Improving the Geotechnical Properties of Lateritic Soils Using Microfiber Plastic Waste: A Case Study

[1]J. O. Konduah, [2]A. K. Klu and [2] E. N. Asare

[1] Goodwill Geospatial Consults. P. O. Box 12, Bogoso. Ghana
[2] Geological Eng. Dept., University of Mines and Technology, P. O. Box, 237, Tarkwa, Ghana

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Abstract

Plastics have become the most abundantly generated solid wastes in the last three decades and have become an environmental nuisance. In light of this, industry players have tried to adopt models, techniques and mechanisms to harness their non-biodegradable properties and to reuse them for the benefit of society. This paper focuses on the impact that Low Density Polyethylene (LDPE) microfiber has on the geotechnical and hydraulic properties of lateritic soil from Heaven Nkwanta in the Prestea-Huni Valley Municipality of Western Region, Ghana. Particle Size Analysis, Specific Gravity Test, Atterberg Limit Test, Proctor Compaction Test, Direct Shear Test and Constant Head Permeability Test were conducted on the lateritic soil samples to assess the behaviour when mixed with varying concentrations of the Microfiber Plastics (< 600 μm). Specific Gravity results obtained for the MFP was 0.545, while 2.47 to 1.15 were recorded for MFP at 0% to MFP at 50%. The laterite had a well-graded silty-gravel texture with intermediate plasticity of 17.76 %. Upon adding Microfiber Plastic (MFP), the plasticity of the laterite decreased progressively to 9.88 % at 30 % MFP. Shrinkage reduced from 12.06 % at 0 % MFP consistently to 8.57 % at 30 % MFP, increasing to 9.43 % at 50 % MFP. The Maximum Dry Density (MDD) decreased gradually from 2.19 g/cm^3 at 0 % MFP to 1.35 g/cm^3 at 40 % MFP. Optimum Moisture Content (OMC) increased from 10.38 % at 0 % MFP to 14.06 % at 30 % MFP. Frictional angles increased from 31.55 ° at 0 % MFP to 48.54 ° at 30 % MFP. The hydraulic conductivity decreased progressively from 0.078 cm/s at 0 % MFP to 0.004 cm/s at 40 % MFP. The highest cohesion was obtained to be 7.98 kPa at 20 % MFP with the lowest being 4.14 kPa at 10 % MFP. It was observed that the addition of Microfiber Plastic to the lateritic soil improved upon its strength and index properties. The optimal reinforcement benefits were observed at 30 % MFP addition to the laterite.

Keywords: Microfibre Plastic Waste, Lateritic Soils, Geotechnical Properties

1 Introduction

Research has revealed that by 2050, 12000 metric tonnes of plastics will be discarded into landfills which will pose environmental challenges such as diminishing landfill space for disposal. Hence there is a need for reuse of these plastic wastes for the benefit of society (Geyer *et al.*, 2017). Researches are ongoing to find environmentally friendly techniques in utilizing these plastic wastes (Abdelwahab *et al.*, 2017; Bui, 2001). Mancini and Zanin (2004) used neutral hydrolysis reagent technique which is environmentally friendly to recycle plastic wastes. Dankwah *et al*. (2016) also assessed the effect of catalytic loading during the production of liquid fuels from discarded empty water sachets.

Laterites are the predominantly used geologic materials in variety of highway and building in the tropical regions. Untreated lateritic soils are problematic when used for road construction such that, they trigger lateral movements, pavement swells and deformation in the presence of water (Ogundipe, 2012). Christophe (1949) reported that hydrocarbon binders specifically bitumen have good adhesion effect with laterites. Research done by Swami *et al*. (2012) reveals that by partially replacing bitumen with 10 % liquefied plastics, there is a significant reduction in the stripping and penetration values of aggregates. Gangadhara *et al*. (2016) concluded that there is inhibition in settlement when circular footing is made to rest on soils reinforced with plastic strips. Addition of the plastic strips to the soil increase its load bearing capacity. There is an increment in the reinforcement benefit of clays when mixed with pulverized glass and plastic; this renders them suitable for pavement construction (Gowtham *et al*., 2018). Ibrahim *et al.* (2014) also confirmed that inclusion of plastic strips to gravelly soils will serve as hydraulic barriers to obstruct fluid seepages in engineering works.

