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# Effect of Bitumen and Fly Ash on Expansive Soil Properties

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**Abstract** This paper represents an experimental research to investigate the effect of using bitumen and fly ash on strength and swelling properties of expansive soil stabilized with 5% fly ash and varying percentages (0, 5, 10, 15, and 20%) of bitumen. Preliminary tests such as Atterberg limits, compaction parameters tests together with unconfined compression and CBR tests were conducted on stabilized soil. Specimens for unconfined compression and CBR tests were prepared at their respective optimum moistures using Standard compaction effort. For CBR tests, a pair of compacted specimens was prepared at soaking and unsoaking conditions. The study results revealed that addition of bitumen-fly ash to expansive soil has significant influence on its properties. Comparing the tests results, the maximum dry density, unconfined compressive strength (UCS) and CBR of the stabilized soil increased significantly, coupled with reduction in plasticity index (PI) and free swell index (FSI) as the bitumen-fly ash content increased. Addition of 5% bitumen and 5% fly ash resulted in increment in soaked CBR almost 3 times the initial value, while unsoaked CBR and UCS increment is 60% compared to virgin soil. The reduction in PI and FSI with addition of 15% bitumen and 5% fly ash is about 64% and 86% respectively. It is concluded that the study findings are expected to be useful to civil engineers in the field implementation of stabilization schemes.

**Keywords** Bitumen; expansive soil; fly ash; strength; swelling

## Introduction

Expansive soils are characterized by very low bearing capacity, high compressibility, low permeability and high volume change under changing moisture conditions. They tend to lose strength further upon wetting and other physical disturbances. These soils are especially troublesome as pavement subgrades and unsuitable for construction of embankments, buildings or other light structures in their natural state [1-2]. For the purpose of enhancing the engineering properties of this soil by mechanical or chemical means or both, soil stabilization will be conducted by adding a stabilizing agent to the natural soil. In this process, the additive agent is typically a manufactured commercial product that enhances the soil quality only if it is added in right amounts. Such products include Portland cement, lime, fly ash, bitumen alone or accompanied with something else.

Bituminous materials are extensively used for pavement construction, primarily because of their excellent binding characteristics, sustainable and water proofing properties. Soil stabilization with bitumen is one of the oldest methods used to improve soil properties. When bitumen mixed soil it binds the particles together by providing cohesive strength to the soil mass (i.e. cementation action) and acts as waterproofing agent [3].

Recently, fly ash was widely used in construction industry such as production of concrete, grout, structural fills, embankments and soil stabilization. Fly ash is regularly used as a partial replacement for cement in treatment of weak soils because of its pozzolanic properties. Fly ash by itself has little cementation effect but in the presence of moisture or bitumen it reacts chemically and forms cemented compounds and attributes to the improvement of strength and swelling characteristics of expansive soils [4]. Increased use of fly ash as a partial cement or lime replacement would also represent a savings in energy. Therefore, fly ash has been called a high-energy waste material. In this regard, an attempt has been made to study the effect of bitumen-fly ash admixture on the properties of expansive soil.

## Literature Review

### Bitumen Stabilization

Bitumen stabilization is the method adopted for improving the engineering properties of soil. It is generally accomplished using bitumen, cutback, bitumen emulsion or foamed bitumen additives. Bitumen is a by-product that remains after distillation or evaporation of crude petroleum. Asphalt consists of mineral particles impregnated or cemented by bitumen. Bitumen emulsion is a two-phase system consisting of bitumen and water. The bitumen content can vary from 30% to 70% depending upon the requirements [5]. Bitumen emulsion is manufactured by shearing the hot bitumen rapidly in water containing emulsifying chemical (emulsifier). Since the density of bitumen is slightly more than water so the sedimentation process is very slow that means even after long storage times emulsions can be regenerated by gentle stirring. Depending upon the type of emulsifier used, the bitumen particles can either get positive or negative charge. Bitumen particles getting negative charge are classified as anionic bitumen emulsion (pH more than 7) and those having positive charge are known as cationic bitumen emulsion (pH less than 7). Due care is taken to prevent the mixing of cationic and anionic bitumen emulsion since the electrostatic forces between them can separate the bitumen particles from water resulting in destroying of emulsion [5].

