Original Research Article

Combined Effect of Marble Dust and Waste Paper Sludge in Improving Engineering Properties of Black-cotton Soil of Gelan Area, Ethiopia

ABSTRACT: *Black-cotton soil creates a problem in construction sites of Gelan area, Ethiopia because of its swell and shrinks behavior due to moisture change. In the present study, an alternative method of soil stabilization using the combined effects of Marble dust and waste paper sludge is investigated based on laboratory test results. Standard compaction and unconfined compressive strength tests were performed by mixing Black-cotton soil with waste paper sludge of 5, 10 and 15% by mass of soil. From the tests and experimental studies, addition of 5% waste paper sludge is obtained as optimum blend to improve soil strength. Therefore, soil is mixed with varying percentages of marble dust (i.e., 10, 20, 30 and 40%) in addition to 5% waste paper sludge which resulted in significant improvement of the soil plasticity, swelling and strength characteristics. From the study it is concluded that addition of 5% waste paper sludge with 30% marble dust is the optimum amount to improve the engineering properties of the Black-cotton soil.*

KEYWORDS: Black-cotton Soil, Stabilization, Engineering Properties, Waste Paper Sludge, Marble dust

1. INTRODUCTION

Expansive soil is commonly known as Black-cotton soil because of it's color and it's suitability for growing cotton. It starts swell or shrink excessively due to change in moisture content. When an engineering structure is associated with Black-cotton soil, it experiences either settlement or heave depending on the stress level and the soil swelling pressure (Bhavsar et al., 2014). Black-cotton soils are residual deposits formed from lava or trap rocks, cover a very large area of the world. They are rich in montmorillonite which is responsible for its expansive nature but illite is also present when their parent rock is rich in potash bearing mineral. The presence of this montmorillonite, which is highly responsible for the attendant shrink-swell behavior of the soil depending on the amount of available moisture in the soil, is the root cause of the many problems such as pavement failure and excessive settlement associated with the soil. Shrinkage during the dry season often lead to surface cracks that could open up to 50mm or more and several millimeters deep.

This study is aimed at investigating the combined effect of marble dust and waste paper sludge to improve the geotechnical properties of Black-cotton soils. It uses waste materials for the improvement of Black-cotton soil. These materials are obtained from industries which are polluting the environment.

2. LITERATURE REVIEW

Bhavsar et al., 2014 studied replacing soil with marble dust of 30%, 40%, & 50% its dry weight, it gave maximum improvement in the swelling and linear shrinkage properties of Black-cotton soil. Plastic index has reduced from 26.1 for original soil to 18.14% for 50% of marble dust and dry density of the soil has increased and optimum moisture content has decreased with the increasing amount of marble. Linear shrinkage has reduced with the increasing amount of marble from 23.7% for Black-cotton soil to 4% when mixed with 50% marble by mass of the soil .(Patel et al., 2017) have done experiments with addition 20,30,40,60 % of marble Powder by weight of dry soil. The liquid limit would decrease from 31.3% to 23.5%. The plasticity index decreased from 21.02 % to 4.35%.

Elias studied the effect of waste paper sludge (WPS) on strength of clay soil by mixing the soil with 2, 5,7,10,15,20,25 percent WPS by weight soil was 316.4 and increased to 423 for 5% of WPS. (Raman et al., 2019) studied by using 2,4,6,8,10,12 and 14 % waste paper sludge by weight of soil, Liquid Limit has been reduced to 34.3% from 71.52 % when treated with Waste Paper. Plastic Limit has been reduced to 22.48% from 28.48% and Plasticity index has been reduced to 11.82% from 43.52% compared with untreated soil. Differential swelling index has been reduced and dry density has been increased when treated with Waste Paper Sludge. (Teja et al., 2016) studied Improvement of Properties of Highly Swelling Soil by using Waste Paper Sludge. The result showed Plasticity index has reduced from 43.52% to 11.82% and (Jhariya & Parte, 2018) studied Stabilization of Black-cotton Soil by the Waste Paper Sludge (Hypo-Sludge) resulted in reduction of plastic index.

3. MATERIALS AND METHODS

3.1 Black-cotton soil

Soil samples from two test pits of depth 1.5m are collected from Gelan area at a location of latitude 8°49'30.1"N and longitude 38°51'37.8"E for Test Pit 1 and latitude 8°49'28.7"N and longitude 38°51'38.4"E for Test Pit 2. Elevation of the site is 2085m and 2083m above sea level for Test Pit 1 and Test Pit 2 respectively.

