



IMPROVEMENT OF ENGINEERING PROPERTIES OF IGBOKODA STANDARD SAND WITH SHREDDED POLYETHYLENE WASTES

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ABSTRACT

Geotechnical tests were carried out on sand samples to determine important properties of sand modified with strips of high density polyethylene (HDPE) waste. Strips sizes of 15x20 mm, 20x25mm, 25x30mm were used at concentrations of 1%, 2%, 3%, 4% and 5% by mass of the soil sample. Direct shear test results indicate that with the addition of shredded polyethylene, the shear stress value increased from 4.29kN/m² to a maximum value of 8.21kN/m² (a percentage increase of 68.54%) while the angle of internal friction of the sand increased from 18° to a maximum value of 28° (a percentage increase of 55.56%). The coefficient of permeability "k" reduced with increasing strip size and strip concentration thereby modifying the hydraulic property of the sand from a fine sand range (1.30 x 10⁻⁵m/sec) to a silty sand range (4.95 x 10⁻⁶m/sec). The permeability test result further shows a direct relationship between the increasing shredded polyethylene sizes and a reduction in the permeability of the soil.

Keywords: silica sand, packaging waste, beneficial reuse, strength characteristics, hydraulic barrier

1. INTRODUCTION

Colossal tonnages of waste are produced each year worldwide, with a considerable amount being in the form of polyethylene (PE) wastes. Most of these wastes are non-degradable and destined for landfill [1, 2]. High density polyethylene is the most common nylon waste. The annual global production is approximately 80 million metric tons [3]. Its primary use is in packaging (plastic bags, plastic films, geomembranes, containers including bottles etc.) [3]. Many kinds of polyethylene are known, with most having the generic chemical formula (C₂H₄)_n. Where n is the degree of polymerization i.e., the number of ethylene monomers polymerized to form the chain. Thus PE is usually a mixture of similar organic compounds that differ in terms of the value of n.

The Plastic Waste component of the Municipal Solid Waste is quite problematic because it is non-biodegradable and therefore can stay in the environment for a considerable length of time causing all sorts of problems. The management of plastic waste through combustion (incineration) is not environmentally friendly and sustainable since this may release carbon dioxide, a major contributor to global warming (greenhouse effect). Land filling with Plastic Waste is not also desirable since plastic is non-

degradable and no economic value would have been derived from the waste in that case [4].

The use of polyethylene for improving the engineering properties of the Igbokoda standard sand is the goal of this present study. The scope of the study entails mixing shredded sachet water polyethylene nylon wastes at different percentages of 1%, 2%, 3%, 4% and 5% by weight of the soil and at different sizes of 15 x 20 mm, 20 x 25 mm, 25 x 30 mm with the Igbokoda silica sand, assessing the geotechnical properties necessary for recommending reuse of the sand-plastic waste mix.

The Igbokoda silica sand has been established as a standard baseline sand for engineering research work in south western Nigeria and other parts of Nigeria since it needs little processing to bring it to the same level as standard baseline sand, like the Ottawa sand [5]. Using this standard sand provides a benchmark for assessing the behaviour of other soil types with these plastic wastes. There is an urgent need to arrest the recent trend of increasing littered water sachets and plastic bag wastes in the Nigerian environment (land, subsoil, water ways, drainage structures and green belts) and encourage recycling and beneficial reuse of the plastic wastes.

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The environmental problems associated with plastic waste are enormous. Plastic bags have become major items in the litter stream in municipal solid waste. This has resulted in a number of adverse environmental impacts including choking of animals, soils, blockage of channels, rivers and waterways and blight and mosaics of landscapes. The problem is more pronounced in the marine environment [6]. Plastic wastes ultimately usually accumulate on surface water bodies and certain areas of the sea. The impacts of plastic waste on our health and the environment are only just becoming apparent. In the marine environment, the most well documented impacts are entanglement and ingestion by wildlife. The increased use and production of plastic in developing and emerging countries is a particular concern, as the sophistication of their waste management infrastructure may not be developing at an appropriate rate to deal with the increasing levels of plastic waste. At the heart of the problem is one of plastic's most valued properties: its durability. Combined with the throwaway culture that has grown up around plastic products, this means that we are using materials that are designed to last, but for short-term purposes. It is estimated that in 2008 Norway, Switzerland and twenty seven (27) European Union countries, produced about 24.9 megaton's of plastic waste but its distribution is difficult to ascertain [7]. Perhaps one of the most difficult impacts to fully understand, but also potentially one of the most concerning, is the impact of chemicals associated with plastic waste. There are several chemicals within plastic material itself that have been added to give it certain properties such as bisphenol A, phthalates and flame retardants. These all have known negative effects on human and animal health, mainly affecting the endocrine system. There are also toxic monomers, which have been linked to cancer and reproductive problems. Plastic waste also has the ability to attract contaminants, such as persistent organic pollutants (POPs). This is particularly so in the marine environment since many of these contaminants are hydrophobic, which means they do not mix or bind with water [8].

