	2.5
GARBAGE	65.3	41.6	8.2
TIN	4.6	6.2	3.5
GLASS	2.1	2.5	0.0
RAG	1.6	3.4	4.3
DENSITY (kg/m^3)	256Kg/m^3	280Kg/m^3	296kg/m^3
MOISTURE CONTENT (%)	64.8%	61.4%	49.7%

SOURCE: Lagos State Waste Management Agency (LAWMA).

1.1 Municipal Solid Waste

Waste is defined as any substance or object discarded for any reason, whether part or all such substance may be recycled, for example, rubbish, trash, scraps tiles, cans, papers, chemicals, slugs, machine parts, scrap metals, and so on. Dixon and Langer [1] reported that developing countries often have waste streams that contain more biodegradable material and fewer plastics, while industrialized countries have less biodegradable content and more uniformity in their waste streams, mostly due to well- developed recycling and pre-treatment policies. Total amount of waste produced per capital increases every year due to population growth. Municipal Solid Waste (MSW) is unwanted material generated in a municipal or notified area in either solid or semi-solid from excluding industrial hazardous wastes but including treated bio-medical wastes. MSW consists of household waste, construction and demolition debris sanitation residue and waste from streets. This garbage is generated mainly from residential and commercial complexes. Other sources of MSW are household waste, commercials, street sweeping, hotels and restaurants, clinics and dispensaries, construction and demolition, horticulture and sludge. Municipal Solid Waste (MSW) composed of various materials with different properties. Besides inert materials and daily soil covering, there are also degradable components such as organic matter. Each of these components has a particular mechanical behavior with different strength and compressibility properties that can vary with time [2]. The proportion of each component is highly variable and is related to cultural and economic aspects.

1.2 Mechanics of Wastes

The current understanding of waste behavior is far from being complete. Engineers, researchers and practitioners have relied on their knowledge of the behavior of soils. Although this has been helpful to some extent, there is an increasing realization that behavior of waste should be considered in the context of a separate discipline of waste mechanics (also referred to as Waste Geotechnics) [3]. It is well known that MSW has different geo-mechanical behavior from soil material because of its fibrous components in strength characteristics [4]. The stability of waste bodies consists of the friction between granular particles and fibrous effective cohesion, i.e. tensile forces in the fibrous components such as fibers and foils [5]. The fibrous components come from a wide group of substances (fibrous materials) such as paper/cardboard, soft plastic, hard plastic and wood. However, the individuality of each of these materials implies different physical and mechanical properties [6]. In other words, each of the listed materials has a different influence on the pseudo-cohesion or reinforcement [7]. A good starting point is to compare some of the results from preliminary and novel studies on waste properties available in the literature with those of geological and engineered materials, e.g. granular soils, peat, reinforced soil. Similarities and difference in measured behavior can then lead to the development of laboratory and field tests specially for obtaining engineering properties of MSW. An increasing number of international researchers are investigating engineering behavior of waste and its interaction with engineered containment systems. Evaluating the engineering properties and hence behavior of MSW bodies is challenging due to the variety of materials present. It is preferable to undertake testing on real materials in an undisturbed state. However, this is not always possible. Undisturbed samples cannot be taken and therefore laboratory tests have to be on disturbed material that is re-compacted into test apparatus.

MSW can be highly structured material resulting from the method of placement and this structure will be destroyed. In addition, variation in composition between samples can be extreme, making it difficult to quantify the contribution to behavior of the different components of waste quantify the contribution to behavior of the different components of waste or mechanism of behavior. It is also difficult to systematically change the proportion of waste constituents in order to investigate the role each plays. This is required in order to evaluate the impact of future changes in waste composition. Additional considerations are the very large size of test apparatus required to accommodate large particles, and health and safety requirements that dictate tests on real waste have to be carried out in a controlled laboratory environment. These are both expensive to construct and operate. An additional major factor is that engineering properties of waste vary with time due to degradation process. At present there are no internationally accepted standard sampling testing procedures for waste materials. In addition, there is presently no accepted guidance on selection of appropriate values of the engineering parameters for use in design, or agreed approaches for assessing waste behavior as part of the design process.

