Comparative Analysis of Effect of Industrial Wastes on Index and Engineering Properties of Expansive Soils

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Abstract
A lot of research work has been done worldwide in the direction of utilizing various industrial wastes in the soil stabilization technique. However, from the available literature it is found that little research has been done to compare their effect on expansive soils. This paper therefore presents the results of a laboratory study undertaken to investigate and compare the effect of waste Ceramic dust (WCD) Waste Marble Dust (WMD) and Waste Quarry dust (WQD) on the Index and Engineering properties of expansive soil. The laboratory tests carried out on the natural and stabilized soils includes Atterberg limits, Compaction, California Bearing Ratio (CBR) and swell pressure. For conducting different tests, the soil was mixed separately under the same conditions with WCD, WMD and WQD from 0 to 30% at an increment of 5% by dry weight of the soil. Mixes were prepared and the above mentioned tests were conducted on the samples/mixes according to the standards of the American Society for Testing and Materials. From the analysis of the test results, it was found that the liquid limit of the soil decreased with increase in the percentages of industrial wastes. It decreases from 67% to 35% , 67% to 38% and 67% to 27% for WCD, WMD and WQD respectively. The result of free swell characteristics of the investigated soil revealed a decrease in swell from 111% to 45%, 111% to 53% and 111% to 40% for WCD, WMD and WQD respectively. The soaked CBR increases from 1.6% to 4.1% when WCD was increased from 0 to 30%, from1.6% to 4.1% when WMD was added, and from 1.6% to 4.5% when WQD was added in the same manner. Based on the analysis of the study, it can be inferred that both materials gave satisfactory results however; WQD shows more potentials than WCD and WMD on the index and engineering properties of expansive soils.

Key words: *Expansive soil, Waste Ceramic Dust, Waste Marble Dust, Waste Quarry Dust, Stabilization.*

Introduction

Expansive soil, also called shrink-swell soil, is a very common cause of foundation problems. Foundation soils which are expansive will “heave” and can cause lifting of a building or other structure during periods of high moisture. Expansive soils are present throughout the world and are found predominately in North-Eastern Nigeria, where they occupy an estimated area of 104,000km^2 (Osinubi et al, 2011). They are extremely problematic soils and cause a wide range of problems to a geotechnical engineer.

Different methods are adopted to stabilize these types of soils to suit the specifications of construction industry, which incurs more effort and money. In order to reduce the expenditure towards stabilization, studies using industrial wastes are being carried out to reduce the pollution by dumping and save the environment. Utilizing industrial wastes such as ceramic dust, Marble dust, quarry dust e.t.c as a soil replacement or stabilizer in the stabilization of problem soils will not only solve environmental problems but will also provide a new resource for construction industry. Literature reference on these studies indicates the potential use of industrial wastes for stabilization of soils.

Chen and Idusuyi (2015), studied the effect of waste ceramic dust (WCD) on index and engineering properties of shrink-swell soils mixed with waste ceramic dust from 0 to 30% at an increment of 5%. From their investigation the liquid limit, plastic limit, plasticity index, optimum moisture content, free swell and swelling pressure decreased with increase in WCD. They also reported that the maximum dry density, unconfined compressive strength and California bearing ratio increased with an increase in waste ceramic dust content.

Parte and Singh (2014), investigated the effect of marble dust on index properties of black-cotton soil and reported that the test results showed a significant change in consistency limits of samples containing marble dust. The liquid limit decreased from 57.67% to 33.9%. The plasticity index decreased from 28.35% to 16.67% and shrinkage limit increased from 8.06% to 18.39% with the addition of marble dust from 10% to 40% of the dry weight of the black-cotton soil. They also reported that the differential free swell decreased from 66.6% to 20.0%, showing appreciable decrease in swelling behavior. They concluded that waste marble dust generated from stone industries has a potential to modify the characteristics of expansive soil. Agrawal *et al.* (2011) investigated the effect of Marble dust in the stabilization of expansive soil and reported that the material improved the index and engineering properties like liquid limit (LL), plastic limit (PL), shrinkage limit (SL), compaction, swelling characteristics of the soil.