Bitumen stabilization method improves the strength and swelling characteristics of expansive soils and also performs waterproofing function. According to USACE [6], the type of bitumen to be used depends upon the soil type, construction method, and weather conditions. Depending upon project conditions, the choice made between using bitumen emulsion or foamed bitumen as additive. For example, extremely wet soil conditions might delicate the use of foamed bitumen rather than bitumen emulsions to compensate for the high field moisture content. Emulsion might be chosen for projects where high-performance emulsions are readily available. When using bitumen, it is often the practice to utilize an activator such as cement, lime or fly ash to help in increasing the compressive strength of the soil. Based on the previous researches in the field of soil stabilization using various materials like fly ash, bagasse ash, crushed glass, coconut coir fiber, lime etc, it was observed that very little researches has been done in field of soil stabilization by bitumen. Most suitable bitumen admixtures are used in sandy gravel, sands, silty sands, fine crashed rocks, and highly plastic clays. Bitumen is not as common as other stabilizers like lime and cement, mainly because of its relatively high cost. The effectiveness of bitumen on cohesion and waterproofing depends on the nature of the soil. The amount of fine soil particles is important in workability of bitumen. Too much fines could present problem with mixing, stability and uniformity. Lack of fine could result an unstable mixture, causing loss of adhesion [7]. Stabilization of soils and aggregates with bitumen greatly differs from other stabilizers.

### Fly ash

Fly ash is a by-product of coal combustion in power plants. Fly ash contains silica, alumina, and different oxides and alkalis in its composition [8]. Its general appearance is light to dark gray powder and the size is the same as silt. The specific gravity of fly ash ranges from 1.9 to 2.5. Fly ash can be classified into two main types - class C and class F, based on its chemical composition. This classification mainly depends on the percentages of silica ($SiO_2$), alumina ($Al_2O_3$) and ferric oxide ($Fe_2O_3$), the minimum percentage for class F fly ash is 70%, and for class C is 50%. Class C fly ash is normally produced from lignite or subbituminous coal. This class has pozzolanic properties and because of low concentrations of calcium compounds (less than 10% CaO) exhibits no self-cementing characteristics. Class F fly ash is normally produced from burning anthracite or bituminous coal. This coal has higher percentage of calcium carbonate, so class F fly ash is rich in calcium (more than 20% CaO), resulting in the self-cementing characteristics. Addition of fly ash to lime and cement can improve the engineering properties of soil like lime or cement [8].

According to ACAA [9], class F fly ash should be used in soil stabilization with the addition of cementitious agent such as lime, lime kiln dust, cement, and cement kiln dust. However, there are researches indicating that this fly ash can effectively improve some engineering properties of soil without activators [10-13]. The improvement level of stabilized soils is dependent on soil properties, fly ash addition ratio, delay time and moisture content at the time of compaction [9].

**Previous Investigations**

The previous studies have been conducted on soil stabilization by bitumen and fly ash. The effects of bitumen and fly ash on engineering properties of soils have been investigated by many researchers as reviewed below.

Griffin [14] studied the effect of bitumen stabilization on the strength of compacted soil measured in terms of unconfined compressive strength. They found that initially there is an increase in strength with addition of bitumen until the maximum strength is reached at 7% bitumen and after the peak there is a slow drop in unconfined compressive strength of the soil.

Michael [15] had planned regarding Bench-Scale analysis of asphalt emulsion stabilization of contaminated Soils. During his study, it had been mentioned regarding the appliance of close temperature asphalt emulsion stabilization technology and mentioned to the environmental fixation of soils contaminated by organic contaminants.

Paul [16] suggested soil stabilization in pavement taking a mixture of bitumen and well-graded gravel or crushed aggregate. They observed that soil particles were covered with bitumen that forestalls or abates the entrance of water which could regularly bring about abatement in soil quality. Moreover, bitumen stabilization can enhance durability qualities by making the soil impervious to the unfavorable impacts of water. In granular materials, sands and gravel, pounded gravel, and smashed stone, two fundamental systems are dynamic: waterproofing and adhesion. The asphalt coating on the granular materials gives a film which anticipates or hinders the entrance of water; subsequently reducing the inclination of the material to lose quality in the vicinity of water. The second instrument had been distinguished as adhesion and characteristics of gravelly soils.