2. AIM AND OBJECTIVES OF STUDY

The aim of the study to evaluate the strength and hydraulic barrier application potential of the Igbokoda standard sand-shredded polyethylene waste [ISS-SPW] mix, providing beneficial reuse for this ubiquitous and preponderant polyethylene waste in Nigeria.

The objectives of this study are itemized as follows:

- i. Review of engineering properties of standard sand available in literature
- ii. Review of engineering properties of Igbokoda sand available in literature and obtained by the authors.
- iii. Review of Plastic and HDPE wastes use for soil improvement and in concrete
- iv. Assessment of the strength and hydraulic conductivity characteristics of ISS-SPW mixes for optimal performance

3. ENGINEERING PROPERTIES OF STANDARD SAND IN OTHER COUNTRIES

Standard sand is – high quality silica sand that is free of organic matter and is used in making test samples of concrete and cement. Such sand is the Ottawa sand in the USA. The Ottawa sand was chosen by the American Society for Testing and Materials (ASTM) as the standard sand to be used in testing cement and the strength of concrete. Detailed characterization/mineralogical analyses would not be required prior to experiments, since the sand is typically regarded as a standard, [9]. The engineering properties of sand are described with reference to the Ottawa standard sand which has been widely applied in experiments by geologists and engineers for several decades. Common tests include compressive strength, air content, tensile strength for hydraulic cement, and tests for geochemical properties. The sand also serves as a specification for graded sand, 20/30 sand, as well as masonry cement. Practical applications include building stone, abrasive, manufacturing of glass, and moulding sand. Ottawa standard sand, consists of rounded grains of clear colourless quartz, which have diamond-like hardness, and are pure silica (Silicon Dioxide, SiO₂) uncontaminated by clay, loam, iron compounds, or other foreign substances. Ottawa sand is the general name for sands mined from numerous deposits found in the northern portion of the United States. "White and Northern sands" are other names used to identify Ottawa sand. These sands are considered by many to be the highest quality sands. They are characterized by high purity, whiteness (although some variations in colour do occur), high roundness (sphericity) and lack of dust. There are other high quality standard sands apart from the Ottawa sand in various parts of the world. Committee for European Norms (CEN) Standard sand is natural sand, which is siliceous and has silica content of at least 98% particularly its finest fractions. It is clean and the particles are generally isometric and rounded in shape.

Table 1: Geochemical analysis of the Igbokoda sand and Ottawa sand

	Metal oxide (%)							
	SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	TiO ₂	CaO	K ₂ O	Na ₂ O	MgO
Standard Ottawa sand	99.80	0.02	0.06	0.01	0.01	0.01	0.01	0.01
Igbokoda sand	94.24	0.87	1.47	0.48	0.90	0.82	0.75	0.47

It is usually dried, screened and prepared in a modern workshop which offers every guarantee in terms of quality and consistency. The CEN sand is standard sand used for preparation of mortars in the testing of hydraulic cements by European standard [10]. Toyoura sand is Japanese sand extensively studied by several investigators [11], [12]. Toyoura sand is predominantly a uniform angular to subangular quartz, fine sand with approximately 90% quartz and 4% chert. It has 89.78% SiO₂ content and 3.43% Al₂O₃ Content. Silica sand is available almost in all the states of India. Quartzanium is the Indian standard sand as per IS-650: 1991 of the Bureau of Indian Standards (BIS), to be used in various Cement Plants, Research Laboratories, and Civil Engineering Institutions to ensure the quality of Cement [13]. The Indian standard sand is whitish and has specific gravity (G_s) of 2.65, SiO₂ Content (%): 99.38, Fe₂O₃ Content (%): 0.12 and Al₂O₃ Content (%): 0.25 [14].

The paper [15] investigated the preparation of Ethiopian standard sand for the purpose of construction and testing. The sand samples for laboratory investigation and field test were collected from North Showa (Jema river valley) and Dire Dawa town, Ethiopia. Laboratory and field tests conducted on both local sand samples showed that there is a high possibility that both local sand samples can replace the imported standard sand, especially the sand sample from North Showa. The North Showa (Jema river valley) sand was recommended as the Ethiopian standard sand, since the mineralogical composition revealed 99.09% silicon dioxide SiO₂ content.

