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Effects of Poly Vinyl Acetate on Characteristics of Expansive Soil

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ABSTRACT

Soil stabilization using polymer materials has become of great potential in recent years. In this regard, an attempt is made to investigate and understand the influence of Poly Vinyl Acetate (PVA) on the engineering properties of expansive soil. A series of treated soil specimens were prepared and tested at four different percentages of PVA (0%, 1.5%, 3.75%, and 5% by weight of dry soil). These treated specimens were subjected to laboratory testing for measuring Atterberg's limits, free swell, compaction characteristics, and unconfined compression strength properties. It was found that PVA had significant influence on the properties of treated soil. An increase in PVA content resulted in an increment of unconfined compressive strength of the soil. Addition of 3.75% of PVA increased the unconfined compressive strength value almost 6 times the value of the virgin soil. On the other hand, an increase in PVA content led to a reduction of free swell and plasticity index. The soil plasticity and free swell indices values were reduced from 62% to 0% and from 190% to 50% respectively by addition of 5% PVA. It can be concluded that an increasing trend for soil strength and decreasing in swelling with addition of PVA, suggesting its potential applications in stabilization of expansive soils.

1 Introduction

Expansive soils or swelling clays are mostly found in arid and semiarid regions of the world. In Sudan expansive soil is one of the major regional soil deposits which cover over one-third of the country land area and is predominantly located along Nile river and its branches [1]. Expansive soils denote clayey soils that possess the tendency to swell and shrink when the prevailing moisture condition is allowed to change. Such change of moisture content of these soils can emanate from rains, floods, or leakage of sewer lines. The volumetric changes of expansive soils cause considerable failure to the foundation and damage to the light loaded structures such as retaining walls, road pavements, railways, road sidewalks, canal beds, reservoir linings and light buildings. The repair cost of the damage caused by expansive soils to civil engineering structures is estimated many billions of dollars worldwide [2]. Thus, it is necessary to improve large areas covered by expansive soils that have created problems to foundations because of their low bearing capacity and uplift forces.

There are many methods of soil stabilization to improve required engineering properties such as strength, durability and the swell-shrink behaviour. Extensive studies have been carried out on stabilization of expansive soils using various additives

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such as lime, cement, fly ash, industrial waste products and Polymer. Most of these methods are relatively expensive to be implemented by slowly developing countries and the best way is to use locally available materials with relatively cheap costs.

Polymer stabilization is a new stabilizer agent developed to enhance the geotechnical properties of expansive clayey soils. The use of polymer materials in soil improvement is growing daily. In spite of great interest in polymer soil stabilization, limited number of researches has been conducted and published. In this regard, the purpose of this study is to investigate experimentally the feasibility of stabilizing and improving the geotechnical properties of expansive soil using a polymer material (Poly Vinyl Acetate (PVA)) in different proportions and to study the polymer effect on the engineering characteristics of the stabilized expansive clay.

2 Literature Review

2.1 Soil stabilization

Soil stabilization is a technique to improve the soil properties such as shear strength, compressibility, density, hydraulic conductivity, etc. by addressing the interactions among clay particles. The fundamental target of soil stabilization measures is to change the balance between the interaction forces through the introduction of ions/molecules of the soil stabilization agent or alteration of the environmental conditions. Theng [3] introduced a swelling theory of clay that recognizes the existence of a diffuse double layer of ions around the clay particles in an aqueous condition. Another feature is the access of liquids and substances to the interlayer spaces in clay during crystalline swelling. This theory often is used as the basis for phenomenological and quantitative interpretations. Thus, soil stabilization substances should be able to inhibit clay swelling and shrinkage by reducing the expansion and shrinkage of the interlayer space through bonding the clay particles together on their external surfaces.