1.3 Waste Classifications

There are a number of general waste classification systems in common use, and these have been developed to provide information for specific end uses, e.g. recycling/waste minimization, assessment of biodegradation potential and calorific value. However, for assessment of engineering behavior a classification is required that groups waste constituents in terms of their mechanical properties. In a typical landfill there will be three distinct phases present: solid, liquid and gas. There may also be a need to distinguish between mobile liquid and in large drainable pores (inter-particle), and liquid that is trapped, absorbed or otherwise bound to the solid fraction (intra-particle). The information required to classify waste components can be summarized as: knowledge of component shape to distinguish between soil-like (three-dimensional, e.g. granular) and non-soil-like (two-dimensional, e.g. foils) components. This allows classification of components in relation to their potential for influencing mechanical behavior of the waste mass (e.g. shear strength). A new classification framework for MSW that fulfilled the requirement has been proposed by [8]. It gives a geotechnical classification system. It classifies waste components based on (1) their material engineering properties (e.g. shear, components and tensile strength), (2) a size distribution of the components, (3) the component shape (reinforcing, compressible and incompressible) and (4) the degree of degradability.

1.4 Waste Generation Rate

Waste generation rate is defined as the quantity of solid waste generate in a given unit product. A typical unit solid waste generation is shown in the table below:

Table 2: Waste generation rate in Metric ton/Material ton

Source	Unit	Magnitude
Canned and frozen foods	Metric ton/Metric ton of raw product	0.04- 0.05
Printing and Publishing	Metric ton/ Metric ton of raw paper	0.08 -0.40
Automotive	Metric ton/ vehicle produced	0.6 -0.8
Petroleum refining	Metric ton/ (Employee per day)	0.04 -0.05
Rubber	Metric ton/Metric ton of rubber	0.10 -0.30

1.5 Properties of Municipal Solid Waste

Although waste is heterogeneous, many of the studies show that Municipal Solid Waste (MSW) has mechanical properties that vary in constituent and a predictable way (e.g. with respect to stress state and method of placement).

a. Shear Strength – In terms of mechanical properties, untreated Municipal Solid Waste (MSW) is regarded as a composite material. The shear strength of MSW consists of two major resistance components, friction and tension (reinforcement) [9]. Frictional forces arise between all waste particles, particularly between granular. Tensile force on the other hand are incorporated in fibrous elements (foils, fibers), only. The shear resistance generated by tensile force is called fiber cohesion. In many regards the granular part of the matrix is different from the fibrous part. Among others, isotropy, stress-strain behavior and sensitivity against biological and chemical decay processes vary significantly.

Those different properties result in several consequences. It is a matter of fact, that it is impossible to exactly determine the shear strength in one single laboratory test. Using comprehensive mechanical models help to come over those constraints [10]. Shear Strength Characteristics of the MSW consists of putrescent organics (i.e., food and garden wastes), cinder, dust, paper, plastics, rubber, textiles, wood, glass, metal etc. After being placed in landfills, Waste composition inevitably changes with time due to biological degradation of the organics. It was discovered that the decrease in organic content is related to fast degradation of putrescent organics.

b. Moisture Content –Moisture content of waste depends on the initial composition, local climatic conditions, operating conditions, rate of decomposition and organic content. On exposure to water, the unit weight of any constituent absorbing water would increase (e.g. that of food waste, garden refuse, paper, textiles) due to increased moisture content of the intra-particle voids. This increase in individual particle unit weight is added to the increase in bulk unit weight resulting from increase in the bulk unit weight of the mass. Therefore, older waste would be expected to have a higher bulk unit weight than fresh waste. Although there is limited evidence to support this proposed mechanism, the data from investigation such as those described by [11] provide some corroboration. Daily cover soils play an important role in controlling the amount and distribution of precipitation that enter waste. They result in highly structured waste bodies (i.e. horizontal layers of waste bounded by often low permeability layers of cover soils) and this can cause large spatial variations in the moisture content of waste. Pelkey [12] defined the moisture content of the waste of the refuse as the ratio of the mass of water to the mass of dry solids present. The moisture content collected as shown below:

$$M.C\ \% = \frac{\text{Final weight- Initial weight}}{\text{Final weight}} \times 100 \qquad (1)$$

c. *Permeability* – Is a property of material which permits the passage of any fluid through its interconnecting pore spaces. The coefficient of permeability in compacted waste is:

$$K = Cd^2 \qquad (2)$$

Where, C is dimensionless constant or shape factor
d is average size of pores

Intrinsic permeability as given above is dependent on the property of the solid material, including pore size distribution, tortuosity, specific surface and porosity. Permeability is normally determine using field pumping tests or field percolation tests [11]. Permeability in municipal solid waste is mainly dependent on the pore size and geometry, which in turn varies with the size and shape of the individual particle and packing density.