Sabat (2012), conducted series of tests and concluded that addition of quarry dust decreases Liquid limit, Plastic limit, Plasticity index, Optimum moisture content, Cohesion and increases shrinkage limit, Maximum dry density, Angle of internal friction of expansive soil. Ali and Koranne (2011), presented the results of an experimental programme undertaken to investigate the effect of stone dust and fly ash mixing in different percentages on expansive soil. They observed that at optimum percentages, i.e., 20 to 30% of admixture, the swelling of expansive clay is almost controlled and there is a marked improvement in other properties of the soil as well. It is concluded that the combination of equal proportion of stone dust and fly ash is more effective than the addition of stone dust/fly ash alone to the expansive soil in controlling the swelling nature.

Having highlighted efforts by several authors on handling various industrial waste, it became clear that they were unable to compare the various waste being used as stabilizers in engineering soils with the view to come up with the most effective of them all, which this work is set out to achieve.

Materials and Methods

Materials

The materials used in the experiment are Expansive soil, waste ceramic dust (WCD), waste marble (WMD) and waste quarry dust (WQD).

Expansive Soil

The soil used in this study was obtained from Baure, Yelmatu Deba Local Government Area, Gombe state, North-Eastern Nigeria. The top soil was removed to a depth of 0.5m before the soil samples were taken by disturbed sampling. X-ray diffraction analysis was performed on the clay fraction of the tested soil to identify its mineralogical composition. The X-ray diffraction indicates that the soil consist primarily of montmorillonite, which is mainly responsible for the expansive characteristics of the soil.

Waste Ceramic Dust (WCD)

Ceramic products are produced from natural materials containing a high proportion of clay minerals. Following a process of dehydration and controlled firing at temperatures between 700ºC and 1000ºC, these minerals acquire the characteristic properties of fired clay.

Broken/waste ceramic tiles were collected from construction and demolition sites within Bauchi Metropolis. These tiles were broken into smaller pieces with a hammer and fed into a Los Angeles abrasion testing machine to make it further smaller

Waste Marble Dust (WMD)

Marble is a hard crystalline metamorphic form of lime stone. It is composed primarily of the mineral calcite ($CaC0_3$) and usually contains other mineral such as, clay, minerals, micas, quartz pyrite, iron oxides and graphite. The marble dust was obtained from a marble cutting and polishing industry located at Jos, plateau state, Nigeria.

Figure 1: Views from waste marble dust disposed sites

Waste Quarry Dust (WQD)

Quarry waste is a general term for any material that is generated from the processing of stones at quarries. About 20-25% of the total production in each crusher unit is left out as the waste material-quarry dust. The quarry dust for this study was obtained from Triacter Quarry site at Bayara, Bauchi State, Nigeria.

Experimental Methods

The experimental study was carried out on soil samples collected at a depth of 0.5-1.0m below ground level. The laboratory tests carried out on the natural and stabilized soils includes Atterberg limits, compaction, and swell pressure. For conducting different tests, the soil was mixed separately under the same conditions with waste ceramic and marble dust from 0 to 30% at an increment of 5%. Mixes were prepared and the above mentioned tests were conducted on these samples/mixes according to the standards of the American Society for Testing and Materials.

Compaction Characteristics

The Standard Proctor tests were conducted according to the standards of the American Society for Testing and materials on the natural soil and soil stabilized with WCD, WMD and WQD mixtures to determine its compaction characteristics, namely, the optimum moisture content (OMC) and maximum dry density (MDD). The soil was mixed with various amounts of WCD, WMD and WQD at 5%, 10%, 15%, 20%, 25% and 30% by weight of soil and standard proctor test were conducted on these mixtures.

Testing of Soil Samples for California Bearing Ratio (CBR)

The soaked California bearing ratio test was conducted in accordance with British standards. Soil samples were prepared by dynamic compaction method and placed on the bottom plate of the loading device and load was applied at a strain rate of 1.25 mm/min. Penetration was measured by strain gauge. Load was recorded at the penetration of 0.0, 0.5, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 7.5, 10.0 and 12.5 mm. CBR value is expressed as a percentage of the actual load causing the penetrations of 2.5 mm or 5.0 mm to the standard loads. The greatest value calculated for penetrations at 2.5mm and 5.0mm was recorded as the CBR**.** The California bearing ratio is calculated as follows:

California bearing ratio (CBR) = $\frac{p_t}{p_s}$ x 100

Pt = corrected test load corresponding to the chosen penetration from the load penetration curve

Ps = standard load for the same depth of penetration.

Free Swell Characteristic of the Soil.