The technique of soil stabilization can be categorized into mechanical and chemical stabilization. The mechanical stabilization is a process to improve the coarse-grain soil by adding fine soil and vice versa and then apply compaction to improve the soil strength and stability. On the other hand, chemical stabilization is a mechanism of adding chemical substance or compound to the soil. It can broadly be divided into three groups, traditional stabilizers such as hydrated lime, Portland cement, fly ash, etc.; non-traditional stabilizers comprised of salts, organic materials, enzymes, biological binders and polymers; and by-product stabilizers include steel slag, cement kiln dust, lime kiln dust, etc. [4].

Although traditional materials such as cement and lime have been widely used as soil stabilizers for many decades, the geotechnical engineering community has never stopped searching for alternative stabilizers for circumstances where traditional cementation stabilizers are not applicable or favorable. When cement is used to stabilize soil, shrinkage caused by hydration of the cement as well as drying is a commonly observed phenomenon which significantly reduces the strength and increases the permeability [5]. In addition the stabilized soils although having a high strength are rather brittle especially under dynamic loading [6].The cracking and brittleness of cement stabilized soils have greatly influenced the long-term performance of stabilized soils for many applications. In addition to the cracking and brittleness when used for clay soils the cementations stabilizer can cause significant swelling if excessive sulfate is present [7].

The advantage of unconventional and non-traditional materials such as foams, emulsions of petroleum, enzymes, acids, polymers, and industrial waste materials have shown promising results in stabilizing expansive soils. As these materials are different in nature and chemical composition, they can be used to reduce permeability, mitigate soil liquefaction and increase soil strength by filling the voids and providing bonding between the particles. Among these stabilizers, liquid polymers have gained attention due to their relatively easy use and promising outcomes due to formation of bond between clay minerals and polymer [8].

2.2 Polymer materials

Polymers are large molecules which consist of long hydrocarbon chains. They are easily modified which leads to potentially endless combinations of polymers, resulted in production of polymer materials with various properties. Therefore, polymers are used in different industries. Various polymers have been proposed for polymer soil stabilization including cationic, anionic, and non-ionic polymers [8].

The aqueous polymer stabilization mechanism can be described as pore filling, physicochemical reaction, and enwrapping. When polymer solutions applied to clayey soil, a part of the polymeric material fills up the voids of soil and part is sorted onto soil aggregate surface. The hydrophilic groups (-$OOCCH_3$) in its molecular structure react chemically with the adsorbed ions of clay particles and create physicochemical bonds between polymer molecule and stabilized soil. The bonds are of the ionic, hydrogen, or Van der Waals varieties. Through these bonds, long chain macromolecules of polymers encapsulate the aggregate surfaces and interlink around them to form elastic and viscous membrane structures that decrease the swelling shrinkage capacity of soil [9].

Many studies are available in the literature on stabilization of soils using various polymers compounds. They considered the index properties, swelling characteristics and shear strength in investigating the effect of polymers materials as stabilizers. Some examples of these researched are given in Table 1.

Table 1 - Different types of Polymers and their effectiveness in soil properties

Polymer Type	Soil Used and Sample preparation	Test	Effect on soil properties	Ref.
Polyacrylamide, hydrated with water	• Clay soil rich with Montmorillonite and Kaolinite. • 0.5-5 % (g/l) prepared by adding polymer to distill water. 1 gm of clay mixed 45 ml solution	1) Viscosity 2) Sorption 3) X ray Diffraction	1) Clay amendment provides stabilization. 2) Drying rate of clay reduced. 3) Change in d spacing of treated clay observed.	[9]
1) Sodium Methyl cellulose, Polyethylene oxide, Polyacrylamide 2) Aqueous Polymer	• Clay with Na-Montmorillonite • Clay (1g) was added to 50 ml solution.	1) Swelling 2) Sorption 3) X ray Diffraction	1) Polyacrylamide was most effective. 2) Evaluated sorption polymer molecules on clay. 3) Change in d spacing of treated clay observed.	[10]
1) Acrylic Polymer 2) Aqueous Polymer	• Soil used, LL, % = 31, 41, 52, PI,% = 12, 19, 26 (CL, CL, CH) • Required polymers as percentage of OMC blended to dry soils. Amounts of aqueous polymer 2, 3, 4& 5.	1) Unconfined Compression Strength (UCS) 2) Atterberg's limits	1) UCS increased rapidly 8 days. 2) 4% Polymer has highest increase UCS. 3) PI significantly reduced.	[11]
Polyurethane based polymers, different aqueous concentration used.	• Sand-Clay Mix (1:1, 1:3, 1:5). • Dilatant (3& 5g/cm^3) added was 10% dry soil, ensity1.7g/cm^3. Samples compacted, and then air dried at 25°C for 48hr.	1) UCS 2) Shear Strength 3) Erosion Resistance (ER)	1) Relative increment in UCS 45.41%, 43.06% & 67.225%. 2) Cohesion (samples 1:5 at 5g/cm^3) 15.89, 14.02, 16.01 kpa compared to 8.85 Kpa of untreated. 3) Stabilized specimen has higher ER.	[12]
Poly- Propylene.	• Soil LL=50%, PL= 23%, PI=27% (CH) • Amount of polymer added as percentage of dry mass (0, 3, 6 & 10). Samples remolded at OMC and MDD with proctor test.	1) Atterberg's limits 2) Compressibility 3) Desiccation Crack	1) PI sharply decreased. 2) Compression index values were reduced. 3) Intensity of crack reduced.	[13]