The borehole permeability test is one of the several methods for estimating saturated coefficient of permeability in situ in the vadose zone. Hanso et al [8] estimated the in situ saturated permeability of MSW using the borehole permeability test at 23 locations in a 4-hectare full scale landfill site Florida, USA. A field investigation was conducted to obtain the residual permeability of flow columns over time. The experimental set up confirms to ASTM D 1987 consisting of PVC flow column that houses the waste, soil/geotextile, and gravel supported by stainless steel screen. Other useful tests are Pumping tests and Slug tests [12].

2. Methodology

The following equipment were used for the experiment: Muffle furnace, Stopwatch, Permeability meter, Risdale Laboratory Rammer, Universal Strength Tester, Moisture Tester

2.1 Sample Preparation

Two samples each of solid waste were collected from Ikeja municipal. They were shredded to size suitable for compaction. The most common waste collected included paper, metals, food materials, and glass/ceramics. However, only the combustibles materials are considered for compactions.

1. Moisture Content Determination

50g of sample is weighed and dried using the moisture tester having a thermostats and timer. After drying it is re-weighed again. The moisture content is calculated as shown in eqn. 1 below:

$$M.C. = \frac{\text{Final weight- Initial weight}}{\text{Final weight}} \times 100$$

2. Permeability

This is the volume of air passing through the specimen of 1sq.cm cross sectional area and 1cm height at a pressure difference of 1gm/cm in one minute. It is calculated using eqn. 2 below:

$$Perm = {}^{VH}/_{pAt} \qquad (3)$$

Perm = Permeability

V = Volume of air in cm

H = Height of specimen in cm

p = Pressure of air g/cm^2

A = Cross sectional area of specimen in cm^2

t = time in minutes

3. Expansion

Expansion / Shrinkage during oven drying length of sample are measured upon comparison and drying in the oven. The difference in the height gives the value of expansion/ shrinkage in cm.

4. Composition of Waste

The wastes are separated into constituent and weigh. The percentage composition of each constituent is calculated using equation 3.

$$\text{Composition\%} = \frac{\text{Weight of components}}{\text{Total Weight of Waste}} \times 100 \quad (4)$$

The sample was prepared with the addition of binding agents and water for proper binding. A ramming machine was used to compact the sample. The ramming was done in a cylindrical shell. 1000kg of load was used to produce about 5 blows. The sample was then released from the shell using a stripping machine. 200 cm^3 of air was passed through specimen of weight 5.08cm and cross-sectional area 20.268cm at a pressure of 10g/cm. The total time was recorded.

5. Bulk density

This is determined by dry weight the sample and then increased it in a volume of water. The volume of water displaced is measured and the bulk density is calculated.

$$\text{Bulk Density} = \frac{\text{weight of sample}}{\text{Volume of water displaced}} \quad (5)$$

6. Confined Compression and shear Strength Test

This is done with universal strength Tester. Two compression and stress test were done; green (wet) and Dry.

7. Drying Compression and Strength

The cylindrical sample from is placed between the compression heads while wet. A load is applied to the specimen at uniform rate of about 25N/m with the specimen collapsed. Then the values are read from the scale directly.

8. Dry Compression

The sample is subjected to load as in green compression and shear strength but with different compression loads.

3. Results and Discussion

Tables 3, 4, and 5 shows the results of the green compression, permeability, bulk density, porosity and shear strength test performed on various samples: Samples A, B, and C were at different moisture content. Table 6 gives the mean variation for the combination of the three test samples.