Using synthetic and natural fibers in their microstate to reinforce soil will help solve the problem of heterogeneities in strength properties (Choudhary *et al.*, 2010; Hejazi *et al.*, 2012; Jamellodin *et al.*, 2010; Puppala and Musenda, 2000; Nnochiri *et al.* 2017). Therefore, this project is focused on using a more adoptive technique to grind synthetic fibers into fine particles to assess their interactions with the soils they are mixed with in varying proportions.

2 Location and Geology

The materials studied were collected from Heaven Nkwanta, a village in the Prestea-Huni Valley District of the Western Region of Ghana. It is about 26 km by road northeast of Tarkwa and has a GPS location of Latitude N 05^0 29′ 59.13″ and Longitude W 001^0 53′ 18.64″. Fig 1 depicts a map of the study area. Heaven Nkwanta is geologically suited within the Tarkwaian system; more precisely the Huni Sandstone formation which forms the uppermost part of the system (Fig. 1). The soil is silty-sand interbedded with minor patches of laterites capping the plateaus (Kuma and Younger, 2001). The laterites characterized iron oxides concretions. The soils in this system consist of mostly silty-sands with minor patches of laterites, mainly on hilly areas (Kuma and Younger, 2001).

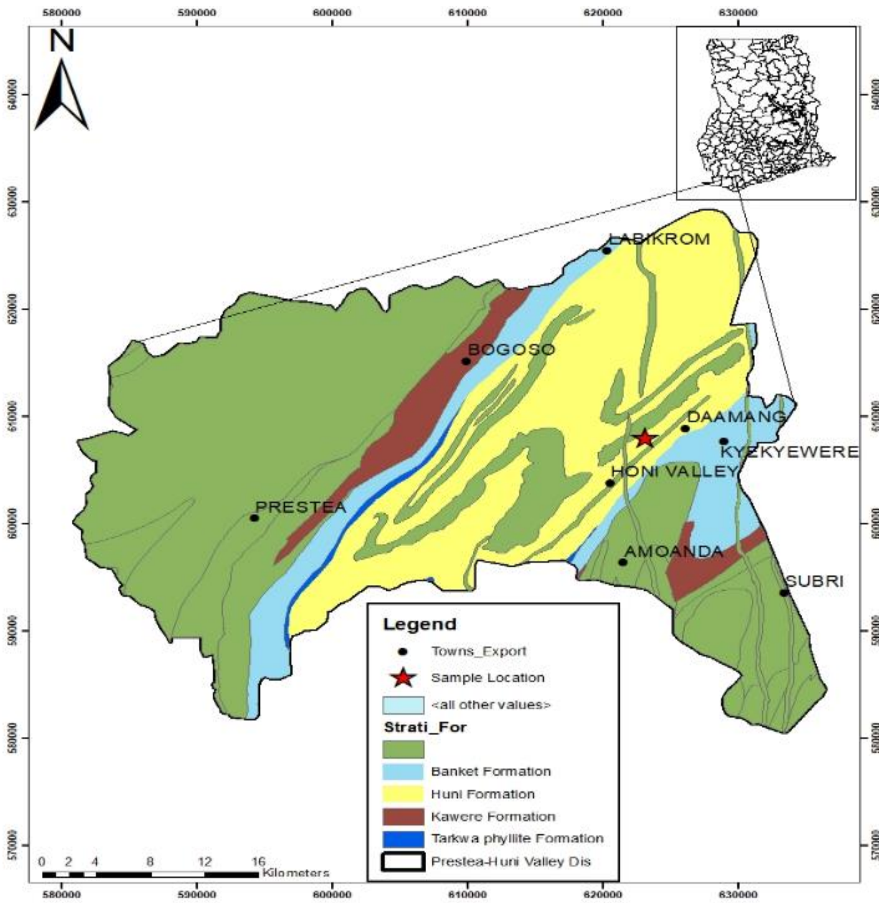

Fig. 1. Geology Map of Heaven Nkwanta

The geological formations in Huni Valley – Heaven Nkwanta are mostly the Birimian and Tarkwaian rocks. The Birimian Group underlying the Tarkwaian Group consist of metamorphosed lava and pyroclastic rocks, which contains significant amounts of greywackes, phyllites and intrusive rocks (Kesse, 1985). The Tarkwaian system is made up of a sequence of clastic sedimentary rocks which comprises sandstones, conglomerates and phyllites.