2.3 Poly Vinyl Acetate (PVA)

A new aqueous polymer named "Poly Vinyl Acetate" (PVA), is introduced in this research as soil stabilizer to evaluate its effect on engineering properties of expansive soils. PVA is a type of organic aqueous polymer, its main component is Acetic-Ethylene-Ester Polymer and it contains a large number of "OOCCH3" functional groups. The structures of Vinyl Alcohol and Poly Vinyl Acetate (VAP) are illustrated in Fig. 1.

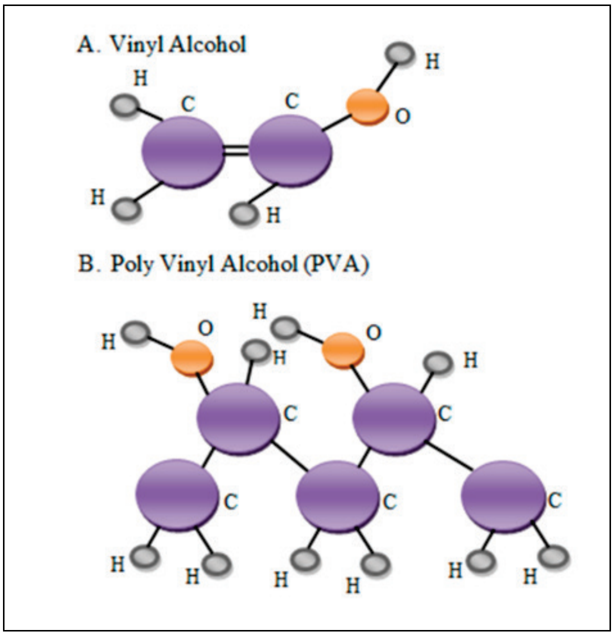

Fig. 1 –The structure of (a) Vinyl Alcohol; (b) Poly Vinyl Alcohol (PVA) [10]

According to Inyang [9], PVA has primary advantages such as (i) it's a water-soluble material which can be diluted to different concentrations; (ii) the presence of PVA soil stabilizer can form an elastic and viscous membrane on soil surface at the natural situation; and (iii) it is an environment-friendly product and easy to be produced at low cost.

The properties of PVA depend on the extent or degree of its hydrolysis, specifically whether it is full or partial, which in turn dictates its categorization into two groups: partially hydrolyzed, and fully hydrolyzed as shown in Fig.2.