3.2 Waste paper sludge

Waste Paper Sludge (WPS) is a solid waste material collected from the Paper recycling Industry. It is the end product obtained from pulping and removing of impurities several times. Waste paper sludge used for this study is brown in color and has pH value of 8.75, which is slightly basic. Specific gravity of Waste paper sludge is 2.3.

Figure 1 Waste paper sludge used for the study

3.3 Marble dust

Marble comes in the form of fine limestone in the beginning. When limestone is exposed to high temperatures and high pressure, it turns into marble. For this study Marble dust is collected from Sof Umar Marble production Industry which is found in Gelan area. Collected Marble dust is white in color and has the grain size distribution of 71.5% sand and 28.5% fine. It is study is white in color and has pH

value of 10.1, which is slightly basic. Specific gravity of marble dust is 2.8.

Figure 2 Marble dust used for the study

Complete silicate analysis test is performed in the Ethiopian Geological survey in order to determine the chemical composition of both waste paper sludge and marble dust.

Table 1 Chemical composition of waste paper sludge and marble dust in percent

Composition	**Waste paper sludge**	**Marble dust**
SiO_2	28.58	17.86
Al_2O_3	4.29	<0.01
Fe_2O_3	10.22	<0.01
CaO	19.38	44.68
MgO	2.96	2.36
Na_2O	0.88	<0.01
K_2O	0.36	<0.01
MnO	0.06	<0.01
P_2O_5	0.14	0.03
TiO_2	0.25	0.02
H_2O	2.03	0.04
LOI	31.39	35.29

3.4 Methods

The following laboratory tests have been carried on natural Black-cotton soil:

- Natural Moisture content
- Grain size distribution
- Atterberg Limit test
- Specific gravity
- Compaction test
- Unconfined compression Strength test
- Free swell test
- Swelling Pressure Test
- Consolidation Test

By mixing Black-cotton soil samples of two test pits with Waste paper sludge of 5, 10 and 15% by mass of soil. The following tests are performed to determine optimum amount of waste paper sludge:

- Standard compaction tests
- Unconfined compressive strength tests

Marble dust is mixed with soil by 10, 20, 30 and 40% by mass of Black-cotton Soil with Pre-determined optimum percentages of waste paper sludge. Then to investigate the combined effect of marble dust and waste paper sludge the following tests are performed:

- Atterberg Limits
- Free swell test
- Compaction test
- Unconfined compressive strength (UCS)

From these tests optimum content of waste paper sludge and Marble dust that improved properties of soil will be obtained. For the optimum amount consolidation test is performed.

4. RESULTS AND DISCUSSIONS

4.1. Laboratory Test Results for Natural Black-cotton soil

Table 2 Summary of Properties of Black-cotton soil of two test pits

Properties	Test Pit 1	Test Pit 2
Natural Moisture Content (%)	36	42
Percentage passing no 200 sieve (%)	90.8	74
Liquid Limit	135	96
Plastic Limit	75	53.33
Plastic index	60	42.67
Specific Gravity	2.38	2.42
AASHTO Soil classification	A-7-5	A-7-5
Unified Soil Classification	MH or OH	MH or OH
Free Swell Index (%)	140	141
Maximum Dry Density (g/cm^3)	1.12	1.102
Optimum Moisture Content (%)	35	44
UCS (KN/m^2)	170.95	157

4.2 Effects of Waste paper sludge on Maximum Dry Density and Optimum Moisture Content of soil

Black-cotton soil is blended with 5, 10 and 15% of waste paper sludge by mass of soil and standard compaction test is performed. With the addition of Waste paper sludge of 5% by mass of soil, the maximum dry density has increased. Further addition of waste paper sludge increased the maximum dry density of a soil but relatively in less value compared with 5% addition of waste paper sludge. Due to comparatively low specific gravity and light weight behavior of waste paper sludge maximum dry density of soil decreases gradually with an increase of waste paper sludge content of 10 and 15%.

Addition of 5% waste paper sludge reduced the optimum moisture content but further addition of waste paper sludge increased the optimum moisture content.

