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ENGINEERING CHARACTERISTICS OF SOILS REINFORCED WITH SHREDDED PLASTIC WASTE

G. O. Adunoye[1*], O. T. Akanbi[2], G. H. Odusina[3] and A. S. Faloye[3]

[1]Department of Civil Engineering, Obafemi Awolowo University, Ile-Ife

[2]Department of Mechatronics, Bowen University, Iwo

[3]Department of Civil Engineering, Obafemi Awolowo University, Ile-Ife

[*]Corresponding E-mail: kayadunoye@yahoo.com

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ABSTRACT: *There is a continuous attempt at seeking different, economical and environmental-friendly means of improving the strength of soils. This work therefore studied the effects of shredded plastic waste (SPW) on the strength of selected soils. To achieve the aim of the study, lateritic soil samples were collected from two identified active borrow pits in Ile-Ife. Following standard procedures, the following tests were conducted on the soils in their natural state: natural moisture content, grain size analysis, specific gravity, Atterberg limits, compaction, and California bearing ratio (CBR). Subsequently, the soils were treated with SPW in 4 %, 8 % and 12 % proportion by weight of soil respectively. They were then subjected to compaction and CBR tests. The natural soils were found to have the following characteristics for sample A and sample B respectively: specific gravity (2.70 and 2.51); liquid limit (40.40 % and 61.00 %); plastic limit (23.11 % and 36.67 %); plasticity index (17.29 % and 24.33 %); American Association of State Highway and Transportation Officials (AASHTO) classification (A-3 and A-2-7); maximum dry density (MDD) (1430 kg/m^3 and 1510kg/m^3); and optimum moisture content (OMC) (21.13 % and 48.0 %). Results further showed that the addition of SPW led to a slight improvement in the strength characteristics of the tested soils. The study concluded that SPW could be used to improve the strength of lateritic soils.*

KEYWORDS: Compaction, Engineering, Characteristics, Plastic Waste, Soil Stabilisation, Strength Properties.

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INTRODUCTION

Plastics are non-renewable and non-biodegradable materials. They are inexpensive, lightweight and durable materials, which can readily be moulded into a variety of products that find use in a wide range of applications. On an average, an individual uses 18 kg of plastic per year. The production and use of plastics have increased and continue to increase remarkably over the years, and it has found its use in vital sectors of the economy. Also, records have it that approximately 4,000–5,000 ton per day plastic wastes are generated, and that these materials can stay unchanged for as long as 4,500 years on earth (Singh & Dixit, 2017). The disposal of plastic wastes causes environmental pollution. Therefore, plastic waste is a sustainable waste which can be recycled or reused (Adeyemi & Olubunmi, 2015).

Failures of engineering structures are common due to non-usage of soils with adequate engineering strength. As a result, improvement of the engineering strength of soils has been the major concern of engineers and researchers. Soil stabilisation therefore aims at improving the strength and quality of soils for engineering purposes. Considering the importance of soil stabilisation, different stabilisation methods and agents have been used and are being used over the years. However, there is an increasing effort in looking for alternative, cost-effective and environment-friendly materials for soil stabilisation. It has been found that for sustainable development, plastic wastes are being explored as an alternative soil stabilising agent. Stabilising soils with waste plastic materials has the dual benefits of solving the challenges of improper plastic waste recycling and improving the properties of soils for engineering purposes.

Choudhary *et al.* (2010) performed a laboratory evaluation on utilisation of plastic wastes for improving the subgrade in flexible pavement. They studied the effects of waste plastic strip (WPS) and strip length on selected soil. The soil was treated by adding WPS from 0.25 % to 4 % by weight of soil. Results showed that addition of WPS of appropriate size and proportions in soil led to an increase in both California bearing ratio (CBR) and secant modules of the soil.

Paramkusam *et al*. (2013) performed an experimental investigation on the stabilising effects of waste plastic on dry density and CBR of red mud, fly ash and red mud, and fly ash mixed with different percentages of waste plastic content. Authors concluded that the Maximum Dry Density (MDD) value of the red mud, fly ash mixed with plastic increased as the plastic content increased up to 2 %, while optimum value of CBR was observed at 2 % plastic content.

Thakare and Sonule (2013) did a laboratory investigation of the effects of reinforcing sandy soil with plastic water bottle. The soil was subjected to plate load tests. They observed that the ultimate bearing capacity of footing increased with increase in the number of layers of plastic bottles used as reinforcement, width of reinforcement and number of layers.