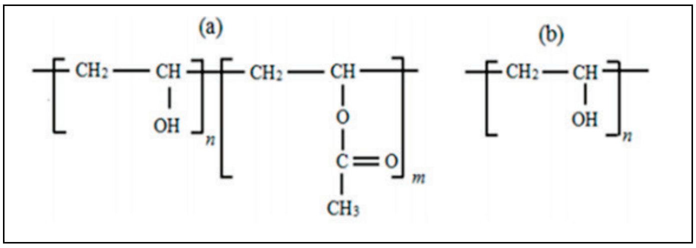

Fig. 2 –Structural formula for PVA: (a) partially hydrolyzed; (b) fully hydrolyzed [10]

The chemical and physical properties of PVA may vary based on the percentage of hydrolysis, which determines the PVA grade and its molecular weight, The surface properties of PVA fillers are fundamentally significant in the selection criteria of PVA fillers, PVA itself has substantial tensile strength, more flexibility, and hardness and gas and aroma barrier characteristics. Compared with any other known polymer, PVA demonstrates remarkably superior features as an oxygen barrier; however, to avoid the degradation of its permeability toward gas, it must be protected from moisture, PVA like proteins, is a water-soluble polymer. The water solubility and physical properties of PVA including its film form are highly affected by the degree of hydrolysis, molecular weight, and its crystal precipitation, PVA is partially crystalline upon formation and is characterized by properties such as chemical resistance, water solubility, and biodegradability. The similarity in physical properties makes it compatible with human tissues. Biocompatible PVA has a structure that can absorb protein molecules and engage with minimal cell adhesion and has no toxic effects, therefore, PVA membranes have been widely developed for biomedical applications, PVA can chemically bound to or physically entangled with a nano-particle surface [10].

Liu et al. [14] conducted laboratory tests to evaluate the effect of PVA on swelling-shrinkage properties of expansive soil. A series of shrink/swell tests were performed with adding PVA at concentration 3 g/cm^3 to four different aggregate sizes in the range of 0 – 5 mm, and five different concentrations (in g/cm^3) 1.5, 3, 4.5, 6 and 9. The results showed that for aggregate size smaller than 1 mm, the Linear Swelling Ratio (LSWR) and Linear Shrinkage Ratio (LSHR) of both treated and untreated soils decrease with the increase of aggregate size. However, when the aggregate size is greater than 1 mm, the trend is reversed. The values of both LSWR and LSHR increase with increase in PVA concentration (see Fig. 3).

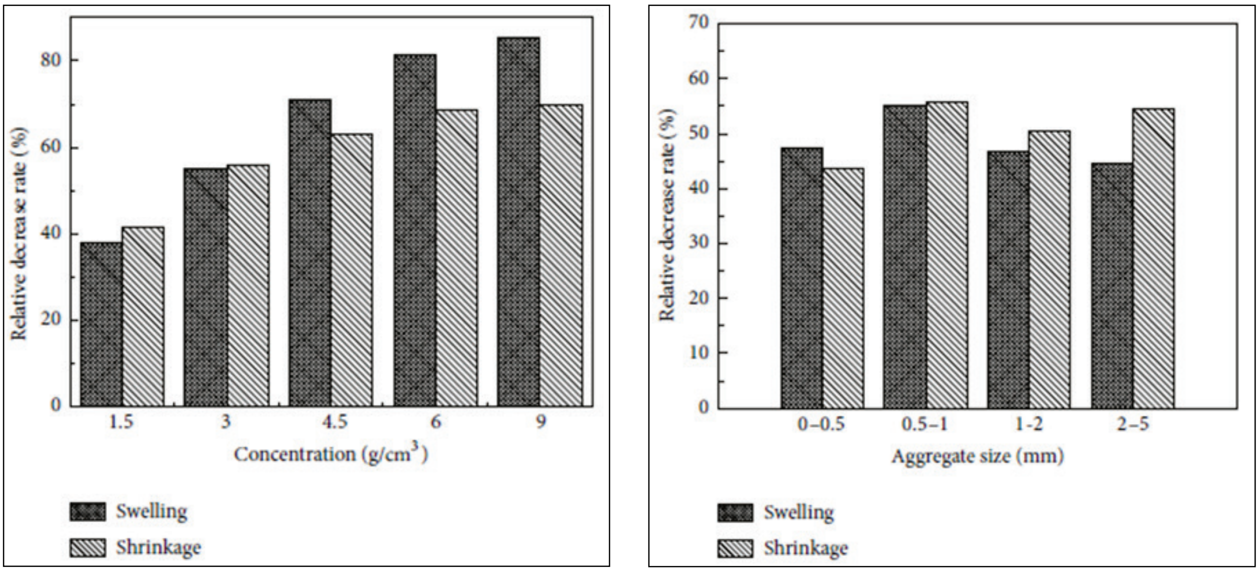

Fig. 3 –Relative decrease of linear swelling and shrinkage of different aggregate sizes and polymer concentrations [14]

