International Journal of Advances in Engineering and Management (IJAEM)
Volume 5, Issue 5 May 2023, pp: 1133-1139 www.ijaem.net ISSN: 2395-5252

Effect of Fly Ash and Sodium Silicate on Soil Stabilization

Sanket Wanare[1], Mayur Chavhan[1], Vaishakh Waghmare[1], Himanshu Meshram [1], Rohit Dewari[1], Tejashri Gulve[2]

[1]*Student, Department of Civil Engineering,Dr.D.Y.Patil Institute of Engineering Management and Research, Akurdi, India*

[2]*Assistant Professor, Department of Civil Engineering,Dr.D.Y.Patil Institute of Engineering Management and Research, Akurdi, India*

Date of Submission: 15-05-2023 Date of Acceptance: 30-05-2023

ABSTRACT: Soil stabilization is a very common process for almost all the road projects and other construction works. In soil stabilization, it is very important to understand the material properties involved in the mixture and the outcome after mixing. Moreover, it is important to find out how the material is going to perform after stabilization. In this paper chemical stabilization will be employed on black cotton soil using sodium silicate and fly ash and the stabilized soil will be tested for unconfined compressive strength and California bearing ratio test. The test results of UCS and CBR test will be used to suggest the optimum percentages of sodium silicate and fly ash that gives optimum strength.

KEYWORDS: Soil Stabilization, sodium silicate, fly ash, Black cotton soil.

I. INTRODUCTION

Abandoned sites due to undesirable soil bearing capacities have dramatically increased, and the outcome of this was the scarcity of land and increased demand for natural resources. Affected areas include those which were susceptible to liquefaction and those covered with soft clay and organic soils. Other areas were those in a landslide and contaminated land. However, in most geotechnical projects, it is not possible to obtain a construction site that will meet the design requirements without ground modification. The current practice is to modify the engineering properties of the native problematic soils to meet the design specifications. Nowadays, soils such as, soft clays and organic soils can be improved to the civil engineering requirements. This state-of-the-art review focuses on soil stabilization method which is one of the several methods of soil improvement. Soil stabilization aims at improving soil strength and increasing resistance to adding fly ash and chemical sodium silicate.

Several researchers have been studying the soil stabilization began in the United States during 1960's and 1970's when shortages of aggregates and petroleum resources forced engineers to consider alternatives of road construction instead of soil replacement. Since 1930 tests have been carried out in the United States with lime stabilization but success was achieved only ten years thereafter. The use of cement stabilization is over 65 years old with methods and materials proven and well established. Non-traditional stabilization products have been in development since the 1960's with many research papers and projects written on the subject.

Soil Stabilization

Soil stabilization is the process of treating the soil in order to stabilize soil conditions and improve or alter its physical properties. Stabilized soil ultimately must have improved strength and durability than it had before. Soil stabilization aims at improving soil strength and increasing resistance to softening by water through bonding the soil particles together, water proofing the particles or combination of the two. Usually, the technology provides an alternative provision structural solution to a practical problem. The simplest stabilization processes are compaction and drainage. The other process is by improving gradation of particle size and further improvement can be achieved by adding binders to the weak soils. Soil stabilization can be accomplished by several methods. All these methods fall into two broad categories namely;

1.Mechanical Stabilization

Under this category, soil stabilization can be achieved throughphysical process by altering the physical nature of native soil particles by either induced vibration or compaction or by incorporating other physical properties such as barriers and nailing.

2.Chemical Stabilization

Under this category, soil stabilization depends mainly on chemical reactions between stabilizer and soil minerals to achieve the desired effect. A chemical stabilization method is the fundamental of this review and, therefore, throughout the rest of this report, the term soil stabilization will mean chemical stabilization.

