IMPROVEMENT OF ENGINEERING PROPERTIES OF SOIL USING POND ASH AND ALCCOFINE

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Abstract: - Soil can be defined as the upper layer of the earth consisting of air, water and solid particles is generally produced by disintegration of rocks. In the third world countries, the need for locally manufactured construction material is increasing due to greater demands for new roads and housing units created by a growing population. Over the years, the availability of conventional material has not been sufficient to meet the demand of growing population. However, development of a large network of roads by traditional means and techniques require heavy financial investments. The values of UCS for both BSL and WAS fell short of the requirement based on Road Note 31 (TRRI, 1977) requirement for economic range of OPC stabilization. However, the UCS value of the BSH compaction could be acceptable for base courses of pavements. The 28 days curing period UCS values obtained showed that the OPC/ALCCOFINE blend has a long term advantage in terms of strength gain. There were tremendous increments in the values of UCS from their natural states. The 28 days curing period UCS produced a peak value of 2616 kN/m^2 at 30% pond ash & 3% alccofine for BSH compaction, showing that the soil treated with this blend can be used (at BSH compaction) as base course of pavement material. The unsoaked CBR values of 5, 7 and 11% (for the natural soil) compacted with BSL, WAS and BSH energy efforts, respectively, increased to 46, 77 and 83% at 30% pond ash & 3% alccofine. The 24 hours soaked CBR values recorded peak values of 42, 66 and 66% with BSL, WAS, BSH energies, respectively, which showed about 10-15% decrease from the unsoaked CBR values. The CBR values of 66% with BSH compaction at 30% pond ash & 3% alccofine blend can be used as sub base material because it meets the 29% recommended values for sub-base by the Nigerian General Specification (1997). Also the 42% recorded with BSL compaction at 30% pond ash & 3% alccofine treatment meets the 15% recommended for subgrade material by the Nigerian General Specification (1997).

The resistance to loss in strength of the soil increased from 13, 7, and 15% for the natural soil to peak values of 42, 13 and 71% for BSL, WAS and BSH energies at 50% pond ash & 3% alccofine, 8% OPC/0% ALCCOFINE and 30% pond ash & 3% alccofine, respectively. Only 71% resistance to loss in strength (29% loss in strength) at 30% pond ash & 3% alccofine with BSH compaction is close to the limiting value of 80% resistance to loss in strength (Ola, 1983) based on 4 days soaking. The 6% OPC 6% ALCCOFINE treatment of the soil can be used, at BSH compaction, for sub-base material because the soil was subjected to a harsher condition (of 7 days soaking) and due to the time dependent gain in strength advantage of the pozzolana.

***Key Words*: Soil, alccofine, Optimum Moisture Content, Maximum dry density, unconfined compressive test (UCS), California bearing ratio (CBR), direct shear test.**

1. INTRODUCTION

Soil can be defined as the upper layer of the earth consisting of air, water and solid particles is generally produced by disintegration of rocks. In the third world countries, the need for locally manufactured construction material is increasing due to greater demands for new roads and housing units created by a growing population. Over the years, the availability of conventional material has not been sufficient to meet the demand of growing population. However, development of a large network of roads by traditional means and techniques require heavy financial investments. So, it becomes need of the hour to find alternative materials, preferably locally available low grade ones for use in pavement construction, which results in sizeable economy without compromising with the engineering performance of structure. Abundantly available soil is the cheapest construction material in most of the regions of the world. The properties of the soil vary from point to point and place to place.

Cohesive soil causes great engineering problems due to its poor strength, high compressibility and low permeability. It covers large and extensively located areas of India and also many parts of the world. Silty soil extends in large stretches and construction of pavements and other structures on such type of soils is a great problem. To set right these problems, it is very much necessary to treat these soils. There are so many methods for the treatment of these soils. Some of them are very costly and some are very tedious. Several methods of soil improvement using Pozzolanic materials have been developed and used successfully in practice. The treatment of soft clayey soils with fly ash, Rice husk ash, Phosphogypsum along with small quantity of cement is very simple, economical and pollution controlling. It has been applied in a variety of civil engineering works, like in the construction of base courses where good materials are not economically available; for reducing the permeability and compressibility of soils in hydraulic and foundation works; for stabilization of slopes, embankments and excavations. A considerable amount of research concerning stabilization of soil with additives such as cement, alccofine, lime – fly ash and salt, bitumen and polymers is available in the literature. Likewise, the coal ash considered as an industrial waste can be effectively used in the construction industry.

2. Objectives: -

To stabilize the locally available weak subgrade, by using 3 per cent of alccofine and with varying the pond ash as the main stabilizing material.

1. To study the influences of pond ash content on the OMC and MDD, strength parameters, UCS and CBR (Soaked).
2. To arrive at the optimum pond ash content.
3. To study the load settlement behavior of soil with different pond ash mixes.
4. Analysis and interpretation of results.