3 Materials and Methods

The testing program was undertaken to achieve the objective of the study. Laboratory tests were conducted on natural and treated soils with PVA to investigate its influence on engineering properties of the soil.

3.1 Materials used

In this study, the materials used in the experimental investigation are expansive soil and PVA as stabilizer.

3.1.1 Expansive soil

The expansive soil used in this study was obtained from Al-Manshia in Khartoum. The soil is stiff clay of dark grey colour and highly plastic soil. The basic soil properties were determined as given in Table 2.

Table 2 - The basic properties of soil studied

Property	Value
Specific gravity	2.75
Sand, %	33
Silt/Clay, %	67
Liquid limit (LL), %	78
Plastic limit (PL), %	16
Plasticity index (PI), %	62
Free Swell Index (FSI), %	190
Unconfined strength (UCS), kPa	177
Soil classification using USCS	CH

3.1.2 Poly Vinyl Acetate (PVA)

Poly Vinyl Acetate (PVA) is an aqueous polymer is used in this research to stabilize expansive soil. The most important physicochemical properties of PVA were determined and presented in Table 3.

Table 3 - Some physicochemical properties of PVA

Property	Value
Physical state	Liquid
Solvability in water	white color
Boiling point, °C	100
PH	6 – 7
Viscosity, Mpa	400
Density, g/cm^3	1.05
Solid content, %	41

3.2 Sample preparation and testing procedure

The soil was initially air dried, sieved through sieve number 4 (4.75mm) and then oven dried at 105-110 °C for 24 hours. The soil samples were subdivided and each sub-sample was mixed with PVA at various concentrations and left for 24 hours. The soil was mixed with PVA at four different percentages (0%, 1.5%, 3.75%, and 5%). Each soil sample was mixed with one of the PVA percent and then subjected to testing.

The tests conducted include Atterberg's limits, free swell and unconfined compression strength. The testing procedures followed were in general conformance with those recommended in the British Standard BS [15]. A brief description of the tests is presented in the following paragraphs.

Atterberg's limits:

The tests performed were the liquid limit and the plastic limit tests. These tests were carried out on fine soils passing sieve no. 40. The soil was mixed with the PVA solutions of different concentrations then placed in plastic bags to remain for 24 hours. The liquid limit was determined by Cassagrande apparatus.

Free swell:

The test is performed by pouring 10cm^3 of soil passing 425µm sieve into a graduated cylinder glass jar of 100ml capacity filled with water. The swollen volume of the soil is observed after 24 hours. The free swell index is expressed as a percentage increase in the volume to the original volume of the soil. The test was carried out for the four concentrations of the PVA.

Unconfined compressive strength (UCS):

The UCS tests were carried out on compacted soil samples by the conventional UCS testing machine. Initially, the soil was subjected to standard proctor test to determine its compaction characteristics (i.e. maximum dry density (MDD) and optimum moisture content (OMC)). Each soil sample was prepared by mixing with the PVA percent then compacted at OMC and MDD. A series of UCS tests was carried out on compacted soil samples treated with PVA. The UCS tests were performed according to BS [15].

4 Results and Discussion

The primary objective of this study is to investigate the influence of PVA on engineering properties of expansive soil. The soil properties measured include Atterberg's limits, compaction parameters, free swell index and unconfined compression strength. The results obtained from the experiments are presented in Table 4.