Types of Stabilizing Agent

These are hydraulic or non-hydraulic materials that when in contact with water or in the presence of pozzolanic minerals reacts with water to form cementitious composite materials. The commonly used binders are:

1.Fly Ash

2.Soil Stabilizing Chemical-Sodium Silicate

1.Fly Ash

Fly ash is a heterogeneous by-product material produced in the combustion process of coal used in power stations. It is a fine grey colored powder having spherical glassy particles that rise with the flue gases. As fly ash contains pozzolanic materials components which react with lime to form cementitious materials. Thus, fly ash is used in concrete, mines, landfills and dams. Fly ash can be a cost-effective substitute for Portland cement in many markets. Fly ash is also recognized as an environmentally friendly material because it is a by-product and has low embodied energy. Fly ash is a by-product of coal fired electric power generation facilities; it has little cementitious properties compared to lime and cement.

Most of the fly ashes belong to secondary binders; these binders cannot produce the desired effect on their own. However, in the presence of a small amount of activator, it can react chemically to form cementitious compound that contributes to improved strength of soft soil. Fly ashes are readily available, cheaper and environment friendly. There are two main classes of fly ashes; class C and class F. Class C fly ashes are produced from burning subbituminous coal; it has high cementing properties because of high content of free CaO. Class C from lignite has the highest CaO (above 30%) resulting in self-cementing characteristics. Class F fly ashes are produced by burning anthracite and bituminous coal; it has low self-cementing properties due to limited amount of free CaO available for flocculation of clay minerals and thus require addition of activators such as lime or cement.

2.Sodium Silicate

Sodium silicate is easily available and cheap material. Soil stabilized with sodium silicate possess high strength than virgin soil. It is very effective in reducing the swelling potential and the swelling pressure of clayey soils. Sodium silicate reacts with soil particles to form colloid which polymerizes further to form a gel that binds soil or sediment particles together and fills voids. Besides, sodium silicate is a white powder or colourless solution that is readily soluble in water, it has also been considered for use as a peptizing agent to improve the mix ability of the in situ and in this way increases the homogeneity and strength of stabilized soil. The sodium silicate could react with lime in presence of water producing calcium silicate, which is much harder than sodium silicate. Water molecules in the interlayer region act as restraints to the silicate structure which increases the soil strength.

The effect of the addition of the silicate to appropriate soils is to increase water-stable aggregation and resistance to crushing and to decrease the plasticity index and swelling. Calcium silicate is precipitated as a continuous matrix in which a strong and rigid ionic polar bond is formed between the soil and stabilizer. These concepts indicate that the important variables might be expected to be (a) the quantity of polymeric silica, which determines the amount of gel; (b) the frequency ofsodium atoms along the chain, which determines the amount of cross-linking possible; and (c) the concentration of the precipitant, which determines the extent of cross-linking. In addition, it is believed that the elevation of the pH resulting from the presence of the sodium silicate solution would generate additional silicate by the solubilization of the already hydrated surface silica in the soil. Thus, the soil would be contributing additional stabilizing material to that added initially.

Sodium silicates constitute a group of chemicals that possess a wide range of physical and chemical properties. They are used in industry as adhesives, cements, detergents, deflocculates, protective coatings, rust inhibitors, catalyst bases, cleaning compounds, and bleaching agents. Silicates are produced at various alkali, Na2O, to silica, SiO2, ratios, water contents, and particle sizes depending on their proposed use. They are usually derived from the relatively abundant raw materials of silica, sodium salts, and water. Manufacturers have widely distributed outlets for the products; therefore, sodium silicates are readily available and are easily obtained in various packages for commercial use. Sodium silicates may be prepared in a number of ways. Several so-called wet processes include the solution of infusorial or diatomaceous earth in the alkaline hydroxides with relatively poor quality and product control. The reaction between ferrosilicon, Mangano silicon, or silico Speigel and concentrated sodium hydroxide can be simply expressed as: -

2NaOH + Si +H2O ------Na2SiO3 ………………………………………. **(I)**

and the reaction of sodium hydroxide and silicon carbide as

4NaOH + SiC ----- 2H2O Na2SiO3 +Na2CO + 2H2…………….. **(II)**

Both of these processes involve relatively high cost. The silicates have also been prepared by reactions of sodium hydroxide with residues of the extraction of metals such as aluminium, beryllium, and tungsten from their respective silicate minerals.