Bisanal and Badiger [17] studied black cotton soil stabilization using bitumen emulsion and sea shell powder. Sea shells are naturally available materials on sea shores. They contain 90% of calcium carbonate which is a major component in Lime. Bisanal and Badiger found significant improvement in strength in terms of Unconfined Compressive Strength (UCS) and California Bearing Ratio (CBR). Addition of 22% bitumen emulsion increased the UCS from 120 to 500 $KN/m^2$ measured after curing for 28 days and the soaked CBR from 2.3 to 7.8%. Also, with addition of 16% sea shell powder, the UCS increased to 441 $KN/m^2$ and the soaked CBR to 5.3%.

On his study, Nikraz [18] tried to mix and blend soil with Portland cement and bitumen emulsion so as to upgrade the soil quality and decrease its weakness to water. Nikraz succeeded to improve the soil cohesive strength and durability. Yuehuan [19] worked on foamed bitumen stabilization for Western Australian pavements. By adding 3 to 5 % of bitumen, Yuehuan attained more strength in subgrade soil.

Zumrawi and Mohammed [20] conducted an experimental study on three expansive soils stabilized by fly ash of varying percentages (0, 10, 20, 25, and 30%). They found additions of Fly ash to the three soils resulted in significant improvement in the strength and reduction in plasticity and swell properties of the soils. The unconfined compressive strength of the soils treated with 10% Fly ash showed almost 2 times improvement compared with untreated soils. For the addition of 10% fly ash, the reduction in free swell, swell pressure and swell potential is in the range 50% to 70%. Further addition of fly ash caused a reduction in the swell characteristics about 90% at 25% fly ash.

Vukićević et al [21] conducted a laboratory research on high plastic clay stabilized using class F fly ash with activator – cement. They tested the soil-fly ash mixtures at different fly ash contents (10-25%). Their findings showed that the optimum dosages of fly ash and cement were 20% and 3%. Addition of fly ash and cement decreased plasticity and increased strength properties of the treated soil.

Al-Dahlaki [22] studied the effect of 0 to 25% fly ash on the swelling properties of expansive soils when subjected to various curing times (0, 10-days and 30-days). Al-Dahlaki found a significant reduction in swelling with increasing fly ash percent and curing time.

In this literature review different works had been done previously on bitumen and fly ash stabilization. But in Sudan the number of work on bitumen stabilization is very few. Actually in Sudan there is no any appropriate practice for bitumen stabilization. As from those papers it is very difficult to get any actual idea about how to mix bitumen with soil and what will be its actual quantity. This experimental investigation is mainly to make a process for mixing bitumen-fly ash with soil.

**Materials and Experiments**

The experimental work was carried out to achieve the objective of the research. Laboratory tests were performed on natural expansive soils and stabilized soils with bitumen-fly ash admixture. Various percentages of bitumen (0, 5, 10, 15, and 20%) mixed with 5% fly ash as activator, were added to the soils to investigate their effects on soil properties.

**Materials Used**

The materials used in the study are expansive soil, bitumen and fly ash. The expansive soil was collected from Madani in Gezira state, Sudan. Bitumen of 60/70 penetration grade and Fly ash class F were used for the soil stabilization.

**Expansive soil**

Expansive soil is considered to be the most problematic soil all over the world due to their swelling behaviour when in contact with water and shrink on removal of water. For this study, the soil was obtained from a road subgrade located in Gezira University at Al-Nishashiba in Madani. The soil was initially air dried and pulverized to pass through IS-425 Micron Sieve and then oven dried at 110 $^{o}$C before testing. The engineering properties measured for the natural soil are presented in Table (1).

**Table 1**: The properties of the soil studied

| Property | | Value |
|---|---|---|
| | Specific Gravity | 2.74 |
| Particle Size | Sand, % | 11 |
| | Silt, % | 28 |
| | Clay, % | 61 |
| Attterberg's Limits | Liquid Limit, % | 63 |
| | Plastic Limit, % | 30 |
| | Plasticity Index, % | 33 |
| Swelling Characteristics | Free Swell Index, % | 133 |
| | Swell Potential, % | 14 |
| | Swell Pressure, KN/m$^2$ | 165 |
| Compaction Characteristics | Optimum Moisture Content, % | 19.0 |
| | Maximum Dry Density, KN/m$^3$ | 15.1 |
| Strength Parameters | Unconfined Compressive Strength, KN/m$^2$ | 284 |
| | Unsoaked CBR, % | 42 |
| | Soaked CBR, % | 1.2 |

**Bitumen**

Asphalt cement is used as stabilizer agent. Based on specifications it may contain other additives such as coating improvers, anti-strips, or break control agents. Bitumen is produced after distillation of crude petroleum. Bitumen of 60/70 penetration grade was used for the soil stabilization. The physical properties measured for the bitumen used is given in Table (2).