10cm^{3}of initial volume (v_i) of dry soil passing through No.40 ASTM sieve was poured into 100cm^3 graduated cylinder containing distilled water. The volume of the soil increases on coming in contact with water. The increased volume of settled soil in the cylinder was measured directly after 24 hours, which gives the final volume swelled volume of soil (v_f). The soil was mixed separately under the same condition with various amounts of waste ceramic, waste marble and waste quarry dusts at varying percentages of 5%, 10%, 15%, 20%, 25% and 30% by weight of soil and free swell test was conducted on these mixtures. The free swell (s_f) was then computed as:

$$s_f = \frac{v_{f} - v_i}{v_i} \times 100$$

where:

s_f = free swell, (%)

v_i= initial volume of dry poured soil, (cm^3)

v_f= final volume of poured soil after 24hours contact with water, (cm^3)

Results and Discussion

Tables 1 and 2 shows the results of index and Engineering properties of natural Shrink-Swell Soil and quarry dust respectively. The results of soil stabilized with waste ceramic and quarry dust are shown in tables 3 and 4.

Table 1: Index and Engineering properties of Natural Shrink-Swell Soil

Property	Quantity
Grain Size Analysis	
Sand, %	3.0
Silt, %	27.0
Clay, %	70.0
Specific gravity	1.9
Natural moisture content, %	35.0
Liquid limit, %	67.0
Plastic limit, %	34.0
Plasticity index, %	33.0
Linear shrinkage, %	17.0

Free swell, %	107.0
Swelling pressure kN/m^2	131.0
Maximum dry density, g/cm^3	15.6
Optimum moisture content, %	20.4
california bearing ratio(CBR)%	1.6
Colour	Greyish black

Table 2: Index and Engineering properties of Quarry dust

Property	Value
Natural moisture content	9.11
Particle Size distribution	
Sand (%)	97.1
Silt %	2.9
Specific gravity	2.76
Liquid limit%	NP∗
Plastic limit%	NP
Plasticity index%	NP
OMC%	11.5
MDD (g/cm^3)	1.97
Angle of internal fiction (^{0})	35
Cohesion kN/m^2	0.07
CBR soaked%	11.5

∗Non plastic

Table 3 Index and Engineering Properties of Soil Stabilized with WCD

WCD (%)	**LL** (%)	**PL** (%)	**PI** (%)	**FS** (%)	**SP** (KN/m^2)	**MDD** (kN/m^3)	**OMC** (%)	**CBR** (%)
0	67	34	33	111	131	15.6	20.4	1.6
5	65	29	36	105	121	15.8	19.8	1.8
10	54	26	28	98	115	16.1	19.4	2.1
15	51	24	27	75	83	16.5	19.0	2.5
20	47	22	25	65	60	17.2	18.5	2.8
25	43	20	23	58	51	17.9	18.2	3.5
30	35	18	17	45	42	18.3	17.6	4.1

***Key**: **WCD**: Waste Ceramic Dust, **LL**: Liquid Limit, **PL:** Plastic Limit, **PI:** Plasticity Index, **FS**: Free Swell, **SP**; Swell Pressure, **MDD**; Maximum Dry Density, **OMC**: Optimum Moisture Content, **CBR**: California Bearing Ratio*

Table 4: Index and Engineering Properties of Soil Stabilized with WMD

WMD (%)	LL (%)	PL (%)	PI (%)	FS (%)	SP (KN/m^2)	MDD (Mg/m^3)	OMC (%)	CBR (%)
0	67	34	33	111	131	15.6	20.4	1.6
5	68	30	38	109	123	15.8	19.4	1.8
10	57	28	29	103	118	16.0	19.0	2.0
15	54	26	28	85	85	16.3	18.6	2.2
20	49	25	24	72	70	17.0	17.9	2.6
25	45	23	22	65	68	17.2	17.4	3.0
30	38	20	18	53	50	17.5	16.8	3.9

***Key**: **WMD**: Waste Marble Dust, **LL**: Liquid Limit, **PL:** Plastic Limit, **PI:** Plasticity Index, **FS**: Free Swell, **SP**; Swell Pressure, **MDD**; Maximum Dry Density, **OMC**: Optimum Moisture Content, **CBR**: California Bearing Ratio*