The Tarkwaian system is subdivided into four: The Kawere Group is the oldest group and consist typically of shallow-water, greenish grey feldspathic, carbonate-spotted quartzites, grits, breccias and conglomerates. The Banket series represents a fluviatile series. It is essentially an accumulation of high energy, coarse clastics, represented by conglomerates, grits and quartzites which have suffered low-grade metamorphism to chloritization and sericitization. The Tarkwa Phyllite consists of chloritoid and magnetite or hematite. Colour banding is common due to alternating bands of sericite and chlorite. The Huni sandstone is the weathered representation of feldspathic quartzites which are in general finer grained than the Banket series quartzites. They contain varying amounts of feldspar, sericite, chlorite, ferriferous carbonate, magnetite and epidote (Kesse, 1985; Junner *et al.*, 1942).

3 Methods Used

Field and Laboratory works were done to acquire relevant data for the study. Field work comprised plastic waste collection and preparation while lab work included soil index tests, mechanical behaviour tests and hydraulic behaviour test. The list of tests conducted during this study is as follows:

Index behaviour

- Specific Gravity
- Particle Size Distribution
- Atterberg Limit

Mechanical behaviour test

- Proctor Compaction
- Direct Shear
- Hydraulic behaviour test
- Constant Head Permeability

3.1 Field works

The field work entailed plastic waste collection and preparation. Disposed Light Density Polyethylene (LDPE) were collected from dustbins in large quantities and then segregated. Afterwards, they were washed and air dried. The materials were then melted and quenched, after which they were grinded and then sieved (Fig. 2)

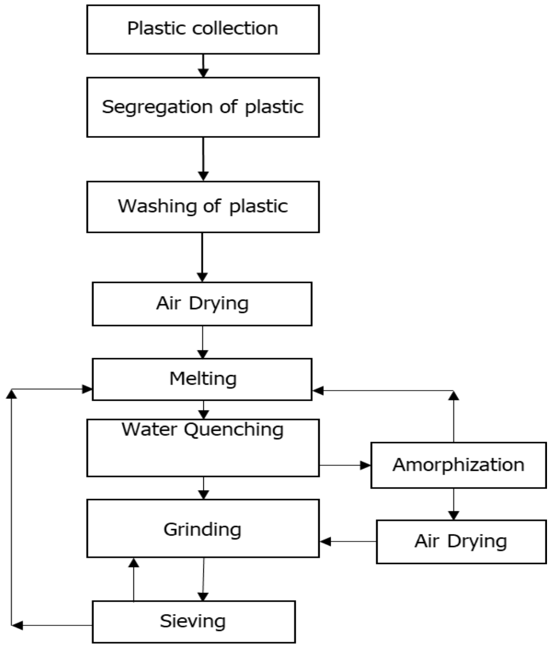

Fig. 2. Plastic Waste Collection and Preparation Process

3.2 Laboratory Works

The retrieved bulk soil samples were air dried to determine the in – situ moisture content. The grinded plastic fibers were sieved using the 600 µm BS sieve. The plastic fiber passing the 600 µm sieve aperture were used to conduct the tests. The test works were conducted for 0 % (laterite only), 10 %, 20 %, 30 %, 40 % and 50 % by weight of laterite replaced with the Microfiber Plastics (MFP) with the exception of the particle size distribution tests which were performed on the laterite and microfiber plastic (MFP) only. All the geotechnical test works were performed in accordance with the British Standard as stated below:

Specific Gravity Test (*BS 1377: 1990, Part 2*)
Particle Size Analysis (*BS 1377: 1990, Part 1*)
Atterberg Limit Tests (*BS 1377: 1990, Part 2*)
Proctor Compaction Test (*BS 1377: 1990, Part 4*)
Constant Head Permeability Test (*BS 1377: 1990, Part 5*)
Direct Shear Test (*BS 1377: 1990, Part 7*).

