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Utilizing Fly Ash and Alccofine for Efficient Soil Stabilization

Lovedeep Singh Sambyal[1], Neeraj Sharma[2]

[1]M.Tech (CE), Sri Sai Group of Institution, Badhani, Punjab, India
[2]Astt. Prof. (CE), Sri Sai Group of Institution, Badhani, Punjab, India

Abstract— The main objective of this research work was to study the engineering characteristics of clay soil. 51.8 million hectares of land area in India are covered with Expansive soil. The property of these expansive soils, in general, is that they are very hard when in dry state, but they lose all of their strength when in wet state. In light of this property of expansive soils, these soils pose problems worldwide that serve as challenge to overcome for the Geotechnical engineers. One of the most important aspects for construction purposes is soil stabilization, which is used widely in foundation and road pavement constructions; this is because such a stabilization regime improves engineering properties of the soil, such as volume stability, strength and durability. In this process, removal or replacing of the problematic soil is done; replacement is done by a better quality material, or the soil is treated with an additive. In the present study, using fly ash obtained from Sesa Sterlite, Jharsuguda, Odisha, stabilization of black cotton soil obtained from Nagpur is attempted. With various proportions of this additive i.e. 10%, 20%, 30%, 40% & 50%, expansive soils is stabilized. Owing to the fact that fly ash possess no plastic property, plasticity index (P.I.) of clay-fly ash mixes show a decrease in value with increasing fly ash content. In conclusion, addition of fly ash results in decrease in plasticity of the expansive soil, and increase in workability by changing its grain size and colloidal reaction. The proposed simulation selected the stabilizer as fly ash because of its pozzolanic activities and act as a stabilizing agent in presence of a strong binder like alccofine which even in a small percentage increase the strength and improving the engineering properties of expansive soils.

Index Terms— Expansive Soil, Fly Ash and Alccofine.

1 INTRODUCTION

For centuries mankind was wondering at the instability of earth materials, especially expansive soil. Expansive soils, which are also called as swell-shrink soil, have the tendency to shrink and swell with variation in moisture content. One day these are dry and hard, and the next day wet and soft. As a result of this variation in the soil, significant distress occurs in the soil, which is subsequently followed by damage to the overlying structures. During periods of greater moisture, like monsoons, these soils imbibe the water, and swell; subsequently, become soft and their water holding capacity diminishes.

Figure 1: Cracks in Expansive Soil.

As opposed to this, in drier seasons, like summers, these soils lose the moisture held in them due to evaporation, resulting in their becoming harder. Generally, found in semi-arid and arid regions of the globe, these types of soils are regarded as potential natural hazard- if not treated, these can cause extensive damage to the structures built upon them, as well causing loss in human life. Soils whose composition includes montmorillonite, in general, display these kinds of properties. These soils have caused extensive damage to civil engineering structures and resulted annually inextensive maintenance cost worldwide.

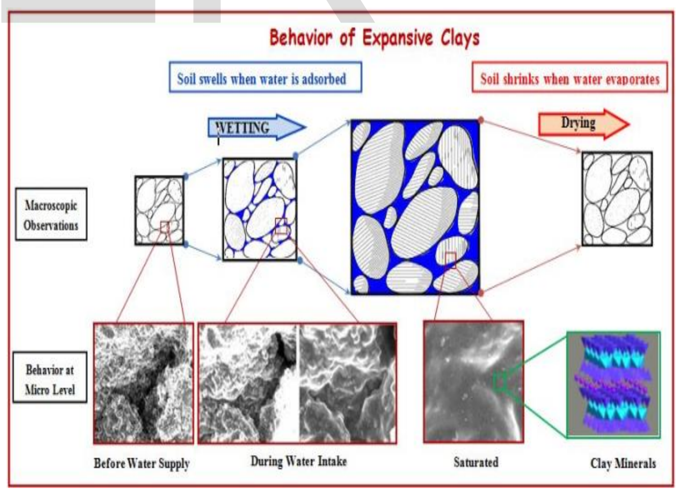

Figure 2: Behaviour of Expansive Soil.