4. ENGINEERING PROPERTIES OF IGBOKODA SAND

Ojuri and Fijabi [5] obtained grain size distribution of coarse sand-10.7%, medium sand-84.0% and fine sand-5.3% and a specific gravity value of 2.63 for the Igbokoda sand. The Ottawa sand has a specific gravity value of 2.65 and a similar grain size distribution. The results of the in-situ porosity and bulk density showed that Igbokoda sand has values almost the same as the Ottawa sand. The chemical composition of the Igbokoda sand viz-a-viz the Ottawa sand is presented in Table 1. The results of chemical analysis reveals oxides of silicon, iron, aluminum, magnesium, potassium, titanium, calcium and sodium.

It is remarkable that the percentage of silicon oxide (94.2%) that is quartz in Igbokoda sand is reasonably close to that of Ottawa sand (99.8%). Furthermore, [16] also obtained silicon oxide content of 95.8% for the Igbokoda Silica sand. A report on the Non-metallic Mineral Endowments in Nigeria by the Raw Materials Research and Development Council, Abuja The paper [17] has an average value of 99.8% SiO₂ for the Igbokoda silica sand. Japanese Toyoura sand has 89.78% SiO₂ content and 3.43% Al₂O₃ Content [12]. The Indian standard sand is whitish and has specific gravity (G_s) of 2.65, SiO₂ Content (%): 99.38, Fe₂O₃ Content (%): 0.12 and Al₂O₃ Content (%): 0.25 [14].

5. CLASSIFICATION of IGBOKODA SAND

The Igbokoda sand is classified as group A-3 (fine Sand) according to the American Association of State Highway and Transportation Officials (AASHTO) soil classification system. The AASHTO Soil Classification System was developed by the American Association of State Highway and Transportation Officials, and is used as a guide for the classification of soils and soil-aggregate mixtures for highway construction purposes. This system was originally developed by Hogentogler and Terzaghi in 1929 as the Public Roads Classification System. Afterwards, there were several revisions. The system is based on the following three soil properties: Particle-size distribution, Liquid Limit (LL) and Plasticity Index (PI) [18].

The Key Elements are;

Grain Size:

- *Gravel*: Fraction passing 75mm sieve and retained on #10 (2mm) US sieve
- *Sand*: Fraction passing #10 sieves and retained #200 sieve
- *Silt and Clay*: Fraction passing #200 sieves

Plasticity:

- Term *silt* is applied when fine fractions have a PI < 10
- Term *clayey* is applied when fine fractions have PI > 11

Groups:

Soils are classified into eight groups, A-1 to A-8, from stone fragments/gravels to sandy soils to clayey soils

(Excellent to fair to poor road sub grade rating). Groups A-1 to A-7 are inorganic soils, while A-8 group is for peat or organic soils. The major groups A-1, A-2 and A-3 represent the coarse grained soils; the A-4, A-5, A-6, and A-7 represent fine grained soils while the A-8 are identified by visual inspection.

6. LITERATURE REVIEW OF PLASTIC WASTES AND HDPE WASTES FOR SOIL IMPROVEMENT AND AS REPLACEMENTS OF AGGREGATES IN CONCRETE

Plastic waste management is one of the serious environmental problems in the world and it has many challenges for the recycling process. The recycling and disposing of some waste polyethylene nylon types have many challenges. These are attributed to the difficulty of making separation, type of polyethylene used, incineration problems, environmental regulations, and increase in the cost of recycling. Use of such waste materials in civil and construction engineering has become an attractive alternative to disposal, to reduce both the cost of disposal and outdoor waste quantities. In view of this, numerous studies had investigated the use of different types of waste and recycled plastics in concrete and geotechnical applications [1, 18, 20].