4 Results and Discussions

The table below (Table 1) represents the summary of the results obtained from the various geotechnical laboratory works upon adding different proportions of the MFPs to the lateritic soil:

Table 1 Summary of the Geotechnical Laboratory Tests Results

Sample ID / Parameters	100 % SOIL	SOIL+ 10 % MFP	SOIL+ 20 % MFP	SOIL+ 30 % MFP	SOIL+ 40 % MFP	SOIL+ 50 % MFP	100 % MFP
Specific Gravity	2.519	2.470	1.767	1.323	1.147	1.180	0.545
Particle size distribution							
Gravel content (%)	≥ 59						
Sand content (%)	≤ 15						
Silt content (%)	≥ 28						
Clay content (%)	≤ 4						
Coefficient of Grading	0.32						0.99
Coefficient of Uniformity	10						2.36
Atterberg Limits							
Liquid Limit (%)	43.18	39.22	42.35	41.32	44.73	42.51	
Plastic Limit (%)	25.42	25.37	32.01	31.44	32.06	29.07	
Plasticity Index (%)	17.76	13.85	10.34	9.88	12.67	13.44	
Shrinkage Limit (%)	12.06	11.21	8.86	8.57	8.94	9.43	
Compaction							
Maximum Dry Density (Mg/m^3)	2.19	1.90	1.69	1.48	1.35		
Optimum Moisture Content (%)	10.38	11.86	13.01	14.06	13.27		
Permeability							
Hydraulic Conductivity (cm/s)	0.078	0.014	0.007	0.005	0.004		
Direct Shear							
Friction Angle (ϕ)	31.55	32.67	37.41	48.54	29.77	22.49	
Cohesion (kPa)	7.92	4.14	7.98	6.68	4.95	4.32	
MFP = Microfiber Plastic							

4.1 Specific Gravity

The specific gravity of the laterite was 2.514. When the percentages of MFP content were increased, the specific gravities decreased. The lowest specific gravity value was observed at 40 % and 50 % additions. The specific gravity for the MFP was 0.545 however, the standard specific gravity for the LDPE ranged between 0.91 – 0.99. The deviation in the specific gravity value is as a result of the water quenching process.

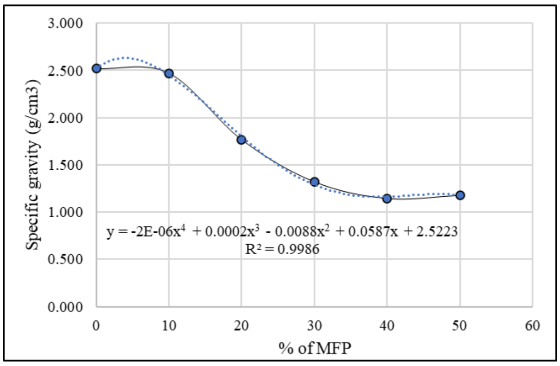

Fig. 3. A Correlation Between Specific Gravity and % of MFP

This distorted the mechanistic behaviour of the MFP used. The progressive decrease in specific gravities from 2.47 to 1.15 comes from the low specific gravity of the MFP (Fig. 3). Greater quantity of MFP is required to give a larger mass.

4.2 Particle Size Analysis

gives a summary of the particle size analysis for the natural lateritic soil and the MFP respectively. The Co-efficient of Uniformity of the lateritic soil was 10 which implies the lateritic soil was well graded gravelly soil with intermediate silts and sand (Table 2). The laterite used was reddish-brown with iron concretions. The clay content of the lateritic soil was very low (Fig. 4).

Table 2 Particle Size Description of Soil and MFP

Parameters	Sample	
	SOIL	**MFP**
Uniformity Co-efficient	10	2.36
Co-efficient of Gradation	0.32	0.99
Description	Well graded gravelly soil with intermediate silts and clays	Poorly graded microfiber plastic particles

From Fig. 5, the grading characteristics for the MFP was found to be poorly graded. The grinding energy had a big impact on the particle size distribution of the plastics materials used. The particle size distribution of the plastic material was dependent on the grinding energy and time.