Table 3 Variation of moisture content with testing parameters on sample A

Moisture Content (%)	Green Compression ‘A’ (N/m^2)	Permeability ‘A’ (cm/sec.)	Bulk Density ‘A’ (g/cm^3)	Porosity ‘A’	Shear Strength ‘A’ (N/m^2)
5	65.00	73.17	2.364	147.46	52.00
10	62.00	86.99	2.200	114.41	58.00
15	58.00	86.54	1.864	189.22	72.00
20	45.00	82.57	1.898	178.98	68.00
25	41.00	75.35	1.486	129.11	60.00

NOTE: Sample A: Corrugated paper, wood waste, leave and nylon waste.

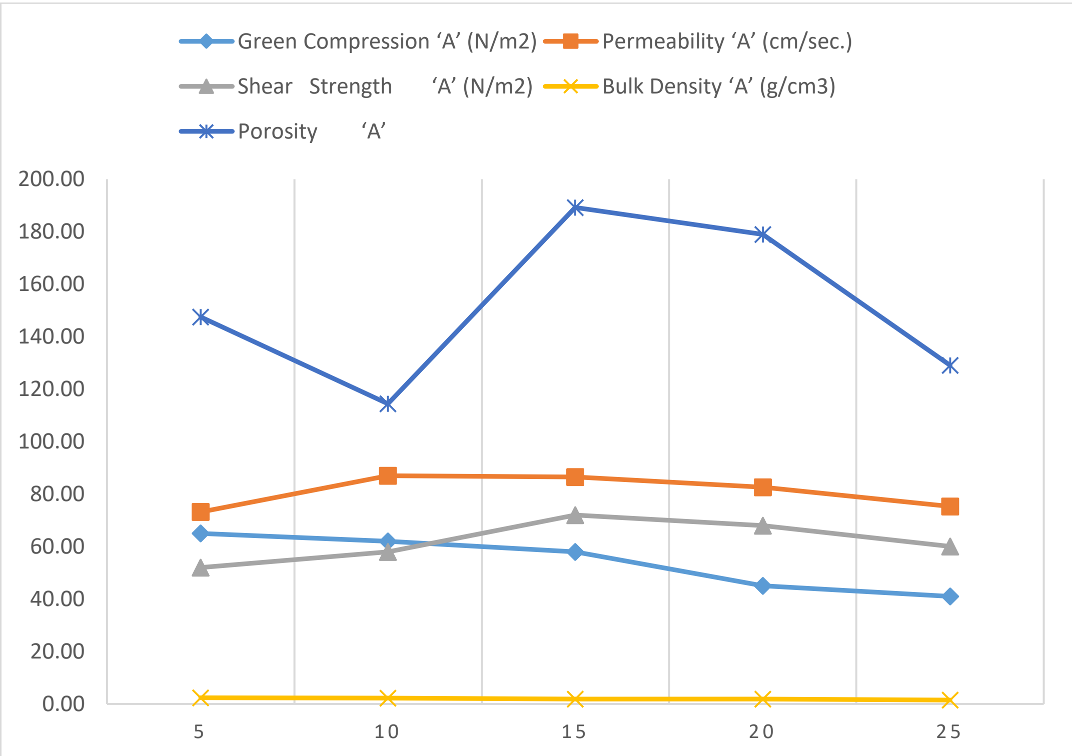

Fig. 1: Variation of moisture content with testing parameters on sample A

Table 4: Variation of moisture content with tested parameters on Sample B

Moisture Content (%)	Green Compression 'B' (N/m^2)	Permeability 'B' (cm/sec.)	Bulk Density 'B' (g/cm^3)	Porosity 'B'	Shear Strength 'B' (N/m^2)
5	50.00	80.84	0.832	108.33	65.00
10	30.00	81.28	0.802	104.39	45.00
15	54.00	81.47	0.740	98.68	77.00
20	50.00	82.14	0.701	93.89	67.00
25	44.00	83.01	0.654	84.97	61.00