3. EXPERIMENTAL STUDY

3.1 Materials

Following are the materials which are used for stabilization of Clay soil:

a) Soil: - The soil sample for study is collected from locally Haryana. The soil was found to be highly plastic and falls below the standard recommendation for most geotechnical construction works especially for sub-base or base courses in highway construction.

Fig.1 Disturbed soil sample

Table 1: Properties of soil used in study

Sr. No.	Characteristics	Value
1	Specific gravity	1.94
2	Atterbergs limits: a) Liquid limit (%) b) Plastic limit (%) c) Plasticity index (%) d) Linear Shrinkage (%) e) Free Swell (%)	 63.0 27.0 36.0 17.0 75.0
3	Colour	Greyish black
4	Dominant clay minerals	Montmorillonite
5	Standard Proctor compaction test result:- Optimum moisture content (%) Maximum dry density(Mg/m^3)	 1.34 24.0
6	Unconfined compressive strength(KN/m^2)	220

b) Alccofine: - There are many byproducts which are generated from industries and factories, dumped openly which cause environmental problems and also spread diseases. These byproducts can be utilized in useful way to save the environment. These by-products or so called waste materials are fly ash, silica fume, ground granulated blast furnace slag and alccofine which are being reused now a days in construction industries for soil stabilization or concrete production mainly by making few stabilized changes in these waste materials. The Alccofine used in this study was obtained from Abuja pond ash outlet. Physical and Chemical properties of Alccofine is presented in table.

Fig. 2. Alccofine

- Alccofine Micro Materials are a range of products of Counto Microfine Products Pvt. Ltd (CMPPL) – a joint venture between ACL and the Goa-based, Alcon Group, launched in the year 2013.

The two products that have been launched are Alccofine 1203 (a supplementary cementitious material suitably replaces Silica fume used in high performance concrete); and Alccofine 1101 (a micro-fine cement based product used for injection grout in underground tunnels and soil stabilization)etc.

Table 2: Types of Alccofine

Alccofine	SCM Alccofine-1203	Low Calcium Silicate
	Grouting Alccofine-1101	High Calcium Silicate

- It is a new-generation, ultrafine product whose basic raw material is slag of high glass content with high reactivity obtained through the process of controlled granulation.
- The raw materials are composed primarily of low calcium silicates. The processing with other select ingredients results in controlled particle size distribution (PSD). Due to its unique chemistry and ultra-fine particle size, ALCCOFINE 1203 provides reduced water demand for a given workability, and can also be used as a high range water reducer to improve compressive strength or as a super workability aid to improve flow.

Table 3: Physical Parameters of Alccofine 1203

Specific gravity	Bulk Density (kg/m^3)	Particle size distribution (μ)		
		d 10	d 50	D 90
2.9	600-700	1-2	4-5	8-9

Table 4: Chemical Composition of Alccofine 1203

CaO	Al_2O_3	SiO_2	Glass content
31-33%	23-25%	33-35%	>90%

c) Pond Ash: - In developing countries like India thermal power is the main source of energy and produces nearly 75 per cent for total energy production. The coal ash generated from all the existing thermal power plants is over 100 million tons per year. This coal ash is obtained in the form of fly ash (70%) and pond ash (30%). It is important to utilize these waste materials for take care of environment. The fly ash along with pond ash or bottom ash generated by the industries is generally disposed of in an engineered ash pond in a form of slurry in a ratio varying from 1 part ash and 6 to 10 parts of water which are situated within few kilometers distance from the power plant. This is why it is called pond ash. In fact, the pond ash is a mixture of fly ash and bottom ash. The main difference between pond ash and fly ash is in their particle size. The pond ash is coarse and less pozzolanic and hence is not being accepted as pozzolana.

Fig. 3: pond ash

Table 5: Physical properties of pond ash

Sr.no.	Properties	Value
1	Lime Reactivity of Pond ash	0.66
2	Specific Gravity	2.16
3	Bulk density in Loose State	824 kg/m^3
4	Bulk density in Compacted State	990 kg/m^3
5	Atterberg's Limits Liquid Limits (%)	47.3
6	Grain size distribution Sand % Silt % Clay %	 72 28 NIL
7	IS Classification	SP-SM

Table 6: Chemical Compositions of Pond Ash

S. No.	Constituent	Pond ash (%)
1.	Silica (SiO_2)	67.40
2.	Alumina (Al_2O_3)	19.44
3.	Iron Oxide (Fe_2O_3)	8.5
4.	Calcium Oxide (CaO)	2.7
5.	Magnesium Oxide (MgO)	0.45
6.	Sulphur (SO_3)	0.30
7	Loss of Ignition	3.46

The pond ash is a waste product from boilers, where the coal is burnt to heat the water for preparing the steam, which is a common process in most of coal, based thermal power plants. It is mainly obtained from the wet disposal of fly ash. The disposal methods commonly adopted are the dry form or the wet method. In wet method, the ashes and water are mixed and are discharged into water bodies in slurry form called as ash ponds. In the ponds, the dissolvable alkalis present in ash are washed with water. The fly ash gets mixed with bottom ash and disposed of in large pond or dykes as slurry. [7]
It is also termed as pond fly ash and contains relatively coarse particles. The large areas of land are used to store such a mixture of pond ash resulting in land degradation near the thermal power plants. As the pond ash is being produced at an alarming rate, hence the efforts are required for its safe disposal and if possible find ways of utilizing it.