Table 4 - Summary of test results for the treated soil with PVA

Soil Property	PVA			
	0 %	**1.5 %**	**3.75 %**	**5 %**
Liquid limit (LL), %	78	75	73	70
Plastic limit (PL), %	16	28	43	70
Plasticity index (PI), %	62	47	30	0
Free swell index (F.S.I), %	190	110	70	50
Unconfined compression strength (UCS), KPa	178	941	1304	236
Max. dry density (kN/m^3)	17.7	19.2	19.7	17.1
Optimum moisture content (OMC), %	22.1	19	17	17.4

4.1 Effect on Atterberg's limits

The values of liquid limit and plastic limit of the soil treated with varying percentages (0%, 1.5%, 3.75%, and 5%) of PVA are presented in Table 4 and plotted in Fig. 4. It is observed that addition of PVA has significant effect on liquid limit and plastic limit. It is shown that an increase in PVA from 0% to 5% gradually decreases the liquid limit while greatly increases the plastic limit. Addition of 5% PVA increases the plastic limit almost 3.3 times the initial value of the untreated soil, while the liquid limit reduced by 10% compared to the natural soil value. This result revealed that the soil changed from high plastic to non-plastic soil with the addition of 5% of PVA.

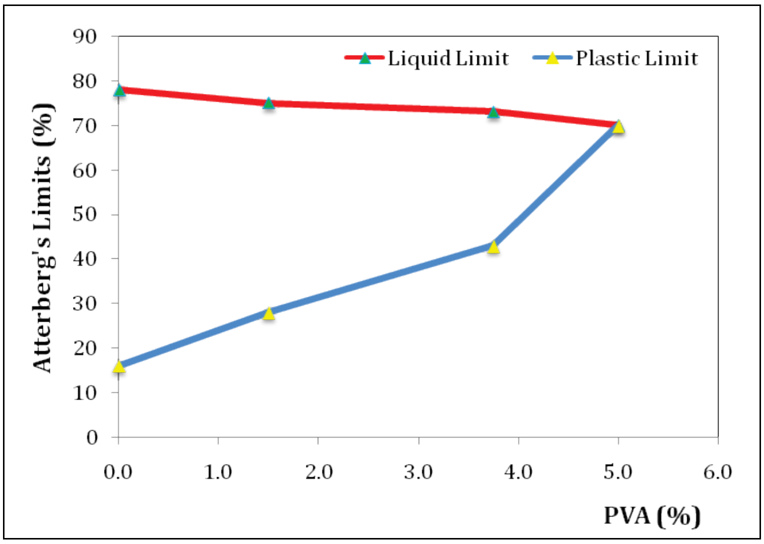

Fig. 4 –Variation of Atterberg's limits of treated soil with PVA

4.2 Effect on Free Swell Index (FSI)

The effect of PVA at different concentrations (0%, 1.5%, 3.75%, and 5%) on free swell index (FSI) of the treated soil is shown in Fig 5. In this figure, it is observed that the FSI value of the treated soil rapidly decreased with addition of PVA. The reduction in FSI of the treated soil with 5% of PVA is almost 80% compared to the virgin soil value. This reduction occurs due to physiochemical bonding which reduce the potential expansion of the soil [9].