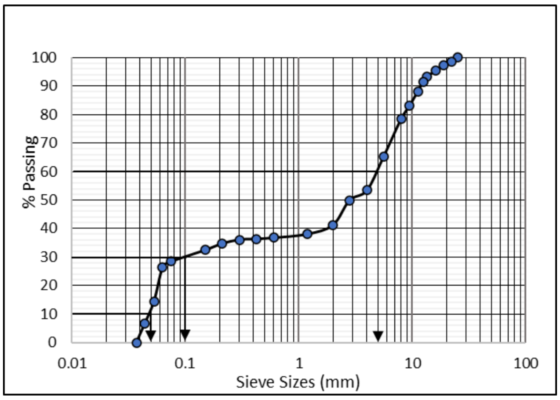

Fig. 4. Grading Curve for Laterite

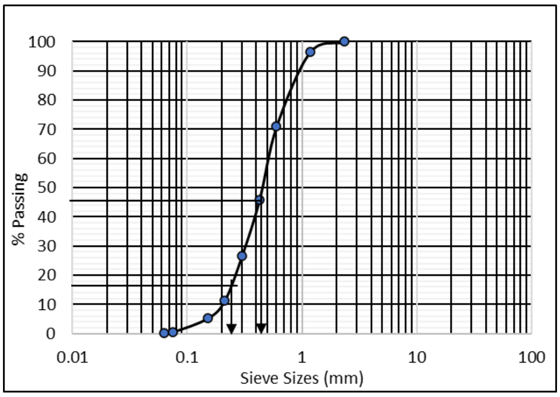

Fig. 5. Grading Curve of 100 % MFP

4.3 Atterberg Limit Tests

The indices of plasticity of the laterite decreased from 17.75 % to 9.89 % with increasing content of Microfiber Plastic from 0% - 30 %. At 40 % MFP and MFP 50 %, the plastic nature of the blend rose from 12.85 % to 13.31 %.

Table 3 Summary of Atterberg Test Results on all Samples

Sample ID	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Shrinkage Limit (%)
SOIL	43.18	25.42	17.76	12.06
SOIL+ 10% MFP	39.22	25.37	13.85	11.21
SOIL + 20% MFP	42.35	32.01	10.34	8.86
SOIL + 30% MFP	41.32	31.44	9.88	8.57
SOIL + 40% MFP	44.73	32.06	12.67	8.94
SOIL + 50% MFP	42.51	29.07	13.44	9.43

The Fig. 6 indicates that the lateritic is made of silty materials with intermediate plasticity. There was a sudden increase in plasticity at 40 % MFP mix and 50 % MFP from 12.66 % to 13.31 %. The decrease in plasticity can be attributed to the replacement of clay particles which the microfiber plastics.

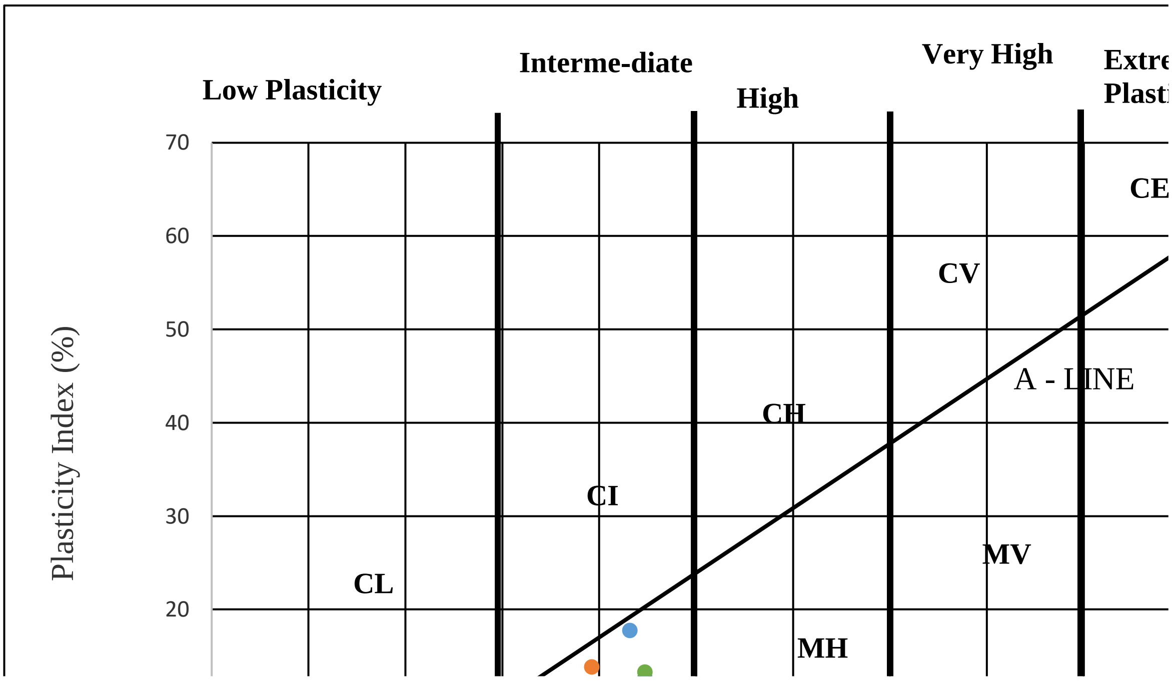

Fig. 6. Plasticity Classification for Lateritic Soil with Respect to their %MFP

This is an indicates the laterite used is made of silty materials with intermediate plasticity. Adding the microfiber plastics to the soil in blends further decreased the plasticity. The lowest plasticity index of the was recorded at 30 % MFP addition.