Fig. 4: Disposal of Pond Ash

The disposal of the waste produced by the manufacturing industries in India is one of the greatest challenges faced by them which make this problem complex. India produces about 180 million metric tons of fly ash every year. The nation uses only about 38 percent of its total fly ash production for cement manufacturing (approximately 10.42 million metric tons), land filling, brick manufacturing, mine filling, agriculture and other uses. With the continued reliance on coal, India will have huge supplies of fly ash in the years to come which is estimated to be about 225 million metric tons of fly ash, which has to be stored in more than 1.8 million acres of ponds by 2032.

Nowadays pond ash/ fly ash have become an attractive construction material because of its self-hardening character, which depends on the availability of free lime in it. Efforts have always been made by the researchers to make pertinent use of pond ash in road constructions in the localities, which exists in the vicinity of thermal power stations. Since, pond ash is the residue after combustion of coal in thermal power plants, so its properties depends upon the coal used and may vary from one power plant to other power plant.

3.2 Experimental Investigation

The following were tests performed for the present study in laboratory:-

1. Specific gravity.
2. Atterberg limits(LL,PL,PI)
3. Standard proctor test (MDD,OMC)
4. Unconfined Compression Test.
5. California Bearing Ratio Test
6. Direct shear Test

3.2.1 Specific gravity: - Specific gravity is the ratio of the weight in air of a given volume of a material at a standard temperature to the weight in air of an equal volume of distilled water at the same stated temperature. The variation of specific gravity of the soil/soil-pond ash mixtures with alccofine is shown in **chart 1.** The specific gravity is calculated using equation.

$$\text{Specific Gravity (G)} = (M_2 - M_1) / (M_4 - M_1) \times (M_3 - M_2)$$

3.2.2 Atterberg's Limits: - The test includes the determination of the liquid limits, plastic limits and the plasticity index for the natural soil and the stabilized soils.

a)Liquid Limits:- The variation of liquid limit of the soil/soil-pond ash mixtures with alccofine is shown in **chart 2.** The addition of alccofine and pond ash, especially, introduces calcium for its strength which caused a decrease in the repulsive force of the soil mixture; thereby needing more water to take the soil to its dynamic shear strength. The value of the liquid limit of the soil increased from 61% of the natural soil to a peak value of 75% at 3% alccofine and 30% pond ash. It was observed that the liquid limit increased steadily from its natural state to 3% alccofine and 30% pond ash before the values reduced.

b) Plastic Limit: - The variation of the plastic limit of the soil/soil-pond ash mixtures with alccofine contents is shown in **chart 3**. Plastic limit generally decreased with higher admixture contents, from a natural soil value of 26.9% to minimum value of 21.5% at 3% alccofine & 20% pond ash.

c) Plasticity Index:- The variation of the plasticity index of soil-pond ash mixtures with alccofine contents are shown in **chart 4.** The plasticity index (PI) is a measure of the plasticity of a soil. The plasticity index is the size of the range of water contents where the soil exhibits plastic properties. The PI is the difference between the liquid limit and the plastic limit (PI = LL-PL). Soils with a high PI tend to be clay, those with a lower PI tend to be silt, and those with a PI of 0 (non-plastic) tend to have little or no silt or clay.

3.2.3 Standard proctor test:-The SPT test commonly known as SPT is a field test usually conducted for sampling cohesionless soils. This test is extemely useful for determining the relative density and angle of shearing resistance of cohesionless soil. It can also be used to determine the unconfined compressive strength of cohesive soil and bearing capacity of soil.

a) Maximum dry density:- The variation of maximum dry densities (MDD) of soil-pond ash mixtures with alccofine contents is presented in **Chart 5.**Generally MDD values increased with higher admixture contents which are due to the presence of pond ash/ash particles filling the voids within the soil.
The MDD increased from 1.42 to 1.64Mg/m^3 at 30% pond ash and 3% alccofine contents and later reduced to 1.62Mg/m^3 at 50% pond ash and 3% alccofine treatment. The reduction may be due to the minimal effect of alccofine (with little calcium) on the workability of the stabilized soil.

b) Optimum moisture content:- The variation of optimum moisture content of soil-pond ash mixtures with alccofine contents is shown in **chart 6.** It is observed that the pond ash values when compaction was at the same energy levels increased to peak values at 3% alccofine for all pond ash contents for all the compactive efforts.
The OMC as per Indian standard compaction increased from 28% for the natural state to 48% at 30% pond ash & 3% alccofine. Further addition of pond ash (to 50%) led to a decrease in the OMC to a value of 30% at 0% alccofine.

