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Effect of Addition of Carpet Waste Fibres on the Unconfined Compressive Strength of Cohesive Soils Samples from Umutu, Agbor and Obiaruku in Delta State, Nigeria

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ABSTRACT: With the latest trend in the beautification of most homes and offices, there has been a great shift from the use of carpets to floor tile and as such most of these carpets have become waste and causing environmental pollution. Therefore the objective of this paper was to evaluate the effect of adding carpet waste fibre on unconfined comprehensive strength of cohesive soil samples from Umutu, Agbor and Obiaruku in Delta State, Nigeria using standard techniques. The results showed that the maximum dry density (MDD) of the natural soil samples from Umutu, Agbor and Obiaruku were 1.76g/cm^3, 1.73 g/cm^3 and 1.72 g/cm^3 respectively while their respective OMC were 13.6%, 13.86% and 14.2%. The UCS of the natural soil samples were 68.6kN/m^2, 73.77kN/m^2 and 76.69kN/m^2 respectively. The MDD decreased from 1.73 g/cm^3 to 1.675g/cm^3, 1.72g/cm^3 to 1.66g/cm^3 and 1.71 g/cm^3 to 1.63 g/cm^3 when the natural soils from these study areas respectively were compacted with 0.1% to 0.4% fibre content. Also, the OMC from the respective soils-fibre mix increased from 13.8% to 19.0%, 16.0% to 19.6% and 14.9% to 19.2% respectively. The UCS for the respective soil-fibre mix decreased from 60.38kN/m^2 to 52.65kN/m^2, 66.28kN/m^2 to 57.70kN/m^2 and72.39kN/m^2 to 57.27kN/m^2. Hence, the study showed that the addition of fibre to natural soil decreases the strength of the soil.

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Synthetic fibres are artificial materials with chemical composition, structure and properties altered during the manufacturing process. They are woven into a large number of consumer and industrial products such as clothes, scarves, carpets, ropes and also artificial hairs. The chemical compounds from which these fibres are produced are referred to as polymers. Most polymers that form synthetic fibres are the same as those compounds that make up plastics, rubbers, adhesives and surface coating. Fibres are known for their strength, toughness, resistance to heat, and ability to resist compression (Mahir et al., 2019). Geosynthetics is the improvement of the civil engineering performance of civil engineering works involving soil by the exclusive use of materials that are artificial products. The materials that are used in the manufacturing of geosynthetics are basically synthetic polymers derived from crude petroleum oil; though rubber, fibrous glass and other materials are also used for the manufacturing geosynthetics (Shukla, 2017). Some materials alter the properties of the soils thereby making them very potent stabilizers. Studies have been carried out using different fibrous materials like human hair, coir fibres, shredded waste plastic bottles, scrap tires and polypropylene fibre. But most of these studies were conducted by the addition of cementitious materials to the soil fibre composite (Abdi et al., 2021; Li et al., 2021; Selvan et al., 2018). The use of geo-polymers has proven to increase the strength properties of soils so also are other chemical additives. Waste includes those materials that have been discarded and no longer useful to anyone. In this case, carpet wastes are synthetic fibres that are made from a low-grade acrylic that is heated and strung into yarn to make rugs. With the use of tiles as most household flooring material, the use of carpets has been on the decline as such, many have discarded the use of rugs for the beautification of their houses. Since, these products are not easily biodegradable, they tend to pose as danger to the environment, as they form part of municipal solid waste. Hence, there is a need to find an alternative use of this, and thereby reducing the cost of some engineering works. Cohesive soils are fine grained soils with low-strength, easily deformable and have the ability of the particles to stick to one another. The soil is termed cohesive if the fines content that is the silt and clay-sized material in the soil exceeds 50% by weight. These soils are soils that have high clay content, high plasticity, and greater shrinkage and swell potential, high compressibility and low shear strength. Soils from the Anioma part of Delta State of Nigeria tend to be cohesive in nature, as they have high plasticity, and low shear strength, and as such led to the failures of some road pavements constructed on them, as they cannot withstand the vehicular loads that are constructed on them. In addition to their strength, they also have high compressibility which give rise to the high rate of consolidation; hence most structures are constructed on deep foundations. The construction cost is also high as most of these soils are carted out of the site, and replaced with suitable soils. Carpet waste is becoming an increasing constituent of the most landfill waste since the acceptability of tiles in building flooring purposes. Thereby, making the former to be out of date. The replacement of carpet with tiles, have made carpet which is synthetic in nature and is not biodegradable to become a nuisance to society and hence needed to be discarded without harming the environment. This paper ascertains the effect of using carpet waste as a synthetic fibre on the compressive strength of cohesive soils, thereby reducing the waste that are produced from discarded carpet waste, and also reinforcing cohesive soils could be used as fills for embankment, backfills for retaining walls and the construction of road pavements. Many researchers have worked on the soil reinforcement using geo-synthetic fibre materials (Carlos et al (2016);Kaniraj and Fung (2018); Hejazi et al., (2012); Mehrotra et al (2014); Mishra (2016); Pathan et al (2017); Ramirez et al (2015); Suresh et al (2018); Singh and Dwivedi (2018); Vajrala and Yenigalla (2019); Karimah et al (2021);Neeraja (2017); Ghosh et al., (2014); Nair and Deepthy (2017); Singh and Yadav (2016); Son and Lee (2018); Mirzababaei et al (2013)). From the reviews it was observed that most of the contributors worked on the soil reinforcement of clay soils by the use of synthetic materials that are readily available. These soils were not local with respect to our environment and our peculiar challenges. Therefore, the objective of this paper was to evaluate the effect of adding carpet waste fibre on unconfined comprehensive strength of cohesive soil samples from Umutu, Agbor and Obiaruku in Delta State, Nigeria