Table 5 Index and Engineering Properties of Soil Stabilized with WQD

WQD (%)	LL (%)	PL (%)	PI (%)	FS (%)	SP (KN/m^2)	MDD (kN/m^3)	OMC (%)	CBR (%)
0	67	34	33	111	131	15.6	20.4	1.6
5	60	27	33	99	116	16.0	19.8	1.8
10	51	22	29	93	110	16.3	19.6	2.3
15	48	20	28	71	76	17.1	19.2	2.7
20	42	17	25	60	55	17.8	18.9	2.9
25	38	15	23	52	46	18.2	18.4	3.8
30	27	13	14	40	37	19.0	17.8	4.5

***Key**: **WQD**: Waste Quarry Dust, **LL**: Liquid Limit, **PL:** Plastic Limit, **PI:** Plasticity Index, **FS**: Free Swell, **SP**; Swell Pressure, **MDD**; Maximum Dry Density, **OMC**: Optimum Moisture Content, **CBR**: California Bearing Ratio*

Effect of WCD,WMD and WQD on Liquid Limit

The result of liquid limit tests on expansive soil treated with different percentages of ceramic, marble and quarry dust is shown in fig.2. From the results, it is observed that with increase in different percentages of the admixtures from 0 to 30% at an increment of 5%, the liquid limit of the soil goes on decreasing. It decreases from 67% to 35% when WCD was added from 0 to 30%, from 67% to 38% when WMD was addee and from 67% to 27% when WQD was increased from 0 to 30%. It can be inferred from the results that WQD has more positive effect on the liquid limit than WCD andWMD.

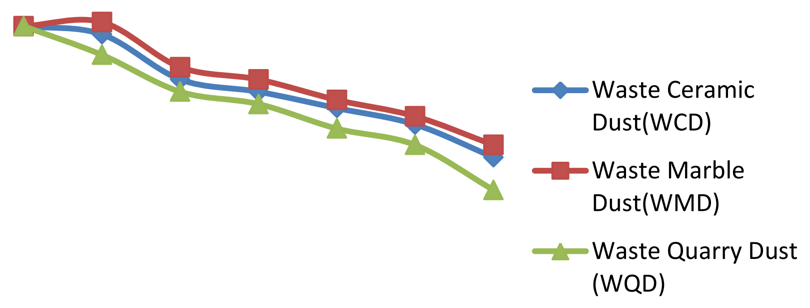

Figure 2: Variation of Liquid limit with percentages of WCD,WMD and WQD

Effect of WCD,WMD and WQD on Plastic Limit

The result of plastic limit tests on expansive soil treated with different percentages of WCD,WMD and WQD is shown in fig.3. From the results it is observed that with the increase in different percentages of the admixtures from 0 to 30% at an increment of 5%, the Plastic limit of the soil goes on decreasing. It decreases from 34% to 18% when WCD was added from 0 to 30%, from 34% to 20% when WMD was added and from 34% to 13% when WQD was added under the same condition. From the comparative point of view,WQD improved the plastic characteristics of the soil more than WCD and WMD.

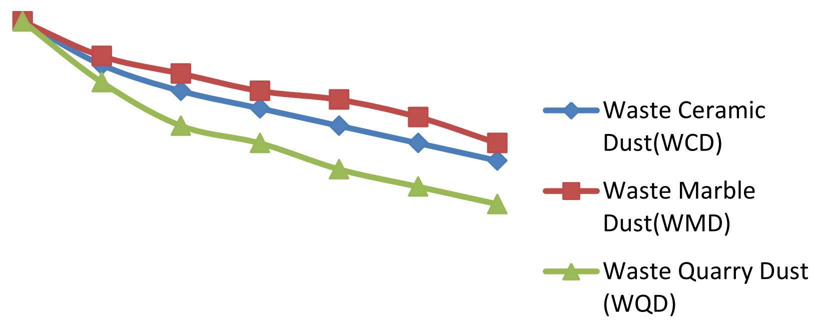

Figure 3: Variation of Plastic limit with percentages of WCD,WMD and WQD

Effects of WCD, WMD and WQD on Free swell Characteristics

The result of free swell characteristics of the investigated soil treated with industrial wastes is shown in fig 4. From the result it can be seen that the percentage of free swell goes on decreasing with the addition of WCD, WMD and WQD, from 0 to 30% at an increment of 5% for each stabilizer. It decreases from 111% to 45%, 111% to 53% and 111% to 40% for WCD, WMD and WQD respectively. It can therefore be opined that WQD has more positive effect on swell characteristic of expansive soil than WCD and WMD.