The key element which imparts swelling characteristics to any ordinary non-swelling soil is a clay mineral. There are several types of clay minerals of which Montmorillonite has the maximum swelling potential. The origin of such soil is sub aqueous decomposition of blast rocks, or weathering due to which in situ formation of important clay mineral takes place under alkaline environments. Due to weathering conditions, there is adequate supply of magnesium of ferric or ferrous oxides and alkaline environments. Along with sufficient silica and aluminum, it will favor the formation of montmorillonite. The depth of expansive soil is shallow at the place of formation with the parent rock underneath.

2 Fly Ash

A waste material extracted from the gases emanating from coal fired furnaces, generally of a thermal power plant, is called fly ash. One of the chief usages of volcanic ashes in the ancient ages was the use of it as hydraulic cements, and fly ash bears close resemblance to these volcanic ashes. These ashes were believed to be one of the best pozzolans (binding agent) used in and around the globe. The demand of power supply has exponentially heightened these days due to increasing urbanization and industrialization phenomena. Subsequently, this growth has resulted in the increase in number of power supplying thermal power plants that use coal as a burning fuel to produce electricity. The mineral residue that is left behind after the burning of coal is the fly ash. The Electro Static Precipitator (ESP) of the power plants collects these fly ashes. Production of fly ash comes with two major concerns – safe disposal and management of fly ash. Because of the possession of complex characteristics of wasters which are generated from the industries, and their hazardous nature, these wastes pose a necessity of being disposed in a safe and effective way, so as to not disturb the ecological system, and not causing any sort of catastrophe to human life and nature. Environmental pollution is imminent unless these industrial wastes are pretreated before their disposal or storage. Essentially consisting of alumina, silica and iron, fly ashes are micro-sized particles. Fly ash particles are generally spherical in size, and this property makes it easy for them to blend and flow, to make a suitable concoction. Both amorphous and crystalline natures of minerals are the content of fly ash generated. Its content varies with the change in nature of the coal used for the burning process, but it basically is non-plastic silt. For waste liners, fly ash is a potential material that can be employed; and in combination with certain minerals (lime and bentonite), fly ash can be used as a barrier material. In present scenario, the generation of this waste material in picture (fly ash) is far more than its current utilization. In other words, we are producing more of fly ash than we can spend.

2.1 Generation and Disposal

Usage of coal in thermal power plants for the generation of steam is a common practice. A method that was proved to be non-energy efficient was used in the past, where coal in form of lumps was expended in the furnaces of the boilers to generate the evaporated content: steam. Thus, in order to optimize the production of energy from coal mass, the thermal power plants began to use pulverized coal mass instead of the aforementioned content. In this process, firstly, this pulverized coal is infused into the combustion chamber, where the instant but efficient burning of fuel happens. The ash formed as a result of this is called the fly ash, and this fly ash contains molten minerals. The steam around this molten mass, when the coal ash travels with the flue gases, results in the spherical shape of the fly ash particle. Next, the employment of the economizer recovers the heat from the steam gases and fly ash. As a result of this process, the temperature of the fly ash shows a sudden reduction in value. If this temperature fall is rapid, then the resulting structure of the fly ash material is amorphous. However, if the temperature drop during this cooling process is gradual, then the fly ash assumes a more crystalline in nature. This shows the implementation of the economizer, and how it improves the reactivity process.

In the process where fly ash is not subjected to the economizer, it forms a 4.3% soluble matter, and its pozzolanic activity index clocks to 94%. Whereas, during the process where the fly ash exposed to the economizer, its pozzolanic activity clocks to 103% and it forms a 8.8% soluble matter. In conclusion, fly ashes are separated from the flue gases by a mechanical dust collector, which is commonly referred to as Electro Static Precipitator (ESP), or scrubbers. Free of fly ashes, the rest of the flue gases are liberated into the atmosphere via the chimney.