Table8:-Result of specific gravity, atterberg limits (LL,PL,PI)SPT test(MDD,OMC) pond ash-alccofine

Pond Ash Content (%)	Specific gravity		Liquid Limit Test		Plastic Limits Test		Plasticity Index Tests		MDD (mg/m^3)		Omc (%)	
	Alccofine (%)		Alccofine (%)		Alccofine (%)		Alccofine (%)		Alccofine (%)		Alccofine (%)	
	0	3	0	3	0	3	0	3	0	3	0	3
0	1.93	1.94	61	69	26.9	21.8	34.1	47.2	1.42	1.55	28	38
15	1.92	1.92	63	70	30.7	22.9	32.3	47.1	1.44	1.57	31	41
20	1.93	1.91	67	74	32.2	21.5	24.8	52.5	1.48	1.61	33	45
30	1.90	1.89	65	75	29.5	22.9	35.5	52.1	1.51	1.64	37	48
50	1.91	1.90	63	71	30.5	24.6	32.5	46.4	1.53	1.62	30	40

Chart-1,2,3,4 showing the variation of curves specific gravity,LL,PL,PI with %age of pond ash

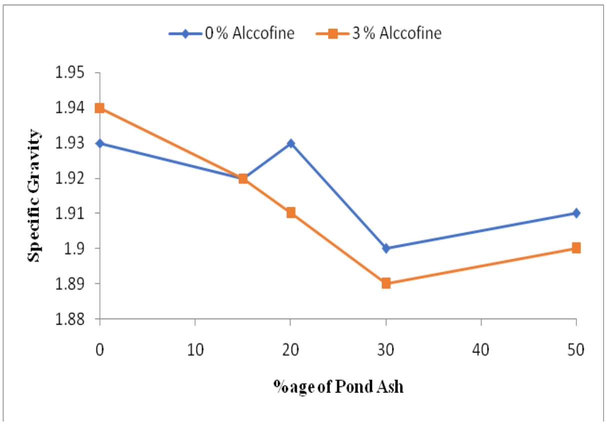

Chart-1: Variation of specific gravity with % of alccofine

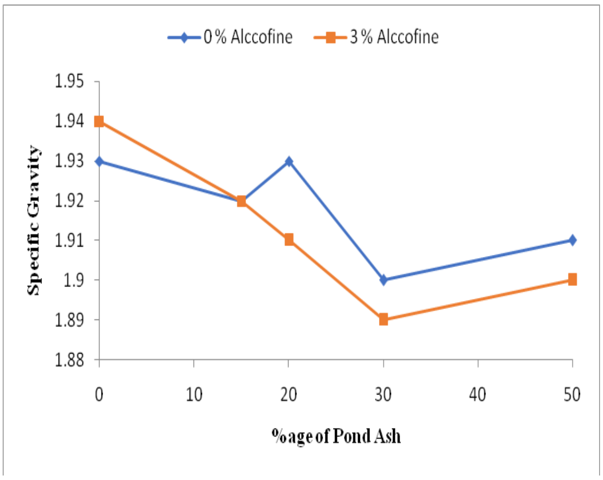

Chart-2: Variation of liduid limit with % of alccofine

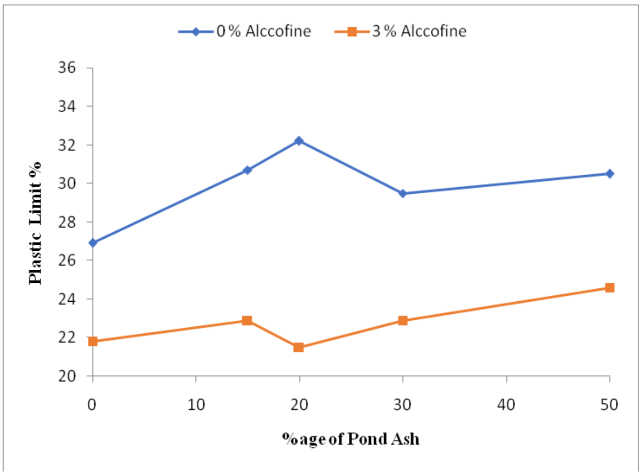

Chart-3: Variation of plastic limit with % of alccofine

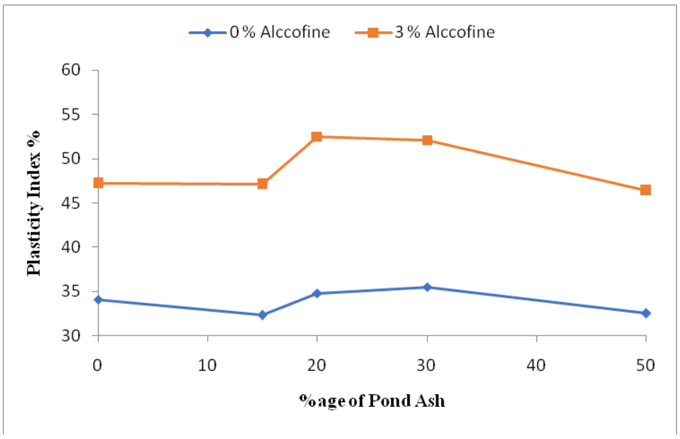

Chart-4: Variation of plasticity limit with % of alccofine

Chart -5&6 showing the variation of curves MDD and OMC with %age of pond ash

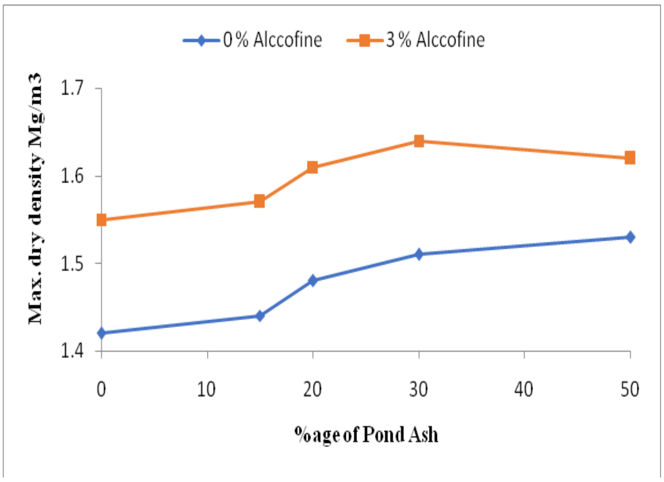

Chart-5: Variation of maximum dry density with % of alccofine

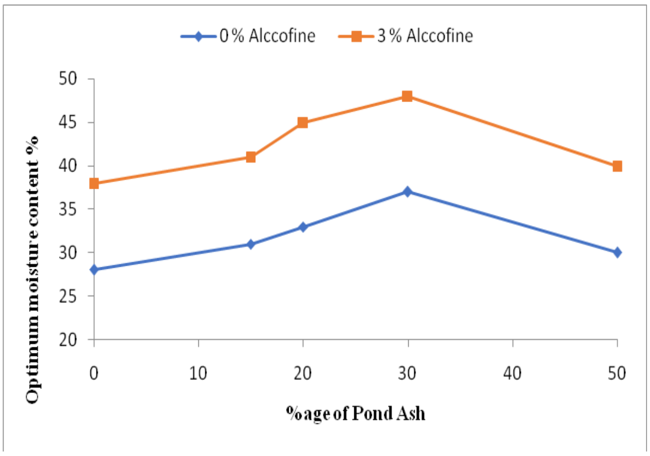

Chart-6: Variation of maximum dry density with % of alccofine

3.2.4 Unconfined Compression Test:- It is recommended for use in the determination of the additive to be used in the stabilization of soil is the unconfirmed compressive strength (UCS) test. It is an important factor in the evaluation of the design criteria for the use of soil as a pavement material or building foundations.