Note: Sample B: Milled Papers Table

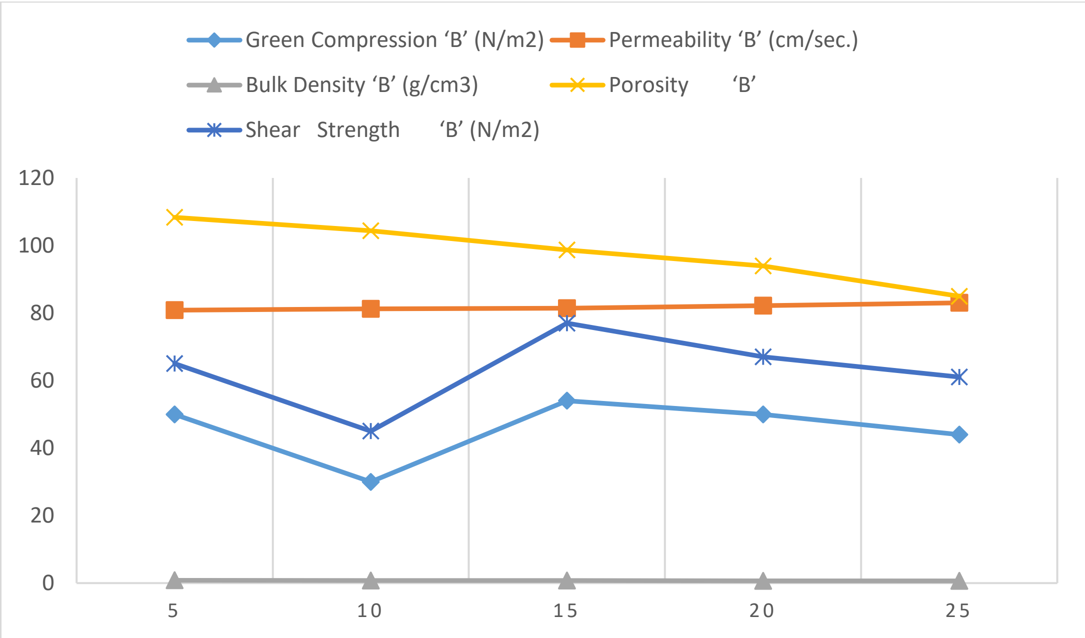

Fig. 2: Variation of moisture content with tested parameters on Sample B

Table 5 Variation of moisture content with tested parameters on Sample C

Moisture Content (%)	Green Compression 'C' (N/m^2)	Permeability 'C' (cm/sec.)	Bulk Density 'C' (g/cm^3)	Porosity 'C'	Shear Strength 'C' (N/m^2)
5	24.00	209.56	1.226	212.06	78.00
10	37.00	138.07	1.220	204.09	85.00
15	48.00	88.24	1.183	98.54	75.00
20	54.00	97.80	1.093	87.55	70.00
25	64.00	99.04	1.005	83.19	62.00

Note: Sample C: Wood waste, leave and nylon.