With about 90%-98%, the efficiency of ESPs for the separation of finer and lighter fly ash particles is high. In general, the fly ash consists of four to six hoppers, named as field. The fineness of the fly ash particles collected are thus proportional to the number of fields available in an ESP. Therefore, the fly ashes that are collected from the first hopper have a specific surface area of about 2800 $cm2/\text{gm}$, whereas the fly ash collected from the last hopper exhibit a greater specific surface area, that is, 8200 $cm2/\text{gm}$. With the scorching of pulverized coal, the resulting ash content forming during the process are either collected as fly ash or bottom ash. 80% of coal ashes that are removed from the flue gases are recovered as fly ash, whereas the remaining 20%, that are generally coarser in size, are collected at the bottom of the furnace as bottom ash. Either in dry form, or its collection from a water-filled hopper, bottom ash is taken from the bottom of the furnace. When there is a sufficient amount of bottom ash in the water-filled hopper, beyond which its disposal becomes imminent before moving on to the next process, the transference can occur by water jets or water sluice to a disposal pond which. This disposed waste is then called as pond ash. The below figure gives an idea of disposal of coal ash in a thermal power plant where coal is a fuel.

2.2 Classification of Fly Ash

The extracted ash from the flue gases via an Electro Static Precipitator, after the process of pulverization, is called fly ash. It is the finest of particles among bottom ash, pond ash and fly ash. With some unburned carbon, the fly ash chiefly consists of non-combustible particulate matter. These generally consist of silt-sized particles. On the basis of a lime reactivity test, fly ashes have been classified into four different types, as given:

1) Cementitious fly ash
2) Cementitious and pozzolanic fly ash
3) Pozzolanic fly ash
4) Non-pozzolanic fly ash

Based on the chemical composition of fly ash, fly ash has been categorized into two categories, as given:

1) Class C fly ash

2) Class F fly ash

Table 1: Chemical Requirements of Class C and Class F fly ashes.

Particulars		Fly ash	
		Class F	Class C
$SiO_2 + Al_2O_3 + Fe_2O_3$	% minimum	70.0	50.0
SO_2	% maximum	5.0	5.0
MC	% maximum	3.0	3.0
LOI	% maximum	6.0	6.0

Burning of sub-bituminous type of coal and lignite, which contains more than 20% Calcium Oxide, gives the Class C fly ash. By ignition of anthracite and bituminous type of coal, Class F fly ash comes into the picture. This fly ash contains less than 20% Calcium Oxide. The chemical configuration of Class C and Class F fly ashes are as follows, in the given Table 1:

2.3 Utilization of Fly Ash

The utilization of fly ash can be largely grouped into following three classes:

1) The Low Value Utilizations, which includes back filling, structural fills, road construction, soil stabilization, and embankment & dam construction, ash dykes, etc.
2) The Medium Value Utilizations, which includes grouting, cellular cement, pozzolana cement, bricks/blocks, soil amendment agents, prefabricated building blocks, fly ash concrete, weight aggregate, etc.
3) The High Value Utilizations, which includes, fly ash paints, ceramic industry, extraction of magnetite, distempers, metal recovery, acid refractory bricks, floor and wall tiles, etc.

3 Alccofine

ALCCOFINE is a new generation, micro fine material of particle size much finer than other hydraulic materials like cement, fly ash etc. manufactured in India.

Figure 3: Alccofine.

It has unique characteristics to enhance 'performance of concrete' in fresh and hardened stages. It can be used as practical substitute for Silica Fume. Alccofine is manufactured in the controlled conditions with special equipment to produce optimized particle size distribution which is its unique property. Alccofine 1203 and Alccofine 1101 are two types with low calcium silicate and high calcium silicate respectively. The computed blain value based on PSD is approximately 12000cm2/gm and is truly ultra-fine. Due to its ultra-fineness of Alccofine 1203, it provides reduced water demand for a given workability, even up to 70% replacement level as per requirement [8].