4.4 Proctor Compaction

The results show that at 0 % MFP to 40% MFP content, the Maximum Dry Density decreased from 2.19 g/cm^3 to 1.35 g/cm^3 (Table 4 and Fig. 7). This declination in densities is attributed to the low specific gravity values of the MFP which replace the denser soil particle upon increasing the percentages of MFP. The drastic decrease in the Maximum Dry Densities can also be attributed to the shielding offered by the MFP which coagulate the soil particles to form larger masses of lesser densities.

The Optimum Moisture Content increased with increase in the percentages of MFP content from 10.38 % to 14.06 % at 0 % MFP to 30 % MFP content. There was a discrepancy observed in the moisture at 40 % MFP content in the soil. This is due to the fact that addition 40 % by weight of MFP occupies greater volume but less strength. The density becomes very low and requires lesser amount of water to fail. Z

Table 4 Compaction Test Results

Sample ID	Maximum Dry Density (g/cm^3)	Optimum Moisture Content (%)
SOIL	2.19	10.38
SOIL+ 10% MFP	1.90	11.86
SOIL + 20% MFP	1.69	13.01
SOIL + 30% MFP	1.48	14.06
SOIL + 40% MFP	1.35	13.27

At 30 % microfiber addition, the mixture could accommodate more before reaching its failure limits. The soil reinforced with 30 % MFP portrayed a stiff behaviour and was resistant to failure, hence more water was needed to minimise the non-polar bonding effect exhibited by the MFP. This accounts for the high moisture content at 30 % MFP addition to the lateritic soil.

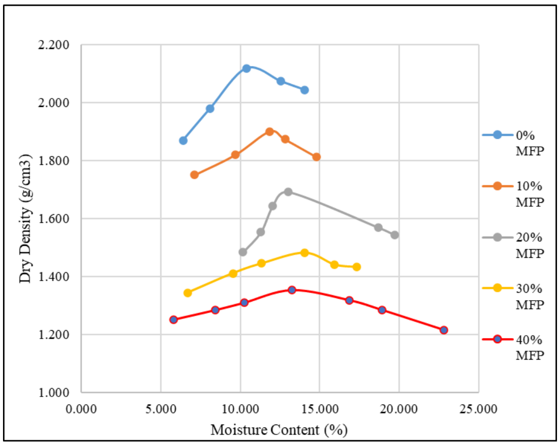

Fig. 7. Compaction Characteristic Curves

4.5 Constant Head Permeability

Table 5 gives a summary of the hydraulic conductivity results obtained from conducting the Constant Head Permeability Test. Increasing the percentages of MFP in the soil mass, substantially reduced the hydraulic conductivities. The least hydraulic conductivity was 0.004 cm/s when the soil was mixed with 40 % of MFP. The hydraulic conductivities decreased with increase in the percentages of microfiber plastic additions. The magnitude of change in hydraulic conductivities at 20 % and 30 % microfiber additions was very small as compared to the others. The decrease in the hydraulic conductivities suggest decrease in permeabilities. This phenomenon results from the high-water repellence nature of the microfiber plastics. Another factor is the high concentration of fines that sealed pores spaces which impeded water flow.

Table 5 Permeability Results for Soil and %MFPs

Sample ID	Hydraulic Conductivity (cm/s)
SOIL	0.078
SOIL+ 10% MFP	0.014
SOIL + 20% MFP	0.007
SOIL + 30% MFP	0.005
SOIL + 40% MFP	0.004

4.6 Direct Shear

When the content of MFP was increased from 0 % to 30 %, the frictional angles also increased from 31.55° to 48.54°. Beyond 30 % MFP content, the frictional angles dropped significantly from 48.54° to 22.49° (Table 6 and Fig. 8). The decrease in the frictional angles at 40 % and 50 % microfiber plastic additions can be attributed to the smoothening effect and low specific gravity (particle density) values. Though surface areas are increased, but there is less work done against friction due to the smoothness of the microfiber plastic-soil mixture. This consequently results in lower values of the frictional angles. The increase in the frictional angles indicate an increase in the bearing capacity factors of the soil when mixed with the MFP. The natural lateritic soil used was very cohesive due to its high silt contents.