Mehrotra *et al*. (2014) also investigated the effects of high-density polyethylene (HDPE) plastic waste on the unconfined compressive strength (UCS) of black cotton soil. The soil was treated with the HDPE plastic waste (40 micron) in 1.5 %, 3 %, 4.5 % and 6 % by weight of dry soil. From their findings, authors concluded that the UCS of black cotton soil increased with the addition of plastic waste. Maximum value of UCS was observed at 4.5 % plastic content.

Poweth *et al.* (2014) investigated the effect of plastic granules on weak soil sample. The tested soil sample was treated with 0.25 %, 0.5 % and 0.75 % plastic gnanules by weight of soil. Highest value of MDD and lowest value of optimum moisture content (OMC) were obtained

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at 0.25 % plastic granules content, while the highest values of CBR and shear strength were recorded at 0.75 % plastic granules content.

Harish and Ashwini (2016) studied the effects of waste plastic strips (WPS) as a stabiliser for red soil and black cotton soil. They conducted compaction and CBR tests on the natural as well as the stabilised soils. They observed an improvement in the strength and CBR at 0.7 % content of WPS for the red soil and 0.5 % WPS content for the black cotton soil.

Kalliyath *et al.* (2016) studied the effects of plastic fibers as soil stabilisers. They conducted various tests, including compaction (standard proctor) and UCS on natural and stabilised samples of silty clay. They observed that the addition of 0.5 % plastic fiber content to the expansive soil led to a reduction in the OMC and an increase in the MDD and UCS. The authors therefore concluded that 0. 5 % is the optimum plastic fiber content for optimum results.

Tiwari and Tiwari (2016) also studied the effects of waste polypropylene fiber (PPF) on shear strength of selected unsaturated soil samples. They reported that the specific gravity of the soil increased by 0.3% at 0.5 % PPF content.

Subhash *et al*. (2016) conducted an experimental study on soil stabilised with glass and plastic granules mixed with soil in varying percentages. Authors observed a decrease in MDD of soil with the addition of glass and plastic in varying percentages. However, the addition of the stabilising mixture led to an increase in UCS and CBR.

Singh and Dixit (2017) did a review of the various soil stabilisation efforts using waste plastic material. From their review of the work of researchers, they observed and concluded that the inclusion of plastic in soils can improve the strength, thus increasing the soil bearing capacity of the soil.

Mali *et al.* (2019) undertook a study of soil stabilisation using plastic waste. After their experimental investigation on both the natural and treated soils, they concluded that plastic strips in optimum amount with suitable dimension could be used for improving the engineering properties of soil.

Sai and Srinivas (2019) studied the effects of plastic waste granules on strength of soil. Plastic waste and plastic granules were mixed randomly with the soil at varying percentages. Compaction, CBR and UCS tests were conducted on natural soil and stabilised soil. Results showed that the inclusion of waste plastic and plastic granules in soil in appropriate amounts improved strength and deformation behaviour of subgrade soils substantially.

Gupta *et al.* (2019) did a review on stabilisation of soil using plastic waste as an additive. After their review of the works of various researchers (Choudhary *et al.*, 2010; Ashraf *et al.*, 2011; Manjari *et al.*, 2011; Harish & Ashwini, 2016; Singh & Dixit, 2017; Fauzi *et al.*, 2016; Chebet & Kalumba, 2014), they concluded that there addition of plastic (HDPE) in the soil improves the engineering properties of the soil.

Kassa *et al.* (2020) also studied soil stabilisation using waste plastic materials. They made an attempt to reinforce and stabilise expansive clay soil with plastic bottle strips. The plastic strips were prepared and added at 0.5 %, 1 % and 2 % proportions by weight of the dry soil, and in three different aspect ratios (5 mm × 7.5 mm, 10 mm × 15 mm and 15 mm × 20 mm). Results showed that the addition of plastic material led to a significant improvement in the shear

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strength parameters of the soil. The swelling and desiccation cracking behavior of the soil were also significantly reduced. There was a substantial reduction in the OMC and increase in MDD, which signifies an improvement in the soil. Authors concluded that the inclusion of plastic material in expansive soils would be effective for ground improvement in geotechnical engineering, and that the optimum plastic size (aspect ratio) and plastic content that give optimum result can be selected based on the particular selected parameters for a specified engineering work.

The outcome of this study is expected to contribute to existing knowledge in the improvement of soil strength using plastic wastes. The aim of the study was to investigate the effects of shredded plastic waste (SPW) on the strength of soil. The specific objectives were to: (i) characterise the selected lateritic soil samples, (ii) determine the strength characteristics of the soils in their natural state, and (iii) determine the effect of SPW on the strength characteristics of the soils.