4 Related Work

In terms of methods of stabilization of soils, there are physical, chemical and biochemical stabilization methods. Various efforts have been made to stabilize expansive soil and dispersive soil for engineering use. Variety of stabilizers may be divided into three groups (a) conventional stabilizers (lime, cement etc.), (b) by-products stabilizers (fly ash, quarry dust, phosphor-gypsum, slag etc.) and (c) non-traditional stabilizers (sulfonated oils, potassium compounds, polymer, enzymes, ammonium chlorides etc.) (Petry 2002). Disposal of large quantities of industrial by-products as fills on disposal sites adjacent to industries not only requires large space but also create a lot of geo-environment problems. Attempts are being made by various organizations and researchers to use them in bulk at suitable places. Stabilization of expansive soil and dispersive soil is one way of utilization of these by-products. Some of the research work conducted by earlier researchers on the above has been described.

4.1 Stabilization of Expansive Soil using Fly Ash

Sharma et al. studied stabilization of expansive soil using mixture of fly ash, gypsumand blast furnace slag. They found that mixture of fly ash, gypsum and blast furnace slag in the proportion of 6: 12: 18 decreased the swelling pressure (SP) of the soil from 248 kN/m^2 to 17 kN/m^2 and increased the unconfined compressive strength by 300%. Srivastava et al. studied the change in micro structure and fabric of expansive soil due to addition of fly ash and lime sludge from SEM photograph and found changes in micro structure and fabric when 16% fly ash and 16% lime sludge were added to expansive soil. Srivastava et al. have also described the results of experiments carried out to study the consolidation and swelling behaviour of expansive soil stabilized with lime sludge and fly ash and the best stabilizing effect was obtained with 16% of fly ash and 16% of lime sludge. Cokca used upto 25% of Class-C fly ash (18.98 % of CaO) and the treated specimens were cured for 7 days and 28 days. The swelling pressure was found to reduce by 75% after 7 days curing and 79% after 28 days curing at 20% addition of fly ash. Pandianet al. had made an effort to stabilize expansive soil with a Class–F Fly ash and found that the fly ash could be an effective additive (about 20%) to improve the CBR of black cotton soil (about 200%)significantly.

4.2 Stabilization of Soil using Alccofine

P J Patel et al studied the effect Alccofine and fly ash on compressive and flexural strength of high performance concrete. The study concluded that:

1) The strength increase up to 7 days was excellent, between 7 to 28 days, strength increase was comparatively less, but between 28 to 56 days, strength rise was high due to of presence of fly ash. The 28 days compressive strength was 1 to 10% less than accepted compressive strength.
2) More than 150 mm slump was determined for all mixes.
3) 90 days compressive strength achieved was better than the strength achieved in 28 days. Maximum compressive strength achieved was 78.58 MPa for M2 mix, which was more than target strength.
4) The acceptable flexural strength was obtained for all mixes. The maximum flexural strength of 7.05 MPa in M4mix was achieved during the study.
5) From the studies of the available literature, it was observed that various efforts have been made to study the possible utilisation of different industrial wastes for stabilization of expansive soil.

Sunil Suthar et al examined the effects of alccofine &fly ash on the strength properties of HPC (high performance concrete). A combination of cementitious materials such as Portland cement, fly ash, and alccofine presents the significant advantages over binary blends and even more improvements in strength properties over Portland cement. The alccofine used in the concrete mix as mineral admixture with fly ash is found to improve the early age strength of hardened concrete. Concerning the durability aspects of concrete, combination of alccofine and fly ash proved to be superior to Portland cement.

The compressive strength of concrete mix prepared with 8% alccofine and different fly ash mixes was found to have higher than 10% silica fumes. A combination of cementitious materials such as Portland cement, fly ash, and Alccofine had achieved high compressive strength than all other silica-fume mixes. The high strength concrete can be achieved with the combination of 8% alccofine and 20% fly ash.