Table 3 Effect of waste paper sludge on maximum dry density and optimum moisture content For Test Pit 1

Percentage of Admixture	MDD(g/cm3)	OMC(%)
Natural Black-cotton Soil	1.121	35
95% Black-cotton Soil + 5% Waste Paper sludge	1.218	26.45
90% Black-cotton Soil + 10% Waste Paper sludge	1.151	39.8
85% Black-cotton Soil + 15% Waste Paper sludge	1.15	40.33

Table 4 Effect of waste paper sludge on maximum dry density (MDD) and optimum moisture content (OMC) For Test Pit 2

Percentage of Admixture	MDD(g/cm3)	OMC(%)
Natural Black-cotton Soil	1.102	44
95% Black-cotton Soil + 5% Waste Paper sludge	1.167	30.6
90% Black-cotton Soil + 10% Waste Paper sludge	1.121	38.73
85% Black-cotton Soil + 15% Waste Paper sludge	1.095	44

4.3 Effects of Waste paper sludge on Unconfined Compressive Strength (UCS) of soil

With the addition of waste paper sludge of 5% by mass of soil, unconfined compressive strength of a soil has increased. Further addition of Waste Paper sludge increased the strength of a soil but relatively in less value compared with 5% addition of waste paper sludge. The reduction of the strength is due to the reduction of the maximum dry density of the soil caused by the relatively less value of the specific gravity of the waste paper sludge compared to the soil. So 5% waste paper sludge is considered as the optimum amount for strength.

Table 5 Effect of addition of waste paper sludge on Unconfined Compressive strength of soil

Percentage of Admixture	Test Pit 1	Test Pit 2
Waste Paper Sludge (%)	UCS (KN/m^2)	UCS (KN/m^2)
Natural Black-cotton Soil	170.95	157
95% Black-cotton Soil + 5% Waste Paper Sludge	227.38	237.07
90% Black-cotton Soil + 10% Waste Paper Sludge	209.94	179.19
85% Black-cotton Soil + 15% Waste Paper Sludge	202.34	162.22

4.4 Combined effects of Marble dust and Waste Paper Sludge on Atterberg Limits

From the results of compaction and unconfined compressive strength tests 5% waste paper sludge is considered the optimum amount to improve the strength of the soil. 5% waste paper sludge is used as a constant and marble dust of 10, 20, 30 and 40% is mixed with this optimum content and the following tests are performed. These tests include Atterberg limit, standard compaction test, unconfined compression strength test and free swell test.

Table 6 Combined effects of waste paper sludge and marble dust on Atterberg limit values for Test Pit 1

Percentage of Admixture	Liquid Limit	Plastic Limit	Plastic Index
Natural Black-cotton soil	135	60	75
95% Black-cotton Soil + 5% Waste paper sludge + 0% Marble Dust	87	52	35
85% Black-cotton Soil + 5% Waste paper sludge + 10% Marble Dust	83	50	33
75% Black-cotton Soil + 5% Waste paper sludge + 20% Marble Dust	60	38	22
65% Black-cotton Soil + 5% Waste paper sludge + 30% Marble Dust	48	27	21
55% Black-cotton Soil + 5% Waste paper sludge + 40% Marble Dust	36	23	13

Table 7 Combined effects of waste paper sludge and marble dust on Atterberg limit values for Test Pit 2

Percentage of Admixture	Liquid Limit	Plastic Limit	Plastic Index
Natural Black-cotton Soil	96	46	50
95% Black-cotton Soil + 5% Waste paper sludge + 0% Marble Dust	76	36	40
85% Black-cotton Soil + 5% Waste paper sludge + 10% Marble Dust	72	34	38
75% Black-cotton Soil + 5% Waste paper sludge + 20% Marble Dust	55	38	23
65% Black-cotton Soil + 5% Waste paper sludge + 30% Marble Dust	40	20	20
55% Black-cotton Soil + 5% Waste paper sludge + 40% Marble Dust	29	18	11

4.5 Combined effects of Marble dust and Waste Paper Sludge on Maximum Dry Density and Optimum Moisture Content

Black-cotton soil is mixed with 5% waste paper sludge and 10, 20, 30and 40% of marble dust by mass of soil and standard compaction test is performed.

Addition of marble dust of 10, 20, 30 and 40% by mass of soil with 5% of waste paper sludge further increased the maximum dry density of a soil. This is due to comparatively high specific gravity behavior of marble dust.