MATERIALS AND METHODS

Study Area: Umutu, Agbor and Obiaruku known as the Anioma part of Delta state is the Igbo speaking part of the state that is connected to the eastern part of southern Nigeria. They are bounded on the East by Anambra State, south-east by Imo and Rivers States, south Bayelsa State, south-west by Isoko, west by Urhobo people, north-west by Edo State and north by Kogi State. Anioma may therefore be regarded to be highly connected to very many neighbouring ethnic groups which boost agricultural business activities in the areas.

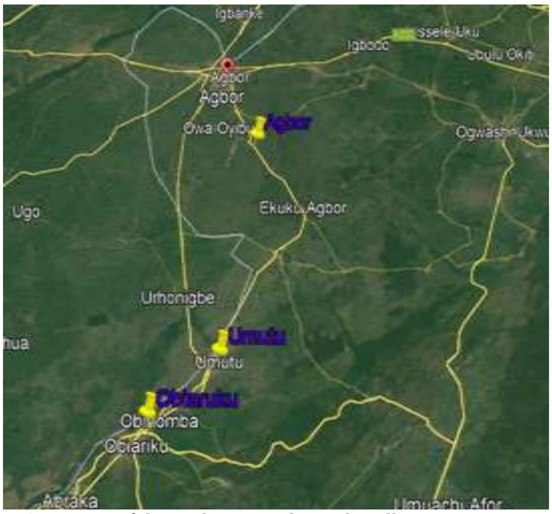

Fig 1: Map of the study area and sample collection Locations (Source: Google Earth)

Waste Carpet Fibre Sample Collection and Preparation

The materials that were used for this study include soils and fibres obtained from used carpet (rug).

The carpet that was used in this research study was the tufted type. Tufted carpets are produce by inserting tufts into the backings by means of needles. Typically, it consists of two layers of backing (usually polypropylene fabrics), joined by $CaCO_3$ filled styrene-butadiene latex rubber (SBR), and face fibres that are tufted into the primary backing (Lowery, 2020). The carpet fibres were supplied as 100% nylon 6 sheared piles from tufted carpets. The average length of these fibres was measured, and the range was from 15 to 25 millimetres in length. The backings and other additives were excluded from the batch. This implies that only the yarns that form the fibre were used for the purpose of this study. Plates 1 and 2 shows how the fibres were obtained from the carpet waste.

Plate 1 Removal of the Yarn from the Carpet

Plate 2: Separation of the fibre

Soil Sample Collection: For the purpose of this research, on evaluating the effect of fibre reinforcement on the unconfined compressive strength of cohesive soils, about 300kg each of disturbed cohesive soil sample were collected from three points along roads Umutu, Agbor and Obiaruku (Delta state) at a depth of 1m from the ground surface by means of a hand auger. The coordinates of the respective points of collection are 5°55'04''N and 6°13'04''E from Umutu, 6°9'44''N and 6°14'44''E from Agbor and 5° 51'24''N and 6°9'52''E from Obiaruku as shown in Figure 1. The soils obtained from Umutu are labelled SO1, those from Agbor SO2 and those from Obiaruku are labelled SO3, respectively.