II. LITERATURE REVIEW

In the construction and maintenance of transportation facilities, geomaterial i.e., soil must be stabilized through chemical and mechanical processes. Chemical stabilization includes the use of chemicals and emulsions as compaction aids to soils, as binders and water repellents, and as a means of modifying the behaviour of clay. Lime can be used to treat soils in order to improve their workability and load-bearing characteristics in a number of situations. Quicklime is frequently used to dry wet soils at construction sites and elsewhere, reducing downtime and providing an improved working surface. Sodium silicate can be used in soil stabilization mainly because it reacts with soluble calcium salts in water solutions to form insoluble gelatinous calcium silicates. That hydrated calcium silicates are cementing agents has been fairly well established. Fly ash has been used successfully in many projects to improve the strength characteristics of soils. Fly ash can be used to stabilize bases or subgrades, to stabilize backfill to reduce lateral earth pressures and to stabilize embankments to improve slope stability. To study the influence of materials like fly ash, lime and sodium silicate upon stabilization various research papers were studied the review of these papers are given below.

Ankit Singh Negi1 et al. (2013)described as Soil stabilization can be explained as the alteration of the soil properties by chemical or physical means in order to enhance the engineering quality of the soil. The main objectives of the soil stabilization are to increase the bearing capacity of the soil, its resistance to weathering process and soil permeability. Improving an on-site soil's engineering properties is called soil stabilization. Soils containing significant levels of silt or clay, have changing geotechnical characteristics: they swell and become plastic in the presence of water, shrink when dry, and expand when exposed to frost. Site traffic is always a delicate and difficult issue when projects are carried out on such soils. Once they have been treated with lime, such soil can be used to create embankments or subgrade of structures, thus avoiding expensive excavation works and transport. Use of lime significantly changes the characteristics of a soil to produce long-term permanent strength and stability, particularly with respect to the action of water and frost. The mineralogical properties of the soils will determine their degree of reactivity with lime and the ultimate strength that the stabilized layers will develop.

Mohammed Faizan et al. (2013)described Improving an on-site soil's engineering properties is called soil stabilization. Soils containing significant levels of silt or clay, have changing geotechnical characteristics: they swell and become plastic in the presence of water, shrink when dry, and expand when exposed to frost. Site traffic is always a delicate and difficult issue when projects are carried out on such soils. Authors concluded his work with following conclusions, lime is used as an excellent soil stabilizing materials for highly active soils which undergo through frequent expansion and shrinkage. Lime acts immediately and improves various property of soil such as carrying capacity of soil, resistance to shrinkage during moist conditions, reduction in plasticity index, increase in CBR value and subsequent increase in the compression resistance with the increase in time. The reaction is very quick and stabilization of soil starts within few hours.

Phani Kumar and Sharma (2007) assessed plasticity, strength, swelling potential, hydraulic conductivity, and compaction characteristics of a clayey soil stabilized with 0 %, 5 %, 10 %, 15 %, and 20 % fly ash. It was revealed that both plasticity index and swelling characteristics of the stabilized soil decreased by about 50 % with addition of 20 % of fly ash. With fly ash content beyond 20 %, there was no significant decrease in swelling potential. In addition, undrained shear strength increased by approximately 27 % with inclusion of 20 % fly ash. Based on compaction test results, it was concluded that the optimum moisture content decreased by about 25 % and the maximum dry unit weight increased by about 5 % with 20 % fly ash inclusion. The results from variable-head permeability tests revealed that the hydraulic conductivity decreased with the inclusion of fly ash.

Cokca et al. (2007) studied the effects of 3 stabilizers, including high calcium and low calcium class C fly ash, lime, and cement, on the swelling potential of an expansive soil. The amounts of lime and cement used were at 0 - 8 % while amount of fly ash used was between 0 - 25 %. Both fly ashes were cured for 7 and 28 days. It was concluded that the plasticity index and swelling potential of all the stabilized soils decreased significantly. Furthermore, there was a remarkable decrease in swelling potential of fly ash stabilized soil from 7 to 28 days curing times

Prabakar et al. (2008) conducted a number of experiments with addition of different percentages of fly ash from 9 % to 46 % on different soil types. Compaction, shear strength, CBR, and swelling characteristics were evaluated on CL (inorganic clay with low plasticity), OL (organic soil with low plasticity), and MH (inorganic silt with high plasticity) soils. Based on the experimental results, dry density of all soil types reduced by between 15 % and 20 % by addition of the fly ash. The shear strength of the soils increased non-linearly with the addition of fly ash. Another important finding was that the swelling behaviour of the soils decreased due to the particle size, shape, and non-expansive structures of fly ash. Moreover, the CBR values of the soils improved with the addition of fly ash in comparison with the pure soil.