The variation of UCS of soil-pond ash mixtures cured for 7 days with alccofine contents are shown in Fig. The UCS values showed a sharp increase from 178KN/m² for the natural soil to 986kN/m² at 30% pond ash & 3% alccofine. Subsequent addition of alccofine content did not increase the UCS; rather, it recorded a slight decrease to a value of 823kN/m² at 50% pond ash & 3% alccofine because of insufficient water to take the pozzolanic reaction to completion.

Table 1:- Results of UCS test (Soil, Pond Ash–Alccofine) for 1 week curing period

Pond Ash content (%)	Alccofine (%)	
	0	3
0	178.38	582.25
15	288.39	568.14
20	450.25	731.91
30	693.04	985.46
50	533.35	822.78

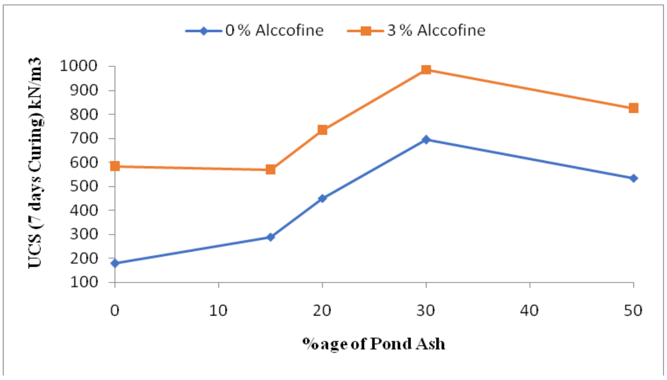

Chart-7: UCS(7 days Curing) Test for Soil Pond Ash–Alccofine

The variation of UCS values (14 days curing) for soil-pond ash mixtures with alccofine contents are shown in Figure
The results recorded increases in the UCS values for the natural soils from with 190kN/m² to peak values of 1326kN/m² at 30% pond ash & 3% alccofine. The trend of increased compressive strength with curing period can be attributed to time dependent strength gain of the pozzolanas. The increase is due to availability of sufficient water which enhanced hydration reaction that has contributed to the reaction between lime liberated from the hydration reaction of pond ash and the alccofine to form secondary pond ash compounds.