Table 6 Results from Direct Shear Test

Sample ID	Frictional Angle (°)	Cohesion (kN/m^2)
SOIL	31.55	7.92
SOIL+ 10 % MFP	32.67	4.14
SOIL + 20 % MFP	37.41	7.98
SOIL + 30 % MFP	48.54	6.68
SOIL + 40 % MFP	29.77	4.95
SOIL + 50 % MFP	22.49	9.28

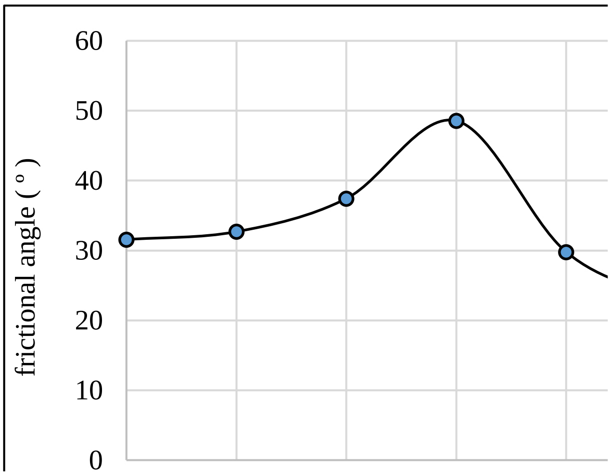

Fig. 8. Plot of Frictional Angles with Increasing % MFP

5 Conclusions and Recommendations

5.1 Conclusions

From the study, these conclusions were made;

- The addition of microfiber plastics to the soil enhanced its engineering and index properties.
- The optimal concentrations of microfiber that enhanced the geotechnical properties of the soil was attained at 30 % of MFP addition.

- At 20 % microfiber plastic addition, the geotechnical properties of the reinforced soil also portrayed enhanced behaviour as compared to 30 % addition. Hence addition of 20 % of microfiber to the soil is also good engineering and economic substitute when used for foundation base materials.
- Addition of the microfiber plastics to the soil increased its failure limits upon load subjection; this indicates an increase in the load bearing capacity of the soil.
- Including microfiber plastics in the soil reduced hydraulic conductivities, hence when it is blended with the right type of materials and in the right proportion can be used an alternative replacement to geo-membranes.
- A reduction in the plasticity indices of the reinforced soils upon the addition of the microfiber plastics suggest a decrease in the shrinkage index.
- Declination in the dry densities of the reinforced soil indicates a decrease in their shrinkage potentials; this was also evidential in the shrinkage limits results.

5.1 Recommendations

It is therefore recommended that;

- Microscopic analyses should be performed on the lateritic soil mixed with microfiber plastics to know how the soil particles interact with the plastic particles.
- Further research should also be conducted on microfiber plastics sizes passing 600 µm size aperture and how they individually affect the soil behaviour.
- Microfibre-reinforced concrete cubes (from MFPs) should be made, after which UCS and other strength tests be conducted to determine their suitability for concrete works.

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Authors

John Owusu Konduah holds a Bachelor's degree in Geological Engineering from the University of Mines and Technology (UMaT), Tarkwa. He currently works with Goodwill Geospatial Consults, Bogoso. He is a research-focused graduate geologist with over two (2) years’ work experience in mineral exploration and geotechnical works. He is also a computer programming enthusiast with endowed knowledge in geospatial modelling using artificial intelligence.

Albert Kafui Klu holds a BSc (Hons) in Geological Engineering from the University of Mines and Technology (UMaT), Tarkwa. He is currently a postgraduate assistant with the Department of Geological Engineering, UMaT. His research interests are in soil mechanics, seismology, application of geophysics and machine learning in geotechnical engineering.

Edmund Nana Asare holds MPhil in Geological Engineering (Geotech. Option) from the University of Mines and Technology, Tarkwa (UMaT). Currently, he is a Lecturer in the Department of Geological Engineering, University of Mines and Technology (UMaT), Tarkwa. His research interests are in Civil, Rock and Soil Mechanics, Foundation Engineering, Tailings and exploration techniques.