III. METHODOLOGY

Materials Required for experimental programme are black cotton (BC) soil, fly ash and sodium silicate. The soil for treatment was collected from on of the fields of Yavatmal District. The preliminary test was conducted on the sample to determine its engineering properties. Table 1 shows properties of untreated soil sample.

Table No 1 Properties of Soil

SR.NO	Properties	Values
1	Color	Light Brown
2	LiquidLimit(%)	48.47
3	PlasticLimit (%)	26.67
4	PlasticityIndex(%)	25.33
5	SpecificGravity	2.66
6	MaxDryDensity	1.7
7	Optimummoisture Content	17.8

In this study standard proctor test, unconfined compression strength test and California bearing ratio test were carried out. These tests were carried for various doses of fly ash, sodium silicate and combination of fly ash and sodium silicate. For the comparison of results soil was treated with fly ash and sodium silicate separately and then after the combination of the fly ash and sodium silicate were tested. The dosages of Fly Ash and Sodium Silicate used for soil treatment are selected based on previous research work and data provided by suppliers. For Fly Ash and Sodium Silicate: The dosages for treatment are selected as 5%,10%,15%,20%,25%,30% & 2.5%,5%,7.5%,10%,12.5% respectively. Curing period of 7 days was considered for treated soil samples. The testing programme was broadly divided in to four series as follows,

Series-1: laboratory test on untreated soil samples
Series-2: laboratory test on fly ash treated soil samples
Series-3: laboratory test on sodium silicate treated soil samples
Series-4: laboratory test on combination of fly ash and sodium silicate treated soil samples.

To study the effect of treatment of Sodium Silicate and fly ash on the subgrade strength characteristic of the soil the California Bearing Ratio test was conducted on the untreated sample and treated sample with optimum dosages of fly ash and sodium silicate and the combination of the same.

IV. RESULTS AND DISCUSSION

Standard Proctor Test, Unconfined Compression Test, California Bearing Ratio Test (CBR) were studied thoroughly by treating the Black Cotton Soil by the available Fly ash and Sodium Silicate and their results were compared with the untreated soil sample.

Series-1: laboratory test on untreated soil samples

Basic tests for determining the geotechnical properties of soil were conducted in laboratory on untreated soil samples. Collected soil samples were tested to find its compaction characteristics, unconfined compressive strength and California bearing ratio test. Results obtained are represented in table 1. Upon conducting the standard proctor test, the observed variation of dry density with the water content is represented with the help of a graph in figure 1. From the graph it can be interpreted that the optimum moisture content is 28% and the maximum dry density is 13.6 kN/m³ for untreated soil sample. Test result of unconfined compression test on untreated soil sample is shown in figure 2. From that the UCS value of soil is 131.69 kN/m2.

International Journal of Advances in Engineering and Management (IJAEM)
Volume 5, Issue 5 May 2023, pp: 1133-1139 www.ijaem.net ISSN: 2395-5252

Figure 3 shows graph of California bearing ratio of untreated soil sample.