Table 2:- Results of UCS test (Soil, Pond Ash–Alccofine) for 2 week curing period

Pond Ash content (%)	Alccofine (%)	
	0	3
0	189.93	873.59
15	359.35	922.97
20	473.44	906.38
30	504.17	1016.25
50	629.41	1326.37

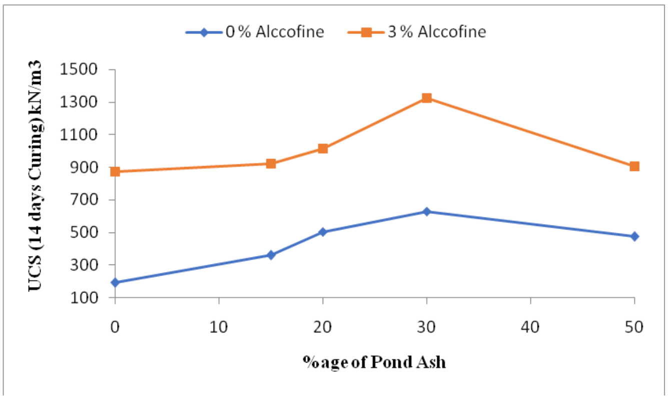

Chart:-8 UCS (14 Days Curing) For Soil-Pond Ash-Alccofine

3.2.5 California Bearing Ratio:- The California bearing ratio (CBR) value of a soil/stabilized soil is an important parameter in gauging the suitability of the soil/stabilized soil for engineering use. It gives the indication of the strength and bearing ability of the soil.

a)Unsoaked CBR:- The variation of the CBR (unsoaked) of soil-pond ash mixtures with alccofine contents are given in Fig. The unsoaked CBR gave a peak value of 46% at 30% pond ash & 3% alccofine from a value of 5% for the natural soil.
It was observed that, though, the value of the CBR increased with higher additive contents at higher compactive efforts, the compactive efforts do not have appreciable effect on the values of the CBR.

Table 10:- Result of CBR (Unsoaked) for Soil-Pond Ash-Alccofine

Pond Ash content (%)	Alccofine (%)	
	0	**3**
0	5.15	17.77
15	10.85	21.94
20	17.51	27.5
30	21.89	46.12
50	22.57	36.21

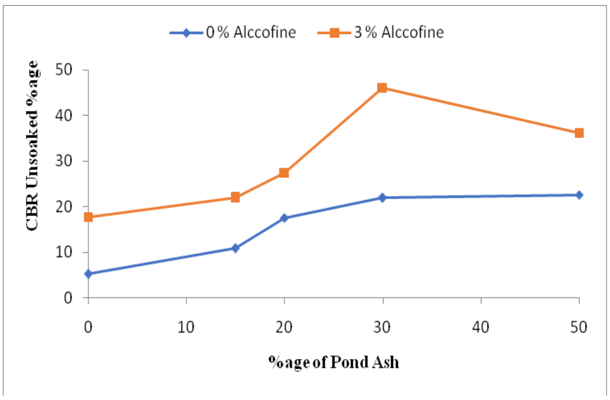

Chart:-9 CBR (Unsoaked) for Soil-Pond Ash-Alccofine

b) Soaked CBR:-

The variation of CBR (soaked for 24 hours) of soil-pond ash mixtures with alccofine contents are shown in Figure.

There were increases in the values of CBR with higher additive contents at higher compactive efforts with a peak value of 42% recorded at 30% pond ash & 3% alccofine. The reduction with respect to the unsoaked CBR values was due to the ingress of water into the specimen when it was soaked for 24 hours, which weakened it and reduced their strength. All the values recorded fell short of the specification required for base courses.

Table11:- Result of CBR(Soaked) for Soil-Pond Ash-Alccofine

Pond Ash content (%)	Alccofine (%)	
	0	**3**
0	4.64	16
15	9.77	19.75
20	15.76	35.74
30	19.7	41.5
50	20.3	32.59

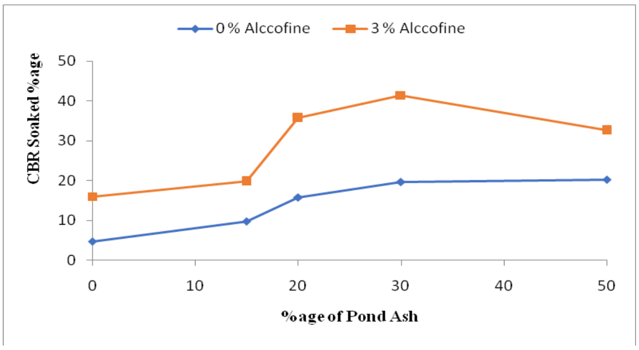

Chart 10:- CBR (Soaked) for Soil-Pond Ash-Alccofine Mixes

3.2.6) Direct Shear Test: - This test is used to understand the concept of shearing of soil. The resistance to shear for cohesion less soil is derived from friction b/w grain and interlocking of grains. The direct shear test is generally conducted on cohesion less soil as C-D test. It is convenient to perform and it gives good result for the strength parameter.