1) Fly ash improves the long-term strength development of the concrete mix.
2) Use of super plasticizer reduces the water demand with increased workability of concrete.
3) The blend of alccofine and fly ash possesses very high resistance to chloride ion permeability.
4) Alccofine helps in increasing the packing of the concrete particles and which in turn increases the strength of concrete.
5) If Fly ash was not used in the mix prepared with silica fume, it increases the water demand.

Yatin Patel et al discussed the durability characteristics of HPC (high performance concrete) with alccofine and fly ash. In the study, the effect of alccofine on the strength and durability properties of concrete was discussed. The study concluded that:

1) The compressive strength of concrete at 28 and 56 days achieved with the combination of 8 % alccofine and 20% fly ash was 54.89Mpa and 72.97 MPa respectively.
2) The minimum loss of weight and compressive strength of concrete was achieved in the chloride resistance test and sea water test in fly ash and alccofine mix concrete. Reason for less permeability of concrete was more compactness with high packing effect. This converts leachable Ca(OH)2 into insoluble, non- leachable cementitious product. The pozzolanic action of alccofine and fly ash is responsible for the higher impermeability of concrete. Also the removal of $Ca(OH)_2$ helps in reducing the effect of chloride attack on concrete.
3) Due to the pore filling and pore refining ability of alccofine, the loss of weight of steel in the alccofine mix concrete was comparable in accelerated electrolytic corrosion test and normal cover was proved to be sufficient to prevent steel reinforcement from corrosion.

Deval Soni et al carried out an investigation on HPC (High-Performance Concrete), developed by combination of alccofine and fly as h in an optimum proportion. The study concluded that:

1) The combination of 8% Alccofine and 16% of fly ash was found an optimum proportion of HPC
2) Alccofine was found to have better performance as well as work ability when compared to other supplementary cementitious materials such as micro silica, GGBFS etc.

Praeen Nayak S. et al compared the hardened properties of concretes prepared with silica fume and alccofine and performance optimization technique was used for the comparative study. The study concluded that:

1) Compressive strengths and flexural strength of alccofine mix concrete was superior to micro silica mix. Optimum proportion of silica fume and alccofine was found to be 13.36% addition or replacement level.
2) Splitting tensile strengths of concrete with micro silica was found to be better than concrete with alccofine at the same addition or replacement level.
3) Impact Strength of micro silica mix was found to be slightly superior to alccofine.

5 Proposed Method

The proposed simulation selected the stabilizer as fly ash because of its pozzolanic activities and act as a stabilizing agent in presence of a strong binder like alccofine which even in a small percentage increase the strength of expansive soil many folds. The proposed steps:

1) To study different characteristics of fly ash and Alccofine
2) Attain different samples of fly ash with Alccofine

3) After adding, analyzing binding gain of soil with different samples
4) Compare physical parameter of samples with previous research.

6 Simulated Results

In this section, the proposed algorithm is evaluated via computer simulation using MATLAB simulator. All simulation results are obtained on the basis of proposed method are picked and concentrated on. Figure 4 show the front end window.

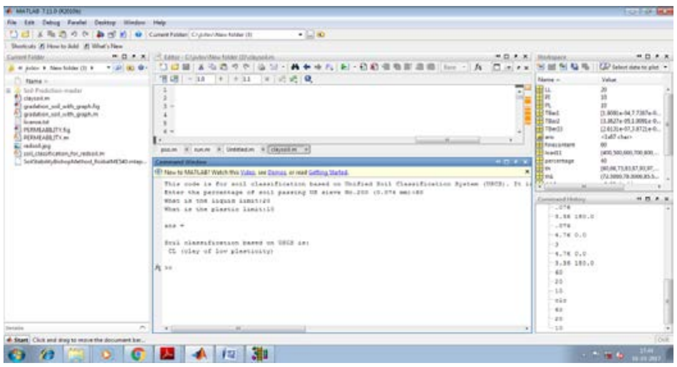

Figure 4: Front End Window.