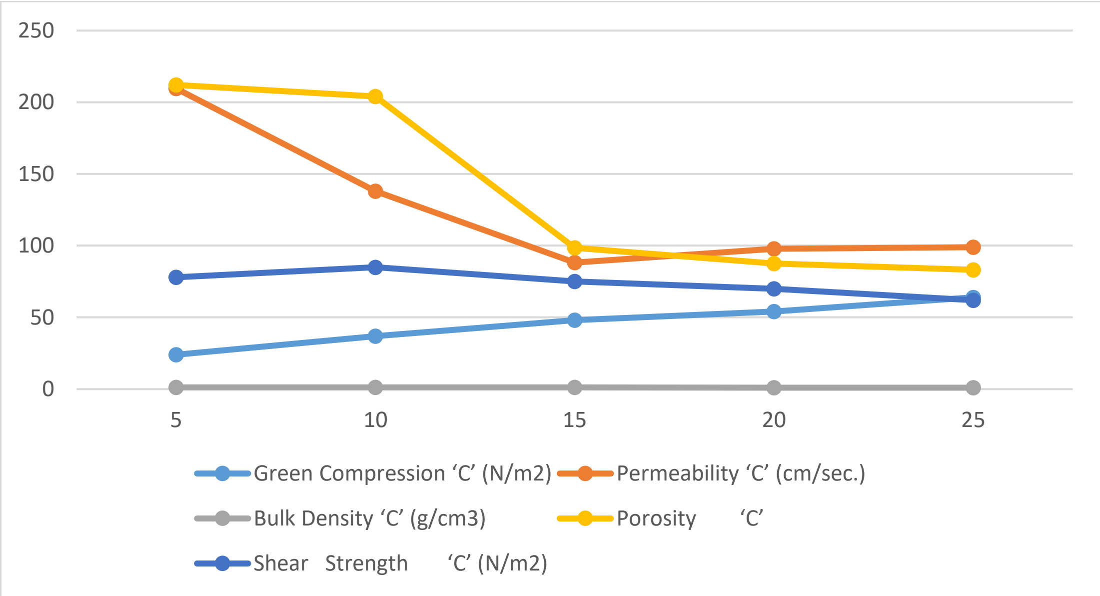

Fig. 3: Variation of moisture content with tested parameters on Sample C

Table 6: Mean Variation for the Combination of the Three Test Samples

Moisture Content (%)	Mean Green Compression 'M' (N/m^2)	Mean Permeability 'M' (cm/sec.)	Mean Bulk Density 'M' (g/cm^3)	Mean Porosity 'M'	Mean Shear Strength 'M' (N/m^2)
5	46.33	121.30	1.447	155.95	65.00
10	43.00	102.10	1.407	140.96	62.67
15	53.33	85.40	1.262	128.81	74.67
20	49.67	87.50	1.231	120.14	68.33
25	49.67	85.80	1.048	99.09	61.00

NOTE: M= Mean

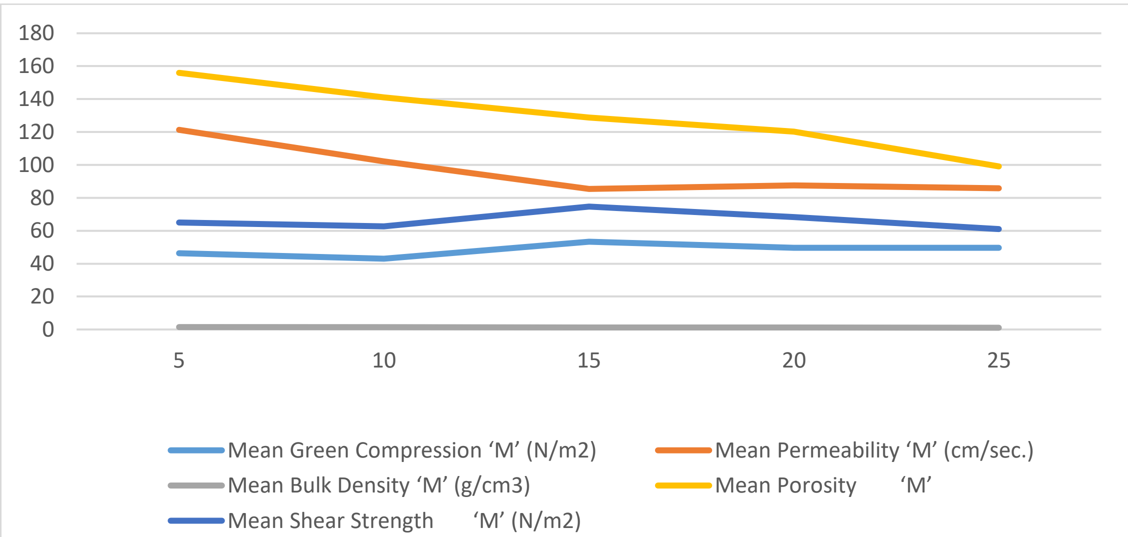

Fig. 4: Mean Variation for the Combination of the Three Test Samples

The behavior of green compression in samples A, B, and C are shown in figure 4. The maximum green compression 65 N/m^2 is obtained for sample A at moisture content of 5% while the minimum green compression of 24 N/m^2 was obtained in sample C at moisture content of 5%. In sample A, the green compression decreases with increase in moisture content. This may be because of the structure of the milled paper particles which seemed to be bounded together unlike sample B and C which are mixed constituents that may not be compatible. In figure 1, the permeability of the waste material in sample A increases from 73.17 cm/sec. at a moisture content of 5% to 86.99 cm/sec at a moisture content of 10% before it falls again to 75.35 cm/sec. at a moisture content of 25% Sample C in contrast to sample A decreases from 209.56 cm/sec. at 5% moisture content. Sample B decreases from 88.24cm/sec. to 83.01 cm/sec. at moisture content of 5% and 25% respectively.
In contrast to above, in figure 2, the bulk density of the samples decreases with increase in moisture content. This may be due to the fact that the materials bring out higher moisture content in such a way that the volume becomes higher than what would have expected. However, sample A has the highest bulk density of 2.364 g/cm^3 with sample B lowest of 0.6514 g/cm^3 due to the composite nature of sample A with various densities combined.