Table 8 The combined effect of waste paper sludge and marble dust on maximum dry density (MDD) and optimum moisture content (OMC) of a soil for Test Pit 1

Percentage of Admixture	MDD (g/cm^3)	OMC (%)
Natural Black-cotton Soil	1.12	35
95% Black-cotton Soil + 5% Waste paper sludge + 0% Marble Dust	1.218	26.45
85% Black-cotton Soil + 5% Waste paper sludge + 10% Marble Dust	1.25	30
75% Black-cotton Soil + 5% Waste paper sludge + 20% Marble Dust	1.3	30
65% Black-cotton Soil + 5% Waste paper sludge + 30% Marble Dust	1.31	31
55% Black-cotton Soil + 5% Waste paper sludge + 40% Marble Dust	1.368	27

Table 9 Combined effects of waste paper sludge and marble dust on maximum dry density (MDD) and optimum moisture content (OMC) of a soil For Test Pit 2

Percentage of Admixture	MDD (g/cm^3)	OMC (%)
Natural Black-cotton Soil	1.102	44
95% Black-cotton Soil + 5% Waste paper sludge + 0% Marble Dust	1.167	30.6
85% Black-cotton Soil + 5% Waste paper sludge + 10% Marble Dust	1.2	35

75% Black-cotton Soil + 5% Waste paper sludge + 20% Marble Dust	1.256	38
65% Black-cotton Soil + 5% Waste paper sludge + 30% Marble Dust	1.345	25.46
55% Black-cotton Soil + 5% Waste paper sludge + 40% Marble Dust	1.358	25

Black-cotton soil of each Test Pits is mixed with 5% waste paper sludge and 10, 20, 30 and 40 % of marble dust. Each sample is prepared and remolded at their respective MDD and OMC from the result of compaction tests.

With the addition of marble dust by mass of the soil as 10, 20, 30 and 40% with the predetermined 5% waste paper sludge, the strength of the soil is further increased. It is seen that as the percentage of marble dust increases the strength of the soil also increased up to 30% of marble dust. The calcium silicate gel formed initially coats and binds lumps of clay together. The gel then crystallizes to form an interlocking structure thus, strength of the soils increases, but the strength of the soil is decreased with the addition of 40% of marble dust due to the fact that the addition of excess cohesion less material to the clay soil reduce its natural cohesive force between the particles of clay soil. So it is seen than addition of 5% waste paper sludge with 30% marble dust is an optimum amount for strength. Combined effects of marble dust and waste paper sludge on unconfined compressive strength (UCS) of a soil are described in Table 9.

Table 10 Combined effects of marble dust and waste paper sludge on unconfined compressive strength (UCS) of a soil

Percentage of Admixture	Test Pit 1	Test Pit 2
Waste paper sludge and Marble dust (%)	UCS (KN/m^2)	UCS (KN/m^2)
Natural Black-cotton Soil	170.95	157
95% Black-cotton Soil + 5% Waste paper sludge + 0% Marble Dust	227.38	237.07
85% Black-cotton Soil + 5% Waste paper sludge + 10% Marble Dust	242.67	242
75% Black-cotton Soil + 5% Waste paper sludge + 20% Marble Dust	246.19	245
65% Black-cotton Soil + 5% Waste paper sludge + 30% Marble Dust	268.33	253.6
55% Black-cotton Soil + 5% Waste paper sludge + 40% Marble Dust	193	211.6

Table 11 Combined effects of marble dust and waste paper sludge dust on free swell index of a soil

Percentage of Admixture	Test Pit 1	Test Pit 2
Natural Black-cotton Soil	140	141
85% Black-cotton Soil+5% Waste Paper Sludge+10% Marble dust	130	105
75% Black-cotton Soil+5% Waste Paper Sludge+20% Marble dust	110	100
65% Black-cotton Soil+5% Waste Paper Sludge+30% Marble dust	60	70
55% Black-cotton Soil+5% Waste Paper Sludge+40% Marble dust	55	50

4.6 Combined effect Marble dust and Waste Paper sludge on Consolidation Characteristics of the soil

Addition of 5% waste paper sludge with 30% marble dust has reduced the void ratio. This causes the decrease in the settlement of the soil. As described in Table 4.9 and Table 4.10 with the addition of 5% waste paper sludge with 30% marble dust Compression index of a soil is reduced from 0.517 to 0.326 and from 0.493 to 0.402 for Test Pit 1 and Test Pit 2 respectively which indicates that the compressibility of the soil is improved.