As demonstrated in Figure 5, soil classification is a dynamic subject, from the structure of the system itself, to the definitions of classes, and finally in the application in the field. Soil classification can be approached from the perspective of soil as a material and soil as a resource.

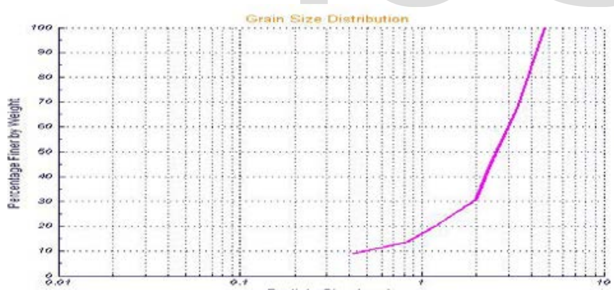

Figure 5: Soil Classification.

As demonstrated in Figure 6, provides the effect of fly ash and Alccofine Mixture on liquid limit behavior of clay soil.

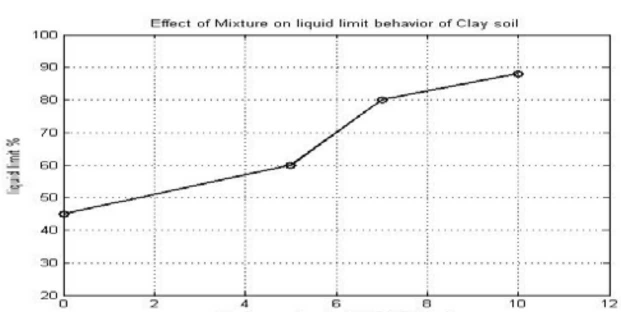

Figure 6: Effect of Mixture on liquid limit behaviour of Clay Soil.

As demonstrated in Figure 7, provides the effect of fly ash and Alccofine Mixture on shrinkage limit behavior of clay soil.

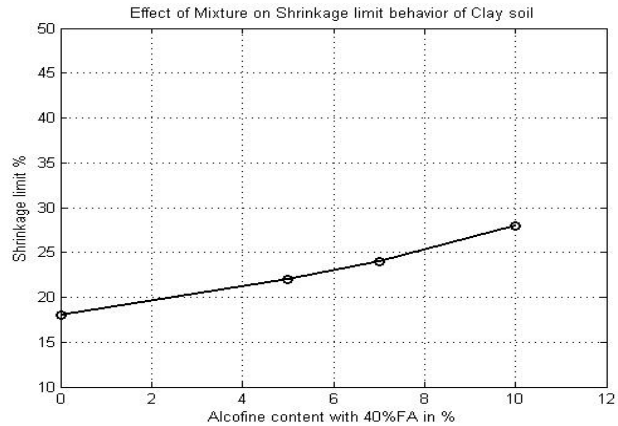

Figure 7: Effect of Mixture on shrinkage limit behaviour of Clay Soil.

As demonstrated in Figure 8, provides the variation of Free Swell index behaviour of clay soil.

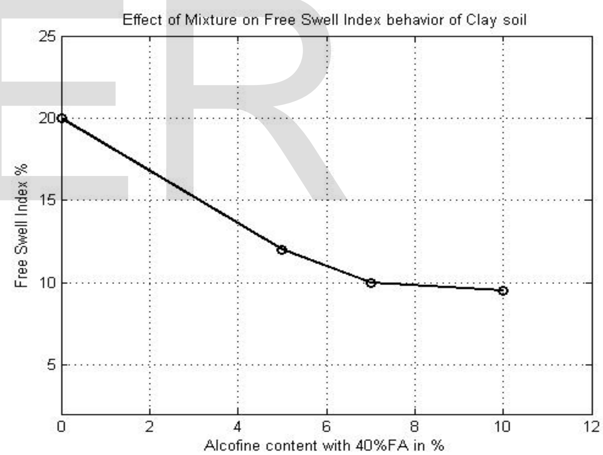

Figure 8: Effect of Mixture on Free Swell behavior of Clay soil.