Table11:- Result of direct shear test for Soil-Pond Ash-Alccofine

S. No.	Properties	Range OF ALCCOFINE (3%)	Range OF ALCCOFINE (5%)	Range OF ALCCOFINE (7%)	Range OF ALCCOFINE (9%)
1	Volume of shear Box	90 cm^3	90 cm^3	90 cm^3	90 cm^3
2	Maximum dry density of soil	1.986 gm/cc	2.025 gm/cc	2.127 gm/cc	2.055 gm/cc
3	Optimum moisture content of soil	12.10 %	12.50 %	13.00 %	13.80 %
4	Weight of the soil to be filled in the shear box	178.74 gm	182.25 gm	191.43 gm	184.95 gm
5	Weight of water to be added	21.62754 gm	22.78125 gm	24.8859 gm	25.5231 gm

Table12:- Calculations for Direct shear test of the soil Admixed with 3%, 5%, 7%, and 9% of Pond Ash

S. No	Normal Stress(kg/cm²)	Shear Stress (kg/cm²) (3%)	Shear Stress (kg/cm²) (5%)	Shear Stress (kg/cm²) (7%)	Shear Stress (kg/cm²)(9%)
1	0.5	0.661	0.67	0.758	0.72
2	1	0.85	0.9	0.98	0.95
3	1.5	1.103	1.13	1.2	1.19

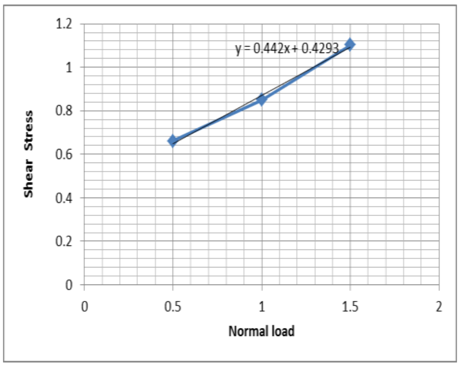

Chart 11:- Normal Load and Shear Stress graph for the soil Admixed with 3% of Pond Ash

Computing from graph:
Cohesion (C) = 0.429 kg/cm²;
Angle of internal friction (φ) = 23⁰50'

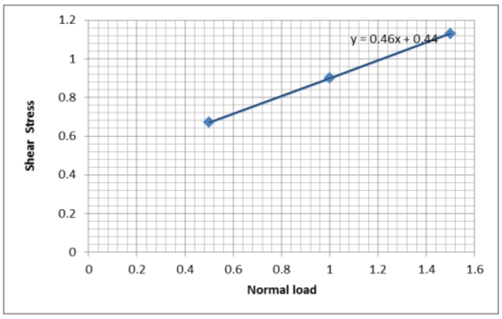

Chart 12:-Normal Load and Shear Stress graph for the soil Admixed with 5% of Pond Ash

Computing from graph:
Cohesion (C) = 0.44 kg/cm²;
Angle of internal friction (φ) = 24.70⁰

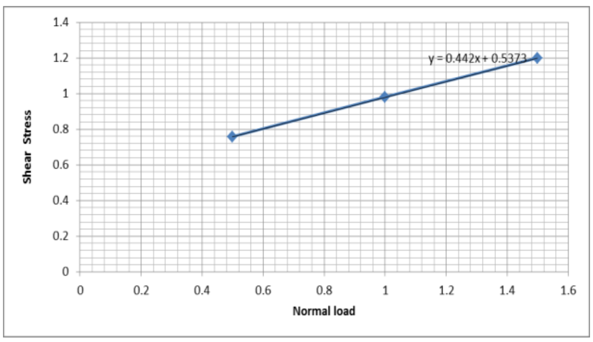

Chart 13:-Normal load and shear stress graph for the soil admixture with 7% of pond ash

Computing from graph,
Cohesion (C)=0.537 kg/cm^2
Angle of internal friction (φ)= 23^{0}50'

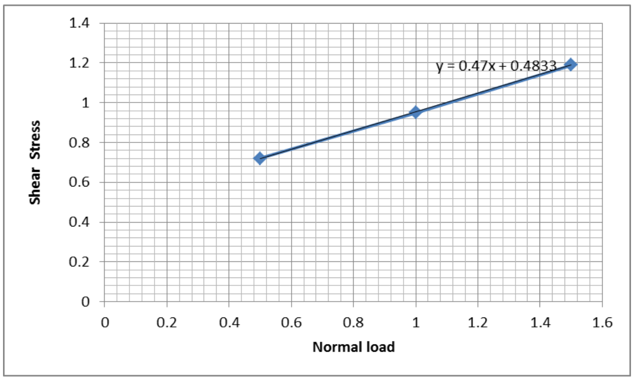

Chart 14:- Normal Load and Shear Stress graph for the soil Admixed with 9% of Pond Ash