Polyethylene when mixed with soil behaves like a fibre reinforced soil. When polyethylene fibres are distributed throughout a soil matrix; they impart strength as micro reinforcements, foster material isotropy and reduce the chance of developing potential planes of weakness. Mixing of polyethylene fibres with soil can be carried out in a concrete mixing plant of the drum mixer type or with a self-propelled rotary mixer [21]. Polyethylene fibres could be introduced either in specific layers or mixed randomly throughout the soil. A soil mass improved with discrete, randomly distributed polyethylene fibres resembles soil reinforced with chemical compounds such as lime, cement etc., in its engineering properties. Recycled and waste polyethylene was used to improve sand properties which include; its shear strength, secant modulus, CBR value, angle of internal friction and permeability. Results showed that the strength, stiffness, ductility and toughness of the soil were improved, piping resistance was improved and compressibility of soil was reduced [20]. Similar results have also been achieved by using biodegradable wastes in soil improvement [22], [23]. Investigation by [19] revealed that the reinforcement benefit increases with an increase in waste plastic strip content and length and that the maximum CBR value of a reinforced system is approximately three

(3) times that of an unreinforced system. The paper [24] evaluated the suitability of low density polyethylene (LDPE) waste as fine aggregate in concrete. From his findings LDPE plastic concrete could be used in production of non-load bearing structural members such as tiles and partitions.

7. MATERIALS AND METHODS

7.1 Study Area

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

7.2 Materials Preparation and Characterization:

7.2.1 Polyethylene Waste

The materials used in the study were high density polyethylene (HDPE) waste. Despite their names (HDPE or LDPE) the difference in density is very small. To ascertain the type of HDPE, melting temperature was used, which agrees with the works of [4]. Melting temperatures for HDPE and LDPE ranges from 120 °C to 126 °C and 110 °C to 115 °C respectively ([4], [25]).

HDPE waste was obtained from the Business Development Company (BDC) sachet water factory of the Federal University of Technology, Akure (FUTA). The physical properties of the HDPE are summarized in Table 2. The material was shredded into distinct rectangular dimensions manually using scissors at the Geotechnical Laboratory.

7.2.2 Soil

The Igbokoda sand sample was collected from a borrow pit at Igbokoda town of Ondo state. The soil sample is greyish in colour with coarse, medium and fine (cmf) components. After collection, the sample was stored in bags prior to their use to preserve their natural moisture content. Preliminary geotechnical tests [26] were performed on Igbokoda sand to determine its basic index properties. The results are presented in Table 3.

8. METHODOLOGY

In order to examine the effect of shredded polyethylene nylons on the engineering properties of Igbokoda sand, direct shear strength test and falling head permeability test were conducted on the Igbokoda sand-HDPE mixtures.

Table 2 Physical properties of HDPE

HDPE Properties	Conventional/Standard [25]	Used	Standards
Tensile Strength (N/mm ²)	0.20 - 0.40	0.36	ASTM D882-12 (2012)
Specific Gravity	0.94 - 0.96	0.94	ASTM D792 (2008)
Thermal Coefficient of Expansion	100 - 220 x 10 ⁻⁶	210 x 10 ⁻⁶	ASTM D696-08e1 (2008)
Melting Point (°C)	120 - 126	120	ASTM D440-15 (2015)
Density (g/cm ³)	0.941 - 0.965	0.95	ASTM D792 (2008)
Thickness (mm)	0.1 - 0.2	0.125	ASTM D5199 (2012)

Shredded polyethylene nylon wastes were introduced to the soil at different percentages of 1%, 2%, 3%, 4% and 5% by weight of the soil and at different sizes of 15 x 20 mm, 20 x 25 mm, 25 x 30 mm. The strip sizes are based on the sizes adopted by [27] so as to control entanglement between the reinforcing strips. The low concentration values were based on the fact that although the shredded polyethylene nylon wastes were light in weight they occupied large volumes. Besides, at those respective concentrations, it was easier to ensure consistency and even distribution of reinforcing elements within the soil sample without entanglement between strips. The direct shear test was carried out on dry soil sample to eliminate any effect of moisture fluctuations. Mix proportions for the Igbokoda sand, shredded polyethylene waste mixtures is presented in Table 4.

9. RESULTS AND DISCUSSION

9.1 Preliminary Geotechnical Tests:

The summary of the preliminary geotechnical tests is presented together with important engineering properties of Igbokoda sand in Table 4, while the result of particle size distribution is shown in Fig. 3. The soil is classified as group A-3 (fine Sand) according to the AASHTO classification system.

9.2 Direct Shear Test Result:

Figure 2 shows the relationship between the angle of internal friction and HDPE waste concentration. The figure shows that all HDPE concentrations between 1% and 5% have internal friction angle value greater than that of 0% concentration, representing Igbokoda sand only.

Similarly, Figure 3 shows the relationship between the angle of internal friction and the sizes of shredded HDPE waste in Igbokoda sand-HDPE waste mixture for 2% strip concentration. It was also observed that Igbokoda sand-HDPE waste mixture has a higher angle of internal friction than Igbokoda sand alone;

leading to the conclusion that the addition of polyethylene leads to the improvement of its angle of internal friction.