Table 12 Summary of the combined effect of marble dust and waste paper sludge on consolidation of soil

Consolidation Factors	Natural Black-cotton Soil	65% Soil+5%Waste paper sludge+30%Marble Dust
Eo	1.496	1.062
Cc	0.517	0.326
Overall Settlement(mm)	4.732	3.41

From void ratio/ log pressure (e/log p) curves as shown in Figure 3 and Figure 4 are found on top positions on the diagram due to their relatively higher void ratios. But with the addition of waste paper sludge and marble dust the curve moved down as a result, the compressibility of the soil is reduced.

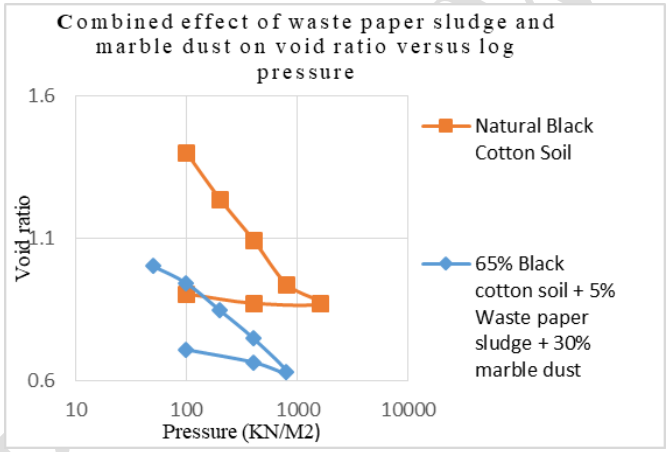

Figure 3 Combined effects of waste paper sludge and marble dust on Void Ratio versus Log Pressure with Loading and Unloading for Test Pit 1

Table 13 Summary of the combined effect of marble dust and waste paper sludge on consolidation of soil for Test Pit 2

Consolidation Factors	Natural Black-cotton Soil	65% Soil+5%Waste paper sludge+30%Marble Dust
Eo	1.498	1.162
Cc	0.493	0.402
Overall settlement(mm)	4.136	3.818

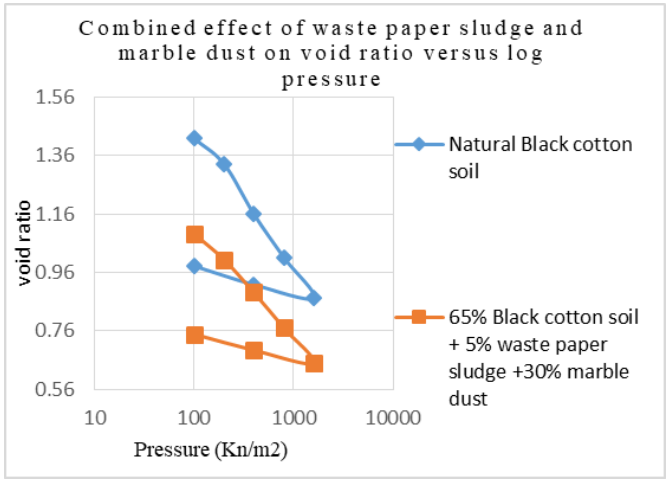

Figure 4 Combined effects of Waste paper sludge and Marble dust on Void Ratio Versus Log Pressure with Loading and Unloading for Test Pit 2

5. CONCLUSIONS

Addition of 5% waste paper sludge increased the maximum dry density and the unconfined compressive strength of the soil. Addition of 10 and 15 % of waste paper sludge reduced the maximum dry density and unconfined compressive strength of the soil. So it is concluded that 5% waste paper sludge is the optimum amount to improve the strength characteristics of the soil. Addition of marble dust and waste paper sludge decreased liquid limit, plastic limit and plasticity index for both Test Pit 1 and Test Pit 2.

Black-cotton soil treated with combination of marble dust and waste paper sludge gave a significant improvement in strength than when the soil is treated with only waste paper sludge. Addition of marble dust with 5% of waste paper sludge has increased the strength up to 30% addition of marble dust and further addition of marble dust reduced the strength. So addition of 5% Waste Paper sludge with 30% of marble dust is an optimum dosage used for stabilizing the soil.

Optimum content used to improve properties of the soil which is addition 5% waste paper sludge with 30% marble dust significantly reduced the swelling potential of the soil so that the expansiveness of the soil is reduced. Moreover, addition of 5% waste paper sludge and 30% marble dust has reduced the void ratio, compression index and total settlement of the soil.

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Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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