Computing from graph,
Cohesion (C) = 0.483 kg/cm^2;
Angle of internal friction (φ) = 25^{0}10'

3. CONCLUSION

The preliminary investigation conducted on the natural sand stabilized with pond ash and alccofine. The natural soil has high moisture content of 35% because it was collected during the rainy period. It has liquid limit of 63%, plastic limit of 27%, plasticity index of 36%, linear shrinkage of 17%, free swell of 75%, specific gravity of 1.94 and NBRRI Classification of high swell potential. All these values indicate that the soil is highly plastic with about 71% of the soil particles passing the B. S. No 200 sieve. The strength characteristics are also very low, thereby rendering the soil unfit for sub-base or road base courses.

In an effort to raise the soil's suitability for engineering use, the air dried samples were treated with OPC/ALCCOFINE in stepped concentration of 0, 2, 4, 6, and 8% by dry weights of the soil. The tests conducted showed that the liquid limit of the natural soil increased from 63% to 77% at 30% pond ash & 3% alccofine. The plastic limit, however, decreased from 26.6% for the natural soil to 21.4% at 6% OPC/4% ALCCOFINE. The plasticity index values for all the concentration of the additive exceeded the 30% value prescribed for sub-grade materials by the Nigeria General Specification (1997).

The MDD increased with higher additive blends and compactive efforts; which is in conformity with the same trend reported by Osinubi (1999a), Osinubi et al (2007b), Staphen (2005) and Akinmade (2008). The peak MDD values recorded for BSL, WAS and BSH compactive efforts are respectively 1.4Mg/m^3, 1.5Mg/m^3 and 1.6Mg/m^3 at 30% pond ash & 3% alccofine treatment. The OMC, on the other hand, decreased with higher compactive efforts but increased with higher ALCCOFINE contents. The decrease may be due to the effect of breakdown of the flocculated aggregates and elimination of large pores, when higher compactive energies were used. The optimum moisture content values at the natural states increased from 24, 21 and 19% to 40, 38 and 33% when compacted using BSL, WAS and BSH energies at 8% OPC/6% ALCCOFINE, 50% pond ash & 3% alccofine and 30% pond ash & 3% alccofine, respectively.

The unconfined compressive strength (UCS) values for natural soil compacted with BSL, WAS and BSH energies at 7 days curing period are 179,

381 and 750kN/m^2 respectively and increased to 986, 1436 and 1650kN/m^2 at 30% pond ash & 3% alccofine treatment. The values of UCS for both BSL and WAS fell short of the requirement based on Road Note 31 (TRRI, 1977) requirement for economic range of OPC stabilization. However, the UCS value of the BSH compaction could be acceptable for base courses of pavements. The 28 days curing period UCS values obtained showed that the OPC/ALCCOFINE blend has a long term advantage in terms of strength gain. There were tremendous increments in the values of UCS from their natural states. The 28 days curing period UCS produced a peak value of 2616kN/m^2 at 30% pond ash & 3% alccofine for BSH compaction, showing that the soil treated with this blend can be used (at BSH compaction) as base course of pavement material.

The unsoaked CBR values of 5, 7 and 11% (for the natural soil) compacted with BSL, WAS and BSH energy efforts, respectively, increased to 46, 77 and 83% at 30% pond ash & 3% alccofine. The 24 hours soaked CBR values recorded peak values of 42, 66 and 66% with BSL, WAS, BSH energies, respectively, which showed about 10-15% decrease from the unsoaked CBR values. The CBR values of 66% with BSH compaction at 30% pond ash & 3% alccofine blend can be used as sub base material because it meets the 29% recommended values for sub-base by the Nigerian General Specification (1997). Also the 42% recorded with BSL compaction at 30% pond ash & 3% alccofine treatment meets the 15% recommended for subgrade material by the Nigerian General Specification (1997).

The resistance to loss in strength of the soil increased from 13, 7, and 15% for the natural soil to peak values of 42, 13 and 71% for BSL, WAS and BSH energies at 50% pond ash & 3% alccofine, 8% OPC/0% ALCCOFINE and 30% pond ash & 3% alccofine, respectively. Only 71% resistance to loss in strength (29% loss in strength) at 30% pond ash & 3% alccofine with BSH compaction is close to the limiting value of 80% resistance to loss in strength (Ola, 1983) based on 4 days soaking. The 6% OPC 6% ALCCOFINE treatment of the soil can be used, at BSH compaction, for sub-base material because the soil was subjected to a harsher condition (of 7 days soaking) and due to the time dependent gain in strength advantage of the pozzolana.

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