As demonstrated in Figure 9, provides the effect of fly ash and Alccofine Mixture on optimum moisture content of clay soil.

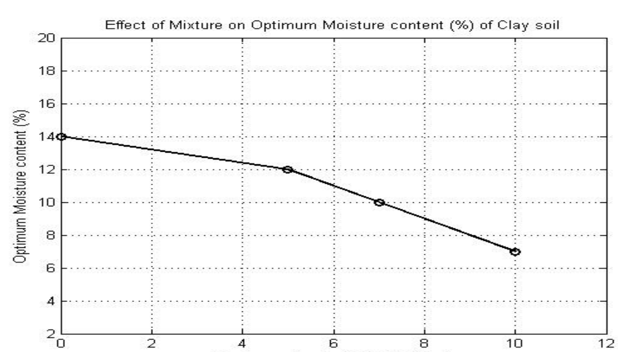

Figure 9: Effect of Mixture on Optimim Moisture Content of Clay soil.

As demonstrated in Figure 10, provides the effect of fly ash and Alccofine Mixture on maximum dry density of clay soil.

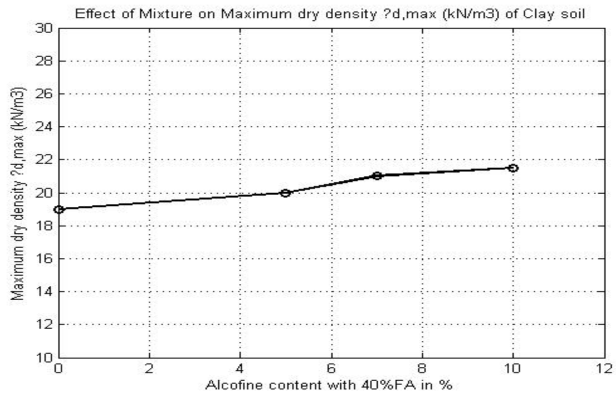

Figure 10: Effect of Mixture on maximum dry density of Clay Soil.

As demonstrated in Figure 11, provides the effect of fly ash and Alccofine Mixture on cohesion of clay soil.

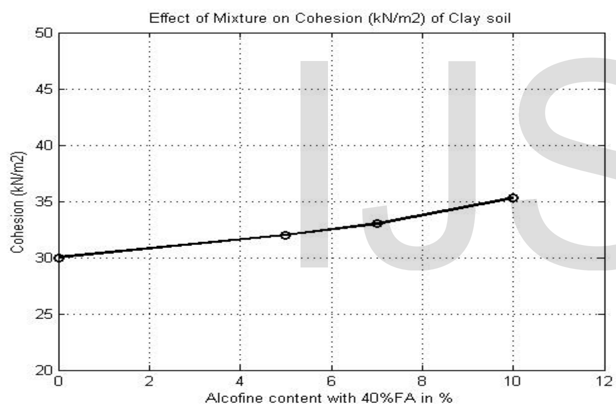

Figure 11: Effect of Mixture on cohesion of Clay Soil.

As demonstrated in Figure 12, provides the effect of fly ash and Alccofine Mixture on unsoaked CBR values of clay soil.

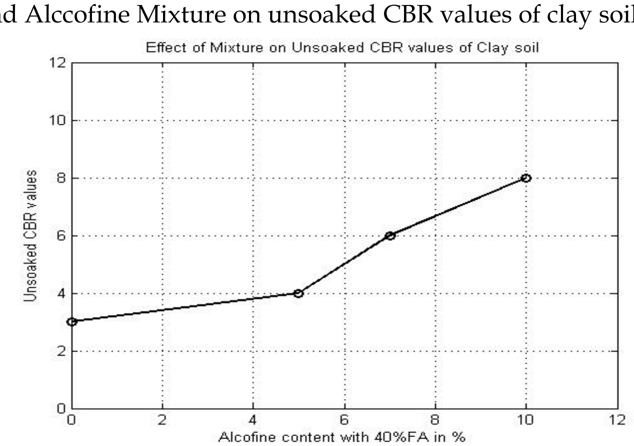

Figure 12: Effect of Mixture on unsoaked CBR values of Clay Soil.