Figure 4 shows stress-strain relationship for samples improved with 2% strip concentration and unimproved with shredded polyethylene waste.

Table 3: Mix proportions for Igbokoda Sand samples with added Shredded Polyethylene Wastes for the various shredded strip sizes

Label	Compositions (168.0g of Igbokoda sand with percentage by weight of HDPE)	Polyethylene strip size (mm) ene strip size
1GSP ₀	Igbokoda sand + 0gHDPE	
1GSP ₁	Igbokoda sand + 1.68gHDPE	
1GSP ₂	Igbokoda sand + 3.36gHDPE	15x20
1GSP ₃	Igbokoda sand + 5.04gHDPE	
1GSP ₄	Igbokoda sand + 6.72gHDPE	
1GSP ₅	Igbokoda sand + 8.40gHDPE	
2GSP ₁	Igbokoda sand + 1.68g HDPE	
2GSP ₂	Igbokoda sand + 3.36g HDPE	
2GSP ₃	Igbokoda sand + 5.04g HDPE	20x25
2GSP ₄	Igbokoda sand + 6.72g HDPE	
2GSP ₅	Igbokoda sand + 8.40g HDPE	
3GSP ₁	Igbokoda sand + 1.68g HDPE	
3GSP ₂	Igbokoda sand + 3.36g HDPE	
3GSP ₃	Igbokoda sand + 5.04g HDPE	25x30
3GSP ₄	Igbokoda sand + 6.72g HDPE	
3GSP ₅	Igbokoda sand + 8.40g HDPE	

Table 4 Engineering properties of the standard Igbokoda sand

Soil engineering properties	Values	Standards
Angle of internal friction (°)	18	
Cohesion (kN/m ²) Apparent	1.78	BS1377, Part 7 (1990)
Shear strength (kN/m ²)	4.29	
Coefficient of permeability (cm/sec)	0.0013	BS1377, Part 5 (1990)
Porosity (%)	33	BS1377, Part 4 (1990)
Bulk density (kg/m ³)	1555.02	
Specific gravity	2.58	
Moisture content (%)	4.02	BS1377, Part 2 (1990)
Effective grain size [D ₁₀] (mm)	0.16	