**Table 2:** The physical properties of the bitumen

| Property | Value |
|---|---|
| Penetration, 0.1mm | 63 |
| Ductility, cm | 100 |
| Kinematic Viscosity, centi-stoke | 920 |
| Softening Point, °C | 47 |
| Flash Point, °C | 270 |
| Fire Point, °C | 295 |
| Specific Gravity | 1.01 |

**Fly ash**

Fly ash class "F" was used for this research which was obtained from thermal power generation station at Setat Dam in River Nile state. The properties of the fly ash sample are presented in Table (3).

**Table 3:** The properties of the Fly ash sample

| Property | Value |
|---|---|
| Specific Gravity | 2.24 |
| Retained on Sieve (45µm) | 6.0 |
| Plasticity Index, % | N.P. |
| Expansion Ratio, % | 0 |
| Water Demand, % | 93 |
| Strength Activity Index for 7 days, % | 87 |

**Experiments**

A laboratory testing program was conducted on expansive soil which comprises common subgrade soil in Gezira state. Soil samples were subjected to laboratory experiments to determine their physical properties such as plasticity, free swell, compaction characteristics, unconfined compressive strength, and CBR as soaked and unsoaked. In this section, a brief description of the testing method and procedure is presented.

The tests carried out on the natural soil sample include specific gravity, sieve analysis, Atterberg's limits (Liquid limit and plastic limit). Also, the natural and the stabilized soil samples were prepared for swelling and strength tests such as free swell, swell potential and swell pressure tests. In addition to compaction, California bearing ratio and unconfined compression tests were conducted. These tests were conducted according to the standard procedures BS 1377 [23].

**Results and Discussion**

The primary objective of this study is to investigate experimentally the effect of bitumen-fly ash admixture on soil properties. Laboratory tests were conducted on soil samples prepared by adding different percentages of bitumen and a fixed percent of fly ash to the expansive soil. The tests results are presented and discussed in this section. Table (4) shows the summary of tests results.

**Table 4:** Tests results for the natural and stabilized soils using bitumen (B) and fly ash (F) percentages

| Property | Natural Soil | 5% B + 5% F | 10% B + 5% F | 15% B + 5% F | 20% B + 5% F |
|---|---|---|---|---|---|
| Liquid Limit, % | 63 | 55 | 53 | 51 | 47 |
| Plastic Limit, % | 30 | 33 | 35 | 39 | 39 |
| Plasticity Index, % | 33 | 22 | 18 | 12 | 8 |
| Free Swell Index, % | 133 | 110 | 100 | 18 | 17 |
| Optimum Moisture Content, % | 19.0 | 15.7 | 15.5 | 14.5 | 11.7 |
| Maximum Dry Density, KN/m$^3$ | 15.1 | 15.2 | 14.8 | 14.3 | 13.9 |
| Unconfined Compressive Strength, KN/m$^2$ | 284 | 455 | 210 | 160 | 90 |
| Unsoaked CBR, % | 42 | 66 | 26 | 20 | 10 |
| Soaked CBR, % | 1.2 | 6.0 | 5.0 | 4.1 | 4.0 |

**Effect on Atterberg's Limits**

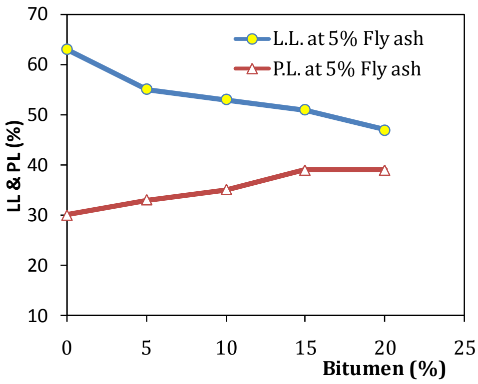


*Figure 1: Variation of liquid and plastic limits of stabilized soil with bitumen-fly ash content*

The variation of Atterberg's limits namely Liquid Limit (LL) and Plastic Limit (PL) values with 5% of fly ash and varying percentages of bitumen (0, 5, 10, 15 and 20) added to the expansive soil is presented in Fig. (1). From this figure, there is significant decrease in liquid limit and increase in plastic limit with the addition of bitumen-fly ash to the soil. The decrease in liquid limit and the increase in plastic limit cause a net reduction in plasticity index. The reduction in the plasticity index value of the stabilized soil with addition of 20% bitumen plus 5% fly ash is 76%. This result could be supported by the fact that fly ash class F has pozzolanic properties and high concentration of calcium compounds (more than 20% CaO) exhibits self-cementing characteristics [8].