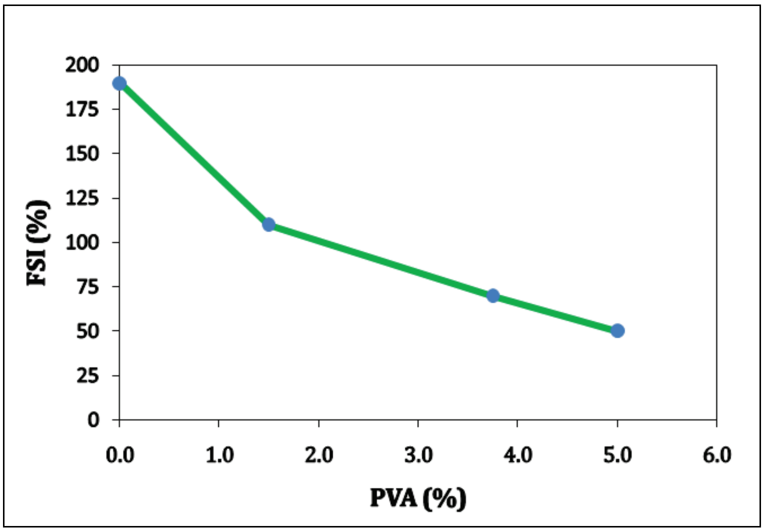

Fig. 5 –Influence of PVA on free swell index of stabilized soil

4.3 Effect on compaction parameters

The variations of compaction parameters such as maximum dry density (MDD) and optimum moisture content (OMC) of treated soil samples with various percent of PVA (0%, 1.5%, 3.75%, and 5.0%) are graphically presented in Figs 6 and 7. It's observed that addition of PVA has significant effect on compaction parameters. From Fig. 7, it is seen that the MDD increases up to 3.75% PVA and thereafter rapidly decreases with addition of PVA to the soil. The reason is due to the high water and PVA absorption with addition of PVA above 3.75%, this will reduce the soil density. The increment of MDD at 3.75% PVA is almost 11% as compared to the natural soil.

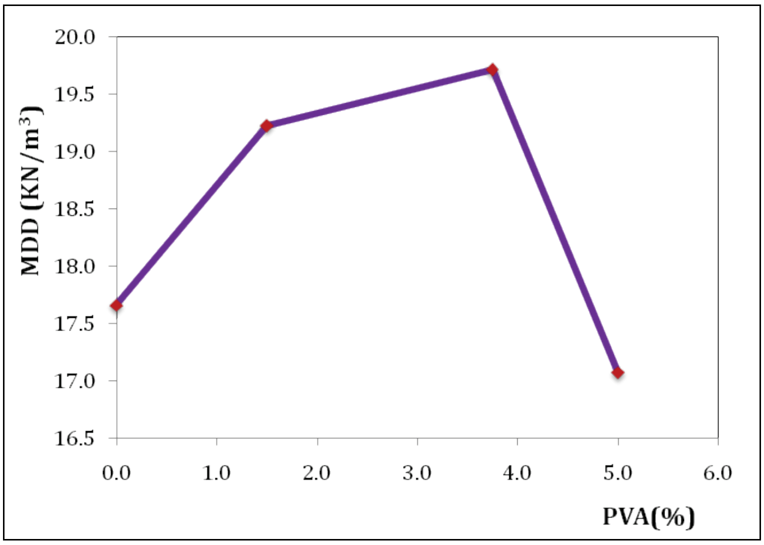

Fig. 6 –Effect of PVA concentration on Maximum Dry Density

On the other hand, the OMC is influenced by addition of PVA to the soil as clearly seen in Fig. 8. From this figure, it was observed that there is a marginal decrease in OMC with increasing percent of PVA. The reduction in OMC of treated soil with 5% PVA is almost 21% of the untreated soil. This reduction may be due to high PVA content decreases the water absorption of the soil.