MATERIALS AND METHODS

Materials and Equipment

The main materials used for this study included lateritic soil samples and shredded plastic waste. The equipment used were: a set of British Standard sieves, mechanical sieve shaker, chemical weighing balance, sensitive balance, drying oven, Cassagrande apparatus for Atterberg limit test, compaction tools and CBR machine.

Methods

Lateritic soil samples were collected from two identified active borrow pits in Ile-Ife. A sample was collected from each borrow pit. Twenty-five kilograms (25 kg) of the soil samples were collected, using disturbed sampling method, with the aid of hand auger. The soils were collected in polythene bags, carefully wrapped and transported to the Geotechnical Engineering Laboratory of the Department of Civil Engineering, Obafemi Awolowo University (OAU), Ile-Ife. Natural moisture content was immediately determined at the laboratory and the soils were spread and air-dried for further laboratory tests.

Collection and Preparation of Shredded Plastic Waste (SPW)

The shredded plastic waste was collected from Greenhill Recycling Company in Lagos, Nigeria. The shredded plastic waste was washed free of any dirt or contaminant and then air-dried for a minimum of 24 hours under atmospheric conditions, to bring its moisture content to the minimum.

Preliminary and Geotechnical Test on Soils in Their Natural State

The following preliminary and geotechnical tests were carried out on soil samples in their natural state: natural moisture content, particle size analysis, specific gravity, Atterberg limits, compaction and CBR. All the tests were conducted following standard procedure as outlined in BS 1377 (1990).

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Determination and Evaluation of Strength Properties of Soil After the Addition of SPW

SPW was added to the soils in 4 %, 8 % and 12 % proportions by weight of soil. Strength tests (compaction and CBR) were subsequently conducted on the treated soils, and the results were evaluated and compared with that of the natural samples, to ascertain the effect of SPW on the tested soils.

RESULTS AND DISCUSSION

Results of Preliminary and Engineering Tests on the Soil in Their Natural State

Table 1 presents the results of geotechnical tests conducted on the soils in their natural state.

The void ratio of lateritic soil is the predominant factor that affects the moisture content; therefore, the lower the moisture content, the lower the void ratio and the better the soil (Jackson & Dhir, 1997). It is therefore clear that Sample A has a lower void ratio (see Table 1).

The specific gravity of the solids making up a given soil sample is useful mainly for deriving other needed properties of the soil. According to Lambert and Whiteman (1969), the specific gravity of most lateritic soils falls within the range of 2.65–2.85. The specific gravity of lateritic soils are generally very high, and these high values are associated with the gravel fraction in which the iron oxides tend to be concentrated. The specific gravity values of the tested soils indicate that the degree of laterisation is between moderate and high in the soils (see Table 1).

According to Das (2006), a soil is said to be clayey soil if it has a plasticity index greater than or equal to 11. It is therefore evident that the tested soils were clayey. The results of Atterberg limit tests and grain size analyses were used to classify the soils. According to the classification by the American Association of State Highway and Transportation Officials (AASHTO), the soil samples were found to belong to A-3 (sample A) and A-2-7 (Sample B) groups (Table 1).

Compaction and CBR tests give indications of the strength of the soils. Considering the results of the preliminary tests, Sample A has a lower OMC (see Table 1). The CBR values of the soils in their natural state are low (less than 10 %), which indicates that the soils in their natural state are only good for subgrade filling in road construction (FMWH, 1997), and they need improvement or treatment to increase their strength for pavement or foundation design.

Effect of SPW on Soil Samples

Figure 1 presents the variation of OMC with SPW contents. According to Lambe and Whitman (1969), the lower the OMC, the better the soil and its workability and vice versa. For Sample A, the lowest was obtained at 0 % SPW content (natural state), which implies that the addition of SPW to Sample A did not improve the soil, with respect to the OMC. It could be explained that the SPW has created more void spaces due to its size, making the soil less compacted. However, for Sample B, the lowest OMC (best soil performance) was achieved at 8 % SPW composition. Figure 2 shows that for the two soil samples, the highest values of MDD was observed at 4 % SPW.