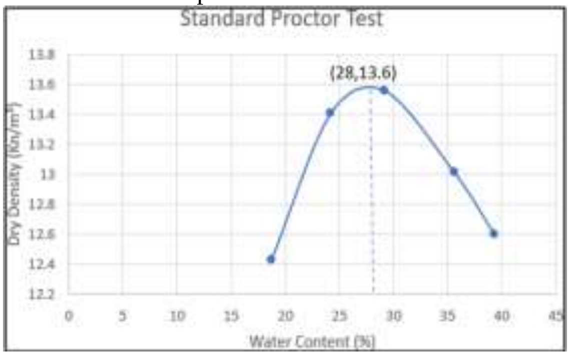

Figure 1 Compaction Characteristics of Untreated Soil Sample

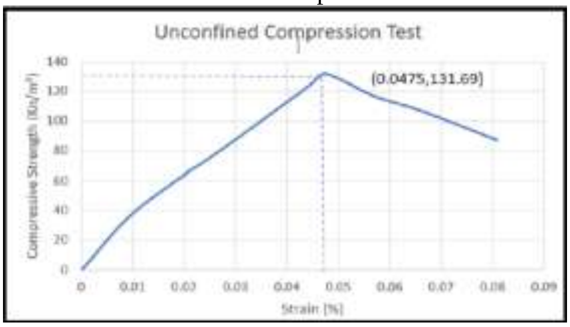

Figure 2 Test Results of Unconfined Compression Test on Untreated Soil Sample

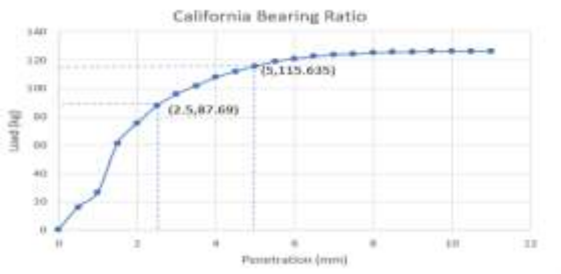

Figure 3 California Bearing Ratio Test on Untreated Soil Sample

Series-2: Laboratory test on fly ash treated soil samples

a. Effect of fly ash on compaction characteristics of soil:

The IS Light compaction test results for the treated soil samples are tabulated in Table 2. It can be clearly seen that when soil is treated with Fly ash the OMC decreases as compared to the original soil and minimum OMC was found for soil treated with 30% Fly ash. It can also be inferred that for any percentage of Fly ash the MDD has always been greater as compared to the original soil with its maximum value for treatment

Table 2 Standard proctor test Results for fly ash treated soil

Sr. No	Dosages	OMC (%)	MDD (kN/m3)
1	Soil + 0% Fly ash	28	13.6
2	Soil + 5% Fly ash	21.5	14.45
3	Soil +10% Fly ash	22	13.95
4	Soil + 15% Fly ash	22	14.75
5	Soil + 20% Fly ash	22	14.65
6	Soil + 25% Fly ash	26	13.90
7	Soil + 30% Fly ash	19	14.2

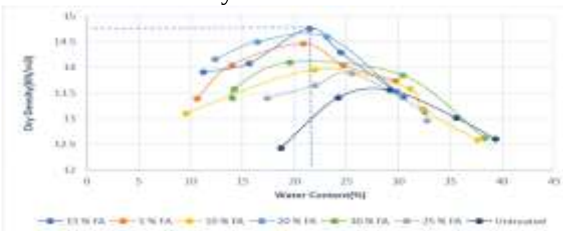

Figure 4 Compaction curve for soil treated with Fly ash

In figure 4 the variation of optimum moisture content (OMC) and Dry density with varying percentages of Fly ash along with the untreated soil mass is represented and it can be seen that all the curves has shifted slightly upward and leftward with respect to the curve representing the untreated soil sample which indicates that the optimum moisture content decreases and the maximum dry density increases upon adding fly ash to the soil and the maximum dry density was found to be achieved with adding 15% of fly ash.

b. Effect of Fly Ash on Unconfined Compression Strength:

Based upon the results of Unconfined Compression Strength test tabulated in Table 3 it can be inferred that the compressive strength of soil increases upon adding fly ash to the untreated soil this may be due to the cementitious effect induced as a result of a chemical reaction between fly ash and clay. The maximum unconfined compressive strength is 371.5 kN/m² for the soil treated with 15% Fly ash. Figure 5 shows the variation of UCS of soil with varying percentage of fly ash. From this graph it is clear that 15 % fly ash is optimum dose for soil stabilization.