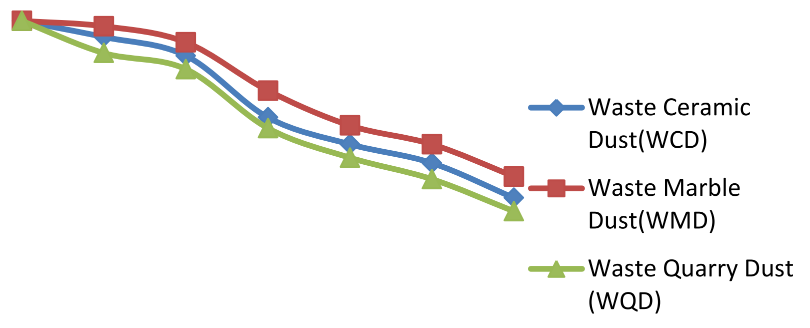

Figure 4: Variation of Free Swell with percentages of WCD,WMD and WQD

Effect of WCD, WMD and WQD on Compaction Characteristics

Figure 5 shows the variation of maximum dry density (MDD) with percentages of WCD, WMD and WQD. With increase in percentage of WCD, WMD and WQD, the MDD of the soil goes on increasing. The MDD increases from 15.6kN/m^3 to 18.1kN/m^3 when WCD was added from 0 to30%, from 15.6kN/m^3 to 3.9kN/m^3 when WMD was added and from 15.6kN/m^3 to 19.0kN/m^3 when WQD was added under the same condition. From the results it can be seen that WQD has more positive effect on the compaction characteristics of expansive soil than WCD and WMD.

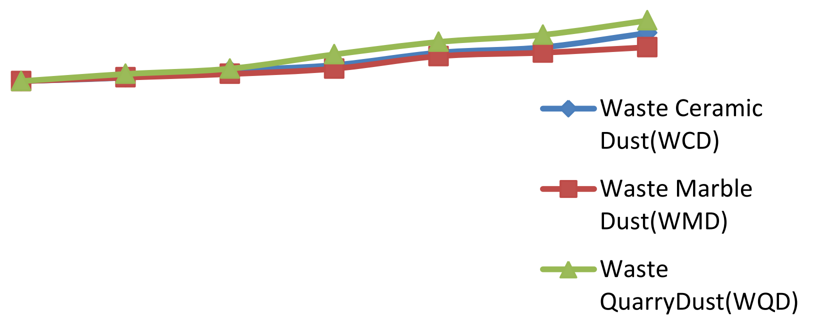

Figure 5: Variation of Dry Density with percentage of WCD,WMD and WQD

Effect of WCD, WMD and WQD on CBR characteristics

The results of soaked CBR tests on shrink- swell soil treated with different percentages of WCD, WMD and WQD are shown in Figure 6. From the results it can be seen that with increase in percentage of WCD, WMD and WQD, the soaked CBR of soil goes on increasing. The soaked CBR increases from 1.6% to 4.1% when WCD was increased from 0 to 30%, from 1.6% to 3.9% when WMD was increased in the same percentage, and from 1.6% to 4.5% when WQD was added in the same manner. It is evident from the result that WQD shows more positive result on CBR characteristic of expansive soil than WCD and WMD.

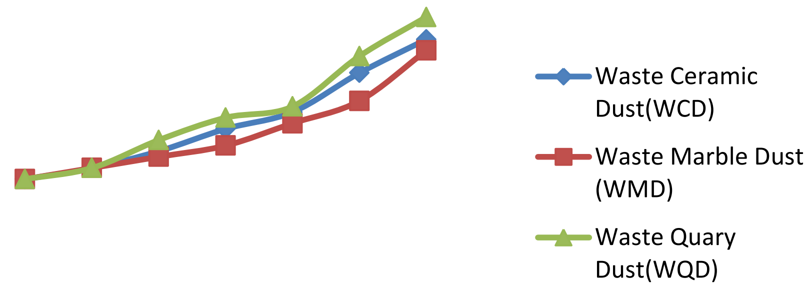

Figure 6: Variation of CBR with percentages of WCD,WMD and WQD

Conclusion/Recommendation

It can be concluded that both materials gave satisfactory results, and from the comparative point of view, WQD shows more potentials on the properties of the soil than WCD and WMD.

The study can be expanded by including other soil property parameters such as permeability, consolidation, strength characteristics etc.

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