Characteristics of Natural Soil from study area: The following laboratory tests were carried out on the natural soil samples: specific gravity test, particle size distribution tests, Atterberg limits tests which are the liquid limit and plastic limit test, compaction tests to determine the optimum moisture content and maximum dry density of the natural soils and Unconfined Compressive Strength Tests in accordance with BS 1377 (1990) standard. The natural soils were thereafter reinforced with the carpet fiber in the proportion shown in Table 1. Unconfined compressive strength tests were carried out on the reinforced samples using their respective ordinary moisture content (OMC) and maximum dry density (MDD) as obtained from the compaction test.

Table 1: Percentage Composition of Soil + Fibre

Description	Soil (%)	Fibre
SO1	100	0
SO1 0.1	99.9	0.1
SO1 0.2	99.8	0.2
SO1 0.3	99.7	0.3
SO1 0.4	99.6	0.4
SO2	100	0
SO2 0.1	99.9	0.1
SO2 0.2	99.8	0.2
SO2 0.3	99.7	0.3
SO2 0.4	99.6	0.4
SO3	100	0
SO3 0.1	99.9	0.1
SO3 0.2	99.8	0.2
SO3 0.3	99.7	0.3
SO3 0.4	99.6	0.4

0 represent the natural soil without the addition of fibre, 0.1 represent fibre content of 0.1%, 0.2 represents fibre content of 0.2%, 0.3 represent fibre content of 0.3% fibres and 0.4 represents the fibre content of 0.4%. These percentages are defined by the weight of the soil.

RESULTS AND DISCUSSION

The results of the laboratory tests on the natural soils as obtained from the location of study are as summarised in Table 2. From the specific gravity tests on the three soil samples, it can be seen that the specific gravity of the soils from the areas lies between 2.5 to 2. 64. Hence, the soils belong to the group of inorganic soils and sandy, as their specific gravity is greater than 2.00 (Hosni et al., (2015). The liquid limits of the soils are within the range of 31.2% to 41.0%, with the soil from Umutu having 38.0%, Agbor 31.2% and Obiaruku having 41.0%, while the plastic limits ranged from 15.72% to 19.96% with the samples from Umutu having the value of 19.96%, that from Agbor 15.72% and that from Obiaruku having 18.05%. With the liquid limits and the plastic limits known the plasticity index was calculated to be 18.04% for the sample from Umutu, 15.48% for that from Agbor and 22.95% from Obiaruku. Hence, since the liquid limits of all the soil sample are between the ranges of 31% to 50%, the soil can be said to be of intermediate plasticity. From the plasticity chart (BS 1377; Part 2: 1990), the soils from the three locations are above the A – Line and when plotted, they are said to be of inorganic clay of medium plasticity (CI).

Table 2: Summary of the laboratory Tests Results on Natural Soils

Tests	Soil Samples		
	SO1	SO2	SO3
Specific Gravity G_s	2.65	2.65	2.54
Atterbergs' Limits Tests			
Liquid Limit (%)	38.0	31.2	41.0
Plastic Limit (%)	19.96	15.72	18.05
Plasticity Index (%)	18.04	15.48	22.95
Particle Size Distribution			
Percentage passing Sieve 20	100	100	100
Percentage passing Sieve 40	87.15	86.95	87.95
Percentage passing Sieve 200	68.15	62.8	68.0

The particle size distribution results showed that the percentage passing the sieve mesh no 200 is 68.15% for the sample from Umutu, 62.8% from Agbor and 68.0% for that from Obiaruku. While the percentage passing sieve no 40 are 87.15%, 86.95% and 87.95% respectively, and those passing sieve 20 are 100%, 100% and 100% respectively. Therefore, the soils from the three locations are said to be clayey sand of intermediate plasticity. According to the AASHTO classification chart it can be seen that the soil samples all have their percentage passing sieve 200 are higher than 36%, the liquid limits of the samples from Umutu (SO1) and Agbor (SO2) are less than 40% while that of the sample from Obiaruku (SO3) is 41.0%. The plasticity indices were all greater than 11%. Hence, the soil samples from Umutu and Agbor belong to the A – 6 class, while that from Obiaruku belong to A – 7 – 5 class from the AASHTO chart. Compaction and Unconfined Compressive Strength (USC) Tests Results. The results of the compaction tests carried out on the natural soils alone and when reinforced with fibres are presented in Table 3.