As demonstrated in Figure 13, provides the effect of fly ash and Alccofine Mixture on soaked CBR values of clay soil.

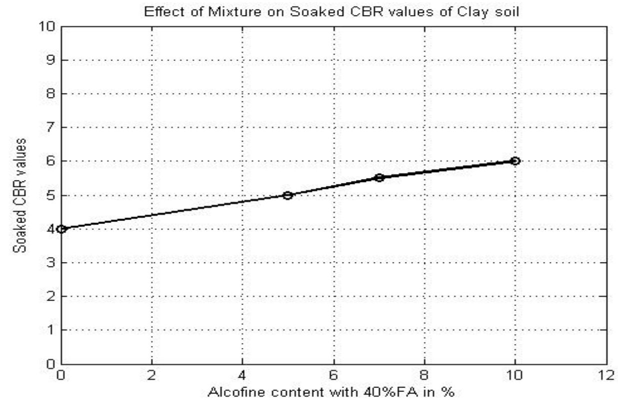

Figure 13: Effect of Mixture on soaked CBR values of of Clay Soil.

7 Conclusion

The present investigation deals with the behavioural aspect of soil. From the experimental results, conclusions have been obtained that some properties of soil can be improved. The unconfined compressive strength, unsoaked CBR and soaked CBR of modified soil is increased with respect to natural soil sample. Thus, the properties of soil can be changed .Materials selected for use in the construction of sub grade must be of adequate strength and at the same time it must be economical for use. The materials selected must also be ensured for the quality and compaction requirements. If the natural soil is weak it needs some improvement to act as a sub-grade. It is therefore, needed to add stabilization with improved strength and compressibility characteristics at the same time lesser thickness of the pavement is required makes the construction economical.

The effect of solid wastes namely fly ash and Alccofine in clay soil on the variation of index properties, compaction characteristics, shear strength and CBR values were analyzed. From the results the following conclusion may be drawn.

1) The liquid limit and the FSI of the soil decreased steeply with the increase in the percentage of mixture. In case of clay soil the liquid limit increased from a value of 45 % to 88 % for the same quantum of addition of mixture. The decrease in the free swell Index was from 20 % to 9.5 %. The shrinkage limit of soil increased to 18 % and 28 % respectively for clay soil from 9 % initially for virgin soil.
2) The Maximum dry density increased from 19KN/m3 to 21.5kN/m3 in case of addition of % mixture to the soil. The Optimum moisture content decreased steeply with % mixture 14% to 7%.
3) The undrained cohesion value of soil mixed with soil increase from 30 kN/m2 to 35.5 kN/m2
4) The unsoaked CBR value of the soil increased from 3% to 8% whereas soaked CBR value from 4% to 8% only in the case of addition of mixture to clay soil.

Table 2: Result Observation.

S/No.	Particulars	Observational Results			
		FA 40%, Alccofine-0%	FA-40%, Alccofine-5%	FA-40%, Alccofine-7%	FA-40%, Alccofine-10%
1	Effect of Mixture on liquid limit behavior of Clay soil	45	60	80	88
2	Effect of Mixture on Shrinkage limit behavior of Clay soil	18	22	24	28
3	Effect of Mixture on Free Swell Index behavior of Clay soil	20	12	10	9.5
4	Effect of Mixture on Optimum Moisture content (%) of Clay soil	14	12	10	7
5	Effect of Mixture on Maximum dry density (kN/m3) of Clay soil	19	20	21	21.5
6	Effect of Mixture on Cohesion (kN/m2) of Clay soil	30	32	33	35.3
7	Effect of Mixture on Unsoaked CBR values of Clay soil	3	4	6	8
8	Effect of Mixture on Soaked CBR values of Clay soil	4	5	5.5	6

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