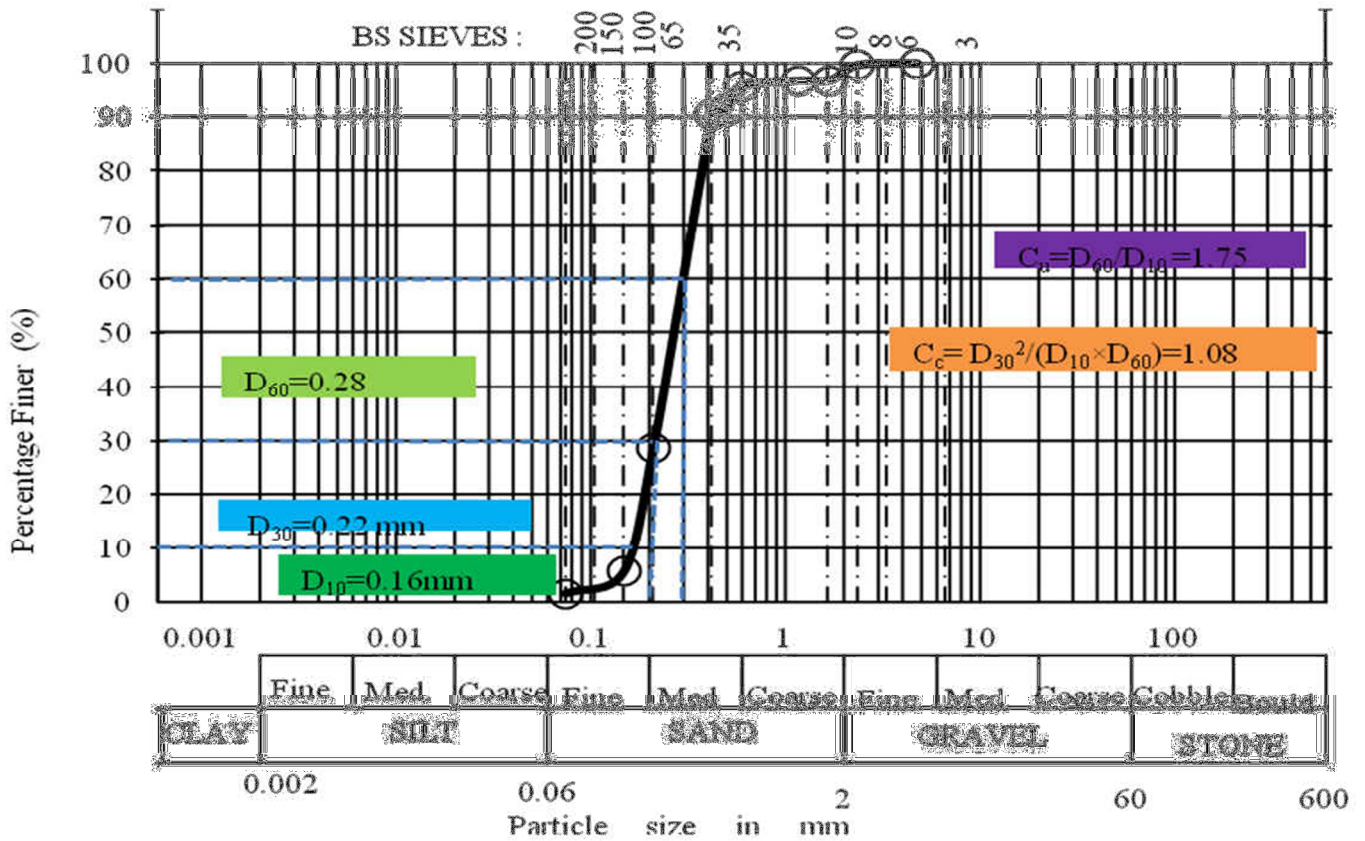


Figure 1: Grain size distribution curve of Igbokoda sand.

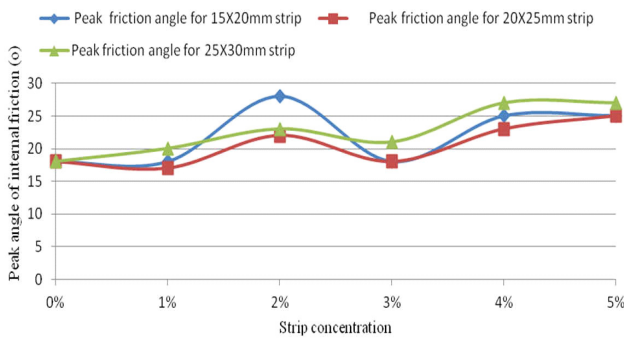


Figure 2: Effect of strip concentration of shredded HDPE on angle of internal friction on Igbokoda sand

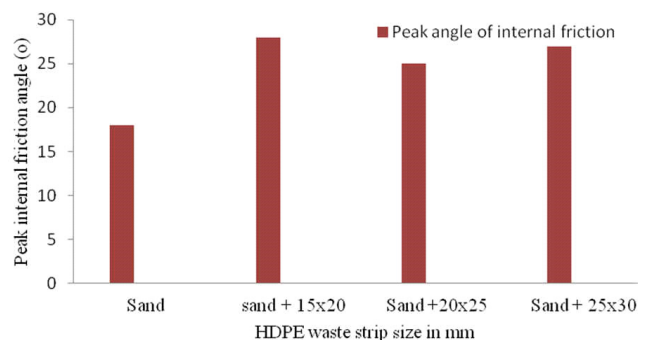


Figure 3: Effect of strip size of shredded polyethylene on friction angle improvement of Igbokoda sand

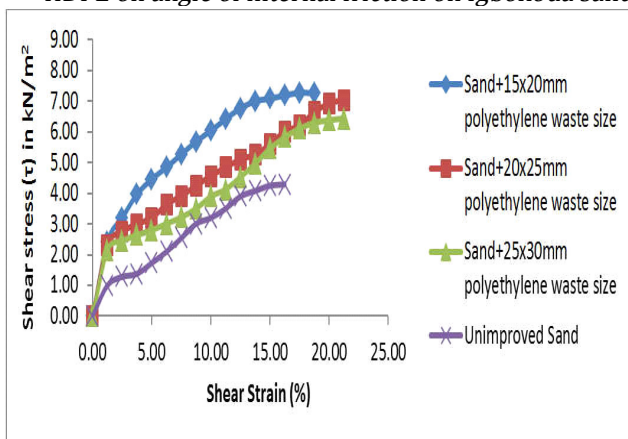


Figure 4: Stress-strain relationships for samples improved with different sizes of 2% strip concentration shredded polyethylene and the unimproved sand.