Table 3: Summary of Compaction Test and UCS on the Soil with and without Fibre

Description	OMC (%)	MDD (g/cm^3)	qu (kN/m^2)
UMUTU SO1	13.6	1.76	68.6
SO1 0.1	13.8	1.73	60.38
SO1 0.2	14.2	1.71	57.56
SO1 0.3	16.0	1.69	57.46
SO1 0.4	19.0	1.675	52.65
AGBOR SO2	13.86	1.73	73.77
SO2 0.1	16.0	1.72	66.38
SO2 0.2	16.8	1.70	60.1
SO2 0.3	17.6	1.685	59.86
SO2 0.4	19.6	1.66	57.70
OBIARUKU SO3	14.2	1.72	76.39
SO3 0.1	14.9	1.71	72.39
SO3 0.2	15.6	1.68	66.02
SO3 0.3	16.9	1.66	64.01
SO3 0.4	19.2	1.63	57.27

From the results it can be seen that with the increase in the fibre content there is a corresponding increase in the optimum moisture content. The OMC increased by 1.47% when the sample from Umutu was compacted with 0.1% of fibre, 4.41% when compacted with 0.2%, 17.65% when compacted with 0.3% and 39.70% when compacted with 0.4% fibre contents respectively. Also, for the sample from Agbor, the OMC increased by 15.44% when compacted with 0.1%, 21.21% with 0.2%, 26.98% with 0.3% and 41.41% when compacted with 0.4% fibre content respectively. And for the sample from Obiaruku, with 0.1% of the fibre content the OMC increased by 4.93%, 9.86% with 0.2% fibre content, 19.01% with 0.3% fibre content and 35.21% when compacted with 0.4% fibre content. This can be attributed to the absorption of water on the dry soil - fibre mix. It can also be seen that with the increase in the fibre contents there is a corresponding decrease in the maximum dry density of the soils from the different sample locations. It was observed that for sample from Umutu, the dry density decreased by 1.70% when compacted with 0.1% fibre content, 2.84% when compacted with 0.2% fibre content, 3.98% when compacted with 0.3% fibre content and 4.83% when compacted with 0.4% fibre content. For the sample from Agbor, the dry density decreased by 0.58% when the fibre content is 0.1%, 1.73% when fibre content is 0.2%, 2.60% when fibre content is 0.3% and 4.05% when the fibre content is 0.4%. And, for the sample from Obiaruku, with the addition of 0.1% fibre content the dry density decreased by 0.58%, that with 0.2% fibre content decreased by 2.33%, with 0.3% fibre content by 3.49% and with 0.4% it decreased by 5.23%. The decrease is as a result of the replacement of the soil grains with the fibres, as it has less specific gravity and weight in comparison to that of the soil grains and the soil to fibre reaction tend to reduce the friction hence reducing the compaction energy. This shows there the effect on the addition of fibres to ordinary soil reduces the maximum dry density in line with the studies conducted by Mirzababaei et al. (2013) and Hejazi et al. (2012). The UCS of the natural soil samples were 68.8kN/m^2, 73.77kN/m^2 and 76.39kN/m^2 respectively. This shows that the soil is medium to firm soil, according to Das (2012), soil that is of medium to firm characteristics lie within the range of 50 -100kN/m^2.The addition of fibre within the range of 0.1% to 0.4%, to the natural soils gave a good mix, as mixing above this results in the mixture not being consistent. The unconfined compressive strength of the fibre soil composite from the three soil samples were 60.38kN/m^2, 57.56 kN/m^2, 57.46 kN/m^2 and 52.65 kN/m^2 for that from Umutu. That from Agbor have the corresponding decrease in the UCS as 66.38kN/m^2,60.10 kN/m^2, 59.86kN/m^2, and 57.70kN/m^2. And the sample from Obiaruku with the corresponding fibre content are 72.39kN/m^2, 66.02kN/m^2, 64.01kN/m^2 and 57.27kN/m^2. These indicate that with the with the fibre content increasing from 0.1 to 0.4%, there is a decreasing trend in the UCS.

Conclusions: It can be concluded that the addition of synthetic fibre to cohesive soil have an impact of the strength of the soil. With the increase in the fibre the weight of the soil fibre composite will be on the decrease hence, leading to a corresponding decrease in the MDD. Based on the experimental results, observation and conclusion, it is hereby recommended that more studies be carried out by increasing the cohesion of the soils with the addition of materials that have high plasticity and cohesion. Such materials like bentonite and lime.

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