Table 3 Effect of variation of dosage of Fly ash on UCS of soil

Sr. No.	Dosage	Unconfined Compressive Strength (kN/m²)
1	Soil +5% FA	327.2
2	Soil + 10% FA	227.84
3	Soil + 15%	371.5

	FA	
4	Soil + 20% FA	352.99

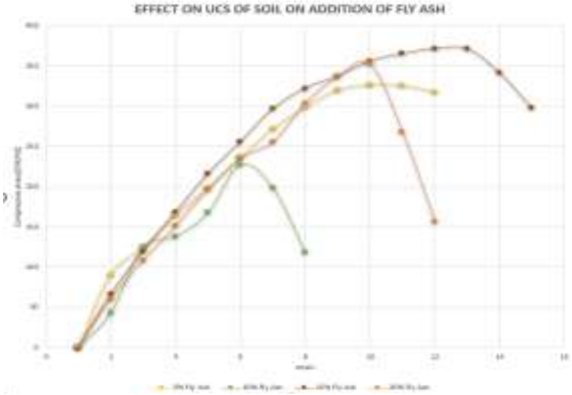

Figure 5 Variation of UCS of soil with varying percentage of Fly ash

Series-3: Laboratory test on sodium silicate treated soil samples

Table 4 shows the variation of unconfined compressive strength of soil with various percentages of sodium silicate with the original soil. From the results obtained it can be concluded that for 5% sodium silicate the unconfined compressive strength is maximum the same can be inferred from the graph given in the figure 6.

Table 4 Effect of various dosages of sodium silicate on the UCS of the soil

Sr. No	Dosages	Unconfined Compressive strength(kN/m2)
1	Soil + 2.5 %SS	139.95
2	Soil + 5 % SS	170.98
3	Soil + 7.5 % SS	160.32
4	Soil +10 % SS	155.72
5	Soil + 12.5% SS	167.64

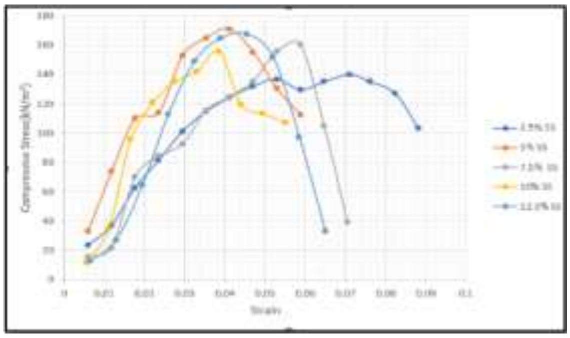

Figure 6 Effect of sodium silicate on the unconfined compressive strength of soil.

Series-4: laboratory test on combination of fly ash and sodium silicate treated soil samples

Based upon the above results optimum dosages of fly ash and sodium silicate can be taken as 15% and 5% respectively. Unconfined compression test was conducted on the soil sample treated with the combination of 15% fly ash and 5% Sodium silicate and the results of this sample is compared with the untreated sample in the figure 7. The compressive strength of untreated soil was found to be 131.69 kN/m2 and with the combination of optimum dosages the compressive strength found was 290.28 kN/m2 and hence a 120.42% gain in strength was obtained.

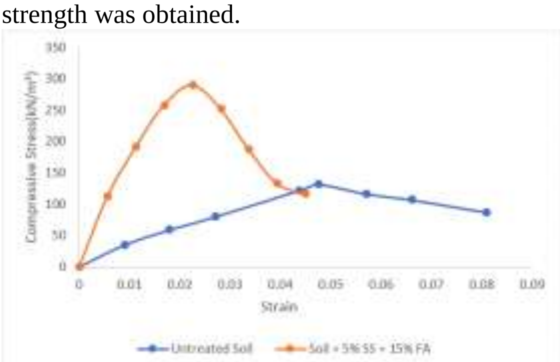

Figure 9 Comparison of treated and Untreated Soil according to unconfined compressive Strength

To study the effect of treatment of sodium silicate and fly ash on the subgrade strength characteristic of soil the California Bearing Test Ratio test was conducted on the untreated sample and treated sample with optimumdosagesofflyash andsodiumsilicateand the combination of the same. It is anticipated that the subgrade strength of the soilwould increase due to the increased density of the soil resulting from the cementitiousproperty of the fly ash and the formation of gel polymer due to the reaction of sodiumsilicatewith the clay.In Table 5 the data of CBR values for 2.5 mm and 5 mm penetration for different combinations for chemical treatment are given and from the table it can be concluded that upon chemical treatment of soil with fly ash or sodium silicate the CBR value increases and the increase is more evident in the case of sodium silicate with 126% increase.