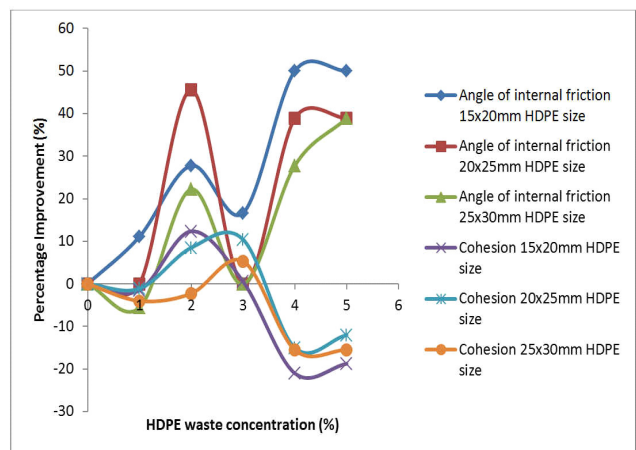


Figure 5: Percentage improvement of Igbokoda sand-HDPE waste mixture engineering properties with strip concentration for the various strip sizes

Also, this Figure indicates that the addition of high density shredded polyethylene nylon waste has a significant effect on the enhancement of stiffness for improved samples compared to Igbokoda sand in its natural state. For example, the shear stress of Igbokoda sand was 4.29kN/m^2 , while it was found to be 8.21kN/m^2 , 7.84kN/m^2 and 6.63kN/m^2 for sand-polyethylene mixtures with $15\times 20\text{mm}$, $20\times 25\text{mm}$ and $25\times 30\text{mm}$ shredded polyethylene sizes respectively. This proves that the addition of polyethylene improved the shear stress of Igbokoda sand in some cases up to about two times its original shear stress.

Figure 5 and Figure 6 show the percentage improvement in angle of internal friction and cohesion in terms of strip concentration and shredded sizes respectively. The percentage improvement is defined as the difference between the ultimate strength of improved sand and Igbokoda sand divided by the ultimate strength of Igbokoda sand. Both angle of internal friction and cohesion increased with the addition of shredded polyethylene. This result agrees with previous study reported by [1, 2, 19, 28, 29].

The increase of Polyethylene content has a more significant effect on the improvement of internal friction angle compared to cohesion as it prevents interlocking. The increase in the shredded sizes of the polyethylene up to $20\times 25\text{mm}$ size increased the cohesion but on further widening of the strips, the cohesion value dropped. From Figure 5, it can be seen that; the best improvement in both cohesion and angle of internal friction of Igbokoda sand occurs at 2% HDPE waste concentration. The inclusion of polyethylene strips in the Igbokoda sand, resulted in a remarkable increase in shear strength in tandem with the findings of [27]. Strains in the soil mass generated strains in the strips, which in turn, generated tensile loads in the strips. These tensile loads acted to restrict soil movements and thus impart additional shear strength. This resulted in the composite soil/strip system having significantly greater strength than the soil mass alone. Polyethylene as a material has low frictional properties and therefore interacts with the soil particles in a unique way. Instead of particles adhering to the polyethylene surface, the particles 'punched' and moulded around the 'soft' strips. As the vertical load was applied and increased this 'punching' became amplified, and due to the fact that this material has good elongation characteristics it could withstand the high strains.

9.3 Permeability Test Result:

Figure 6 shows the permeability curve for Igbokoda sand mixed with shredded HDPE waste of $25\times 30\text{mm}$. It was observed from the figure that the higher the concentration, the lower the coefficient of permeability of the mixture. An appreciable drop was noticed between the unreinforced sand and the reinforced Igbokoda sand with the drop from 1.30×10^{-5} to $4.95 \times 10^{-6}\text{m/sec}$ altering the properties of the sand from that of fine sand to silty sand.

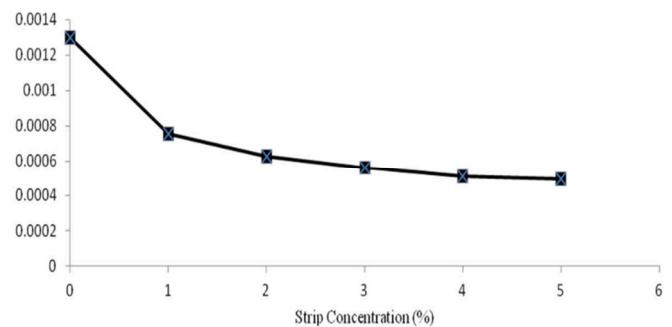


Figure 6: Effect of strip concentration on the coefficient of permeability of Igbokoda sand-HDPE waste mixture

The combined plot of Figure 7 shows the coefficient of permeability of Igbokoda sand-HDPE waste mixtures with varying shredded sizes and concentration. It also reinforced the observation of Figure 6 by showing a noticeable reduction in the permeability of the sample as the sizes were increased and concentration increased.