In figure 3, sample C has both the highest and the lowest porosities while sample B decreases linearly in porosity with highest and lowest porosity at 5% and 25% moisture content respectively. And lastly, in figure 4, shear strength in sample A rises from 52 N/m^2 and peak at 72 N/m^2 before it falls to 60N/m^2. Sample B falls sharply from 65 N/m2 at 5% moisture content to 45 N/m2 at 10% moisture content and peak at 77 N/m^2 at moisture content 20% before it falls back to 61 N/m2 at 25% moisture content. And interestingly all the sample wastes converge almost at the same point at moisture content 25% which show that shear strength properties ultimately becomes similar as moisture content increases.

4. Conclusion

According to statistical survey and experimental result on the types of waste in Ikeja metropolis, papers (milled or corrugated) have the minimum bulk density but maximum permeability. Also, wood waste, nylon and leaf have minimum green compression and permeability but maximum bulk density based on percentage of moisture content. Consequently, as a result of statistical survey on the types of waste in Ikeja metropolis, it can be deduced that over 84.06% of the solid wastes generated in this area are not subjected to short term decomposition except for garbage and paper which are only 15.94% of the total.

5. Recommendation

All the type of wastes generated in Ikeja metropolis can be recycled into one form or the other after carefully sorting out. For example: Plastic can be melted or treated using mechanical recycling. Papers can be bleached, marched and then used to produce brown paper or it can be mixed with fresh pulp to produce more quality paper.

References

[1] Dixon, N., and Langer, U., (2006). Development of a MSW Classification System for the Evaluation of Mechanical Properties. Waste Management, 26 (3), pp. 220-232.

[2] Orencio, M.V and Mdef, C (2004). Mechanical Properties of Municipal Solid Waste. Journal of Testing and Evaluation. Vol.32 (6). DOI: 10,1520/ JTE 11945

[3] Beaven, R.P., and Power, W., (1995). Hydro Geological and Geotechnical Properties of Refuse Using a Large Scale Compression Cell. Proceedings Sardina ’95, 5th International Landfill Symposium, Cagliari, Italy.

[4] Bray, J.D., Zekkos, D., Kavazanjian, E., Athanasopoulos, G.A. and Riemer, M.F., (2009). Shear Strength of Municipal Solid Waste, Journal of Geotechnical and Geo-environmental Engineering, Vol. 135, No. 6, June 2009, pp. 709-722

[5] Bauer, J; K., and Frickle, K. (2007). Proceedings Sardinia 2007, Eleventh International Waste Management and Landfill Symposium S. Margherita di Pula, Cagliari, Italy.

[6] Calle, J.A.C. (2007). Geomechanical behavior of Urban Solid Waste. Doctorate thesis,160p. Coppe/UFRJ, Brazil.

[7] Gotteland, P., Gachet, C., Vullemin, M., (2001). Mechanical Study of a Municipal Solid Waste Landfill. Proceedings Sardina ’01, 8th International Waste Management and Landfill Symposium, Cagliari, Italy, 761767.

[8] Hanson, J.L., Yesiller, N., Stockhausen, S.A. and Wong, W., (2010). Compaction Characteristics of Municipal Solid Waste, Journal of Geotechnical and Geo-environmental Engineering, Vol. 136, No. 8, August 2010,pp. 1095-1102.

[9] Jain, A.K., Tao, Z., Yang, X. and Gillespie, C. (2006). Estimates of global biomass burning emissions for reactive greenhouse gases (CO, NMHCs, and NO_x) and CO_2. *Journal of Geophysical Research 111: doi: 10.1029/2005JD006237. ISSN: 0148-0227.*

[10] Kavazanjian, E. (2001). Mechanical Properties of Municipal Solid Waste Proceedings Sardina ’01, 8th International Waste Management and Landfill Symposium, Cagliari, Italy.

[11] Klsch, S. (2007). Stability Analysis According to Different Shear Strength Concepts. 2nd International Workshop HPM, Southampton.

[12] Pelkey SG (1997). Geotechnical properties of municipal solid waste. M.Sc. thesis University of New Brunswick.