Table 5 CBR value for treated soil with varying Dosages with curing period of 7 Days

Sr.no	Dosage	CBR Value	
		For 2.5mm	For 5 mm
1	Unsoaked untreated soil	6.4	5.79
2	Soaked	1.79	1.69

	Untreated Soil		
3	Soil + 15% Fly ash	6.71	6.75
4	Soil + 5% Sodium silicate	14.49	12.16
5	Soil + 15% Fly ash + 5% Sodium silicate	14.53	13.32

V. CONCLUSIONS

Unconfined compressive strength of organic soils can be increased using fly ash, but the amount of increase depends on the type of soil and characteristics of the fly ash. Addition of fly ash improved the workability of the soil considerably. Over all, the effect of the addition of fly ash is to significantly improve the physical properties of the black cotton soil. The Unconfined compressive strength gain of 182.1% was found upon adding 15% Fly ash to the virgin soil. The diffusion of chemical solution in expansive soil is possible and it develops the positive effects in respect of improving the strength characteristics and reducing the swelling behaviour. The Unconfined compressive strength gain of 29.83% was found upon adding 5% Sodium silicate to the virgin soil. Fly ash and Sodium Silicate acts immediately and improves various properties of soil such as increase in CBR value and subsequent increase in Unconfined compression value. The increase in compressive strength of 120.42% was observed when the soil was treated with combination of 15% Fly ash and 5% Sodium silicate. CBR value gain of 127.03% was observed when the soil was treated with combination of 15% Fly ash and 5% Sodium silicate. The combination of 15% of Fly ash and 5% of Sodium Silicate was found to be the optimum economical combination of material for chemically treated soil to obtain substantial increase in strength characteristic of soil.

Future Scope

The present knowledge of an experimental study on physical strength with addition to the various combinations of Fly ash and Sodium Silicate is limited. The further research may be carried out considering the following aspects:

1. Effect of volumetric change on the combination (Fly ash and Sodium Silicate) can be studied.
2. Other combination can be used to study the effect on Black cotton soil to get significant result.
3. Comparison of Result can be done between other combination and combination obtained from this study.
4. Effect of the combination obtained from this study on soil other than Black cotton soil can also be studied.

REFERENCES

[1]. A.S.Negi, Faizan, M., Siddharth, D.P. and Singh, R., 2013. Soil stabilization using lime. International journal of innovative research in science, engineering and technology, 2(2), pp.448-453.

[2]. Kulkarni, T.A., Padalkar, P.A. and Joshi, C.G., 2017. Stabilization of soil by using fly ash & lime. In International Conference on Recent Trends in Civil Engineering, Science and Management (ICCSM-17), Guru Gobind Singh College of Engineering and Research Center, Nashik (pp. 32-38).

[3]. Neeladharan, C., Sathish, P., Nandhini, A., Priya, R., Fathima, I., Srimathi, J. and Melvisharam, V., 2018. Stabilization of soil by using marble dust with sodium silicate as binder. International Journal of Advanced Research Trends in Engineering and Technology, 5(5), pp.45-49.

[4]. Gobinath, R., Akinwumi, I.I., Afolayan, O.D., Karthikeyan, S., Manojkumar, M., Gowtham, S. and Manikandan, A., 2020. Banana fiber-reinforcement of a soil stabilized with sodium silicate. Silicon, 12(2), pp.357-363.

[5]. Harender, A.B. and Sharma, P., 2019. “Stabilization of soil of hissar city by addition of sodium silicate and lime” International research journal of engineering and technology (IRJET).

[6]. Subzar Ahmad Mir, Er. Vishal Yadav (2018), "Effect of Lime and Sodium Silicate on the stabilization of Soil", JETIR July 2018, Volume 5.

[7]. Phani kumar and Sharma (2007), Kumar (2007), Cocka (2008), Prabhakar (2008)," Soil stabilization with Flyash – Improvements in Engineering Characteristics", International journal of Applied engineering research, Volume 14 Number 7(2008).