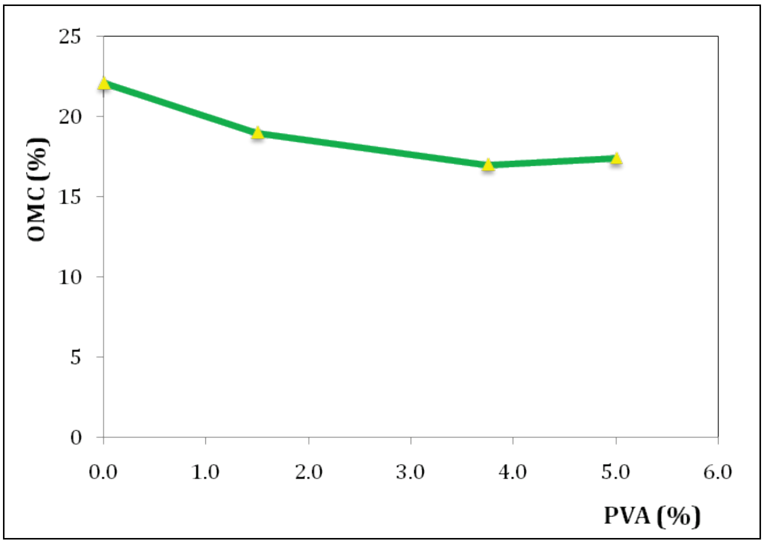

Fig. 7 –Effect of PVA concentration on Optimum Moisture Content

4.4 Effect on Unconfined compressive strength

The effect of unconfined compressive strength (UCS) value of compacted soil at MDD and OMC, with addition of 0%, 1.5%, 3.75%, and 5% of PVA content is plotted in Fig 8. It's observed that addition of PVA has considerable effect on unconfined compressive strength gains. The increment of strength depends on the percentage added. Significant increase in UCS of treated soil was observed with increased percentage up to 3.75%, beyond this percent the UCS is rapidly decreased .The increment in UCS of treated soil with 3.75% PVA is almost 6 times the original soil value.

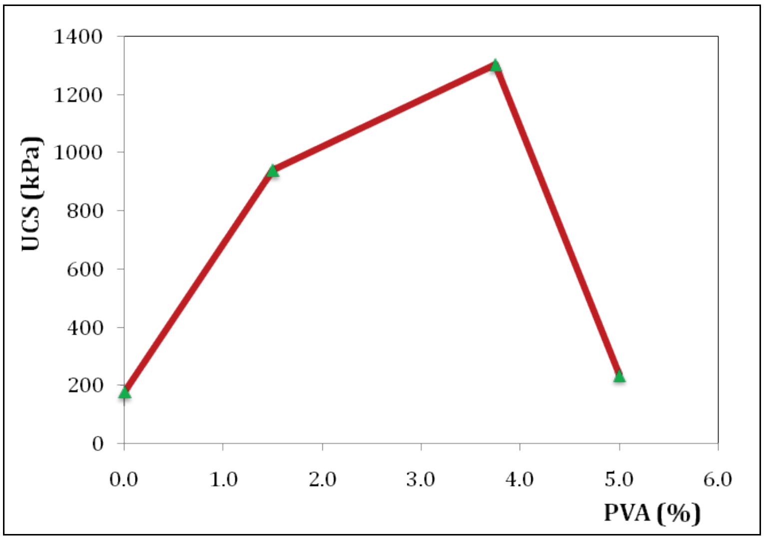

Fig. 8 –Variation of unconfined strength of stabilized soil with PVA

5 Conclusions

This study was conducted to investigate the effect of a polymer material (Polyvinyl Acetate (PVA)) with varying percentages on the swelling and strength properties of expansive clay. Based on the experiment results, the following conclusions are drawn.

The soil studied is classified as sandy Clay (CH) of high plasticity (LL=78% and PI=62%), high free swell (FSI=190%) and low strength (UCS=177 KPa).

PVA is a nontoxic and organic copolymer used with varying contents (1.5%, 3.75, and 5.0) to stabilize clay soils with high plasticity and swelling. The results clearly showed a considerable improvement in the plasticity, swelling and strength properties of expansive soil treated with PVA.

A significant decrease in plasticity and swelling of stabilized soil with increasing percentages of PVA. The reductions in PI and FSI values with addition of 5% PVA were found to be 100% and 80% respectively.

Addition of PVA to a clay soil has significant effect on compaction parameters and strength gain. Addition of 5% PVA to the soil results in a considerable reduction in optimum moisture content about 21% as compared to the natural soil. On the other hand, the maximum dry density (MDD) and unconfined compression strength (UCS) increase up to 3.75% PVA; beyond this percent there is a sharp decrease. The maximum increment in MDD is almost 11% and the UCS of the treated soil is 6 times the virgin soil.

The research findings clearly indicated that increasing in strength characteristics and decreasing in swelling behavior with addition of PVA, suggesting its great potential to be used as an additive for improving the engineering properties of expansive soils.

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