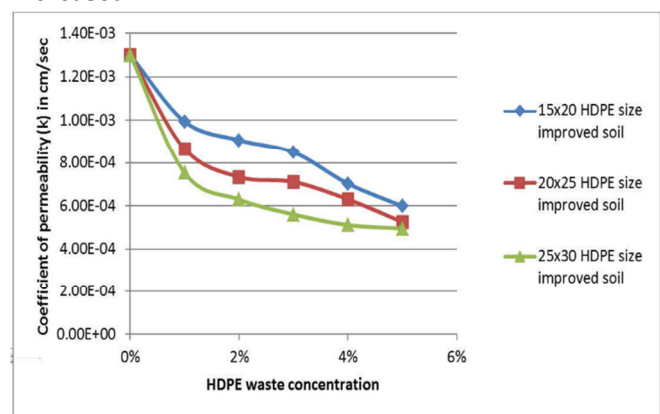


Figure 7: Trend of reduction in coefficient of permeability of Igbokoda sand reinforced with shredded Polyethylene

Figure 8 shows the percentage reduction of the permeability of Igbokoda sand-HDPE waste mixture with the strip sizes. It was observed that Igbokoda sand-HDPE waste mixture with the widest strip has the lowest permeability value.

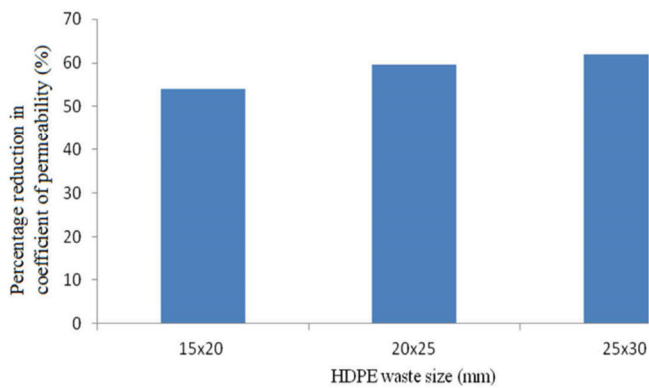


Figure 8: Percentage improvement in permeability of Igbokoda sand

Addition of 15x20 mm polyethylene shredded size led to a 54% reduction in its coefficient of permeability, while the addition of 20x25mm shredded size of HDPE led to 59.6% reduction; the peak reduction was at 5% concentration of 25x30mm shredded size of HDPE waste, where a 62% reduction was recorded. It can thus, be concluded that the wider the HDPE shredded size and the higher the polyethylene the concentration in Igbokoda sand polyethylene mixture, the higher the reduction in the coefficient of permeability. A reduction the void ratio, porosity and interconnection of pores in the Sand-HDPE waste mixtures, has resulted in the reduction in coefficient of permeability with increase in polyethylene strip concentrations and size.

10. CONCLUSIONS AND RECOMMENDATIONS

10.1 Conclusions

The following conclusions can be drawn based on the results of various tests conducted to determine engineering properties of Igbokoda sand - shredded HDPE waste mixtures:

- i. Shredded HDPE waste usage in soil improvement has the potential to reduce the environmental menace of plastic wastes.
- ii. Addition of shredded HDPE waste in Igbokoda sand increased its cohesion value and angle of internal friction.
- iii. Maximum improvement of approximately 28% was obtained in the internal angle of friction with 15x20mm strip @ 2% concentration by weight which has the potential to enhance the shear strength and bearing capacity of Igbokoda sand.
- iv. Maximum cohesion of improved Igbokoda sand was twice that of ordinary Igbokoda sand.
- v. Addition of shredded HDPE waste reduced the coefficient of permeability of Igbokoda sand. The permeability reduced with increase in strip size.

10.2 Recommendations

- i. Further research into the application water sachet waste granules with various binder additives for the improvement of various soil types.
- ii. Establishment of collection scheme for water sachet wastes and the development of recycling facilities for the conversion of plastic wastes to useful products in Nigeria.

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