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Table 1: Results of geotechnical tests on soil samples in their natural state

Properties	Sample A	Sample B
Natural moisture content: (%)	33.33	34.7
Specific gravity	2.7	2.5
Liquid limit (%)	40.4	61
Plastic limit (%)	23.11	36.67
Plasticity index (%)	17.29	24.33
Percentage passing sieve No.200	4.08	1.02
Percentage passing sieve No.40	38.62	32.2
AASTHO Classification	A-3	A-2-7
Optimum moisture content (%)	21.13	48
Maximum dry density (kg/m^3)	1430	1510
California bearing ratio (%)	3	7

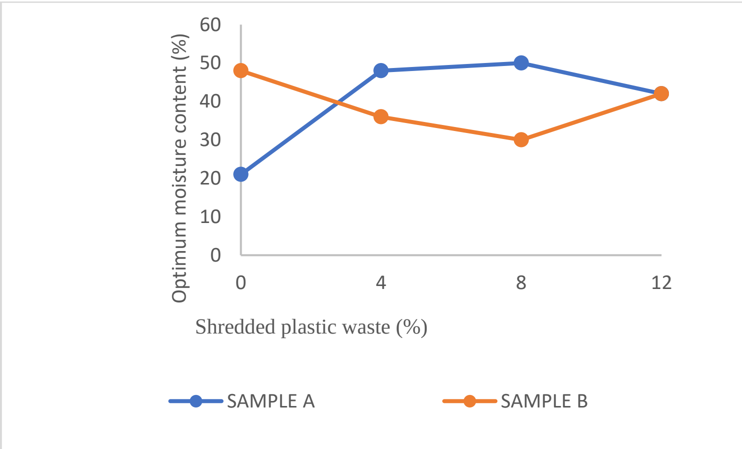

Figure 1: Variation of OMC with percentage SPW

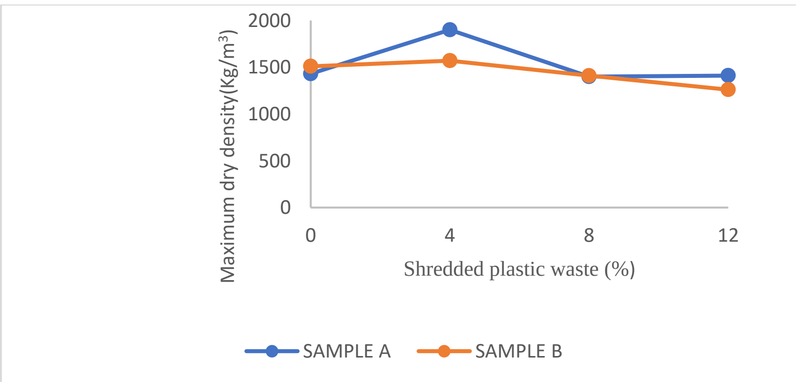

Figure 2: Variation of MDD with percentage SPW

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Figure 3 shows that for the two soil samples, the CBR generally increased with increase in SPW content. The highest values of CBR were obtained at the highest SPW content (12 %). The increase in CBR values was observed not to be high enough to make the stabilisation of the soils with SPW a reliable exercise. This observation may be as a result of the size of the SPW not making the soil samples to be well compacted and so not increasing the strength by a considerable amount.

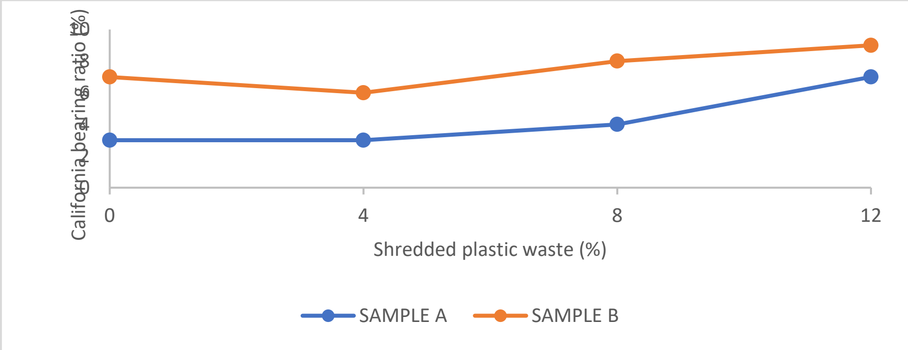

Figure 3: Variation of CBR with SPW content

CONCLUSION

This study investigated the effects of SPW on strength characteristics of soils. The following conclusions are drawn in line with the objectives of this study: (i) The tested soil samples were found to belong to A-3 (sample A) and A-2-7 (sample B), according to AASHTO classification; (ii) the strength properties of the soils showed that, in their natural state, the soils are only suitable for subgrade fill, and addition of SPW to the soils increased their strength characteristics, though the increase was observed to not be impressive.

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