**Effect on Free Swell Index**

The effect of various bitumen contents 0%, 5%, 10%, 15% and 20% and fixed amount of fly ash 5% on free swell index (FSI) of the stabilized soil is shown Fig. (2). In this figure, it is observed that the FSI value of the stabilized soil rapidly decreased with addition up to 15% bitumen-fly ash, beyond this percentage the FSI value marginally decreased with added bitumen-fly ash admixture. The reduction in FSI value of the stabilized soil with 15% bitumen-fly ash is about 86% compared with the natural soil. This reduction may be due to the presence of class F fly ash which is rich in calcium carbonate (CaO > 20%), resulting in the self-cementing characteristics [8].

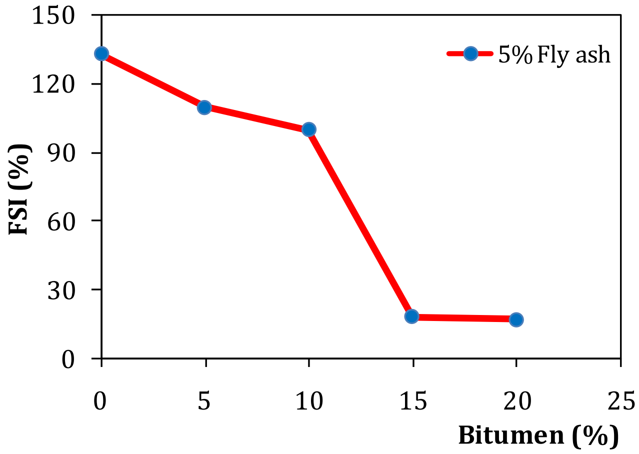


*Figure 2: The effect of varying bitumen-fly ash amount on free swell index (FSI)*

**Effect on Compaction Characteristics**

The influence of bitumen with varying contents (5%, 10%, 15% and 20%) and 5% fly ash on maximum dry density (MDD) and optimum moisture content (OMC) of natural and stabilized soils are presented in Figs. (3) and (4). Significant change in MDD and OMC are observed with addition of bitumen-fly ash admixture to the expansive soil. From Fig. (3), it is seen that the MDD increases up to 5% Bitumen-fly ash and thereafter rapidly decreases with addition of bitumen-fly ash to the soil. The reason is due to the high water and bitumen absorption with addition of bitumen-fly ash above 5%, this will reduce the soil density.

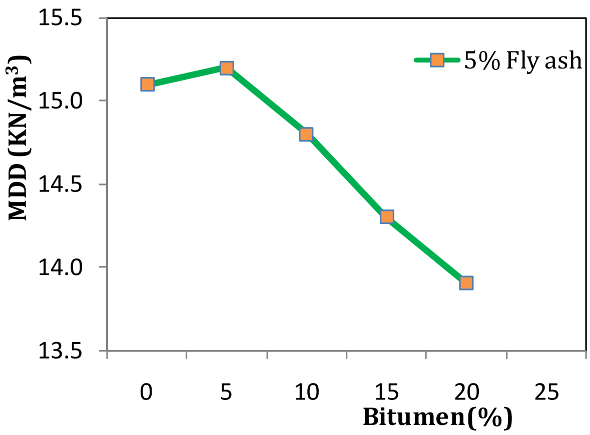


*Figure 3: Effect of varying bitumen-fly ash contents on Maximum Dry Density (MDD)*

On the other hand, the OMC is influenced by addition of bitumen-fly ash admixture to the soil as clearly shown in Fig. (4). From this figure, it was seen that there is a considerable decrease in OMC with increasing amount of bitumen-fly ash admixture. The reduction in OMC of stabilized soil with 20% bitumen-fly ash is almost 40% of the untreated soil. This reduction may be due to high bitumen content increases the waterproofing property and decreases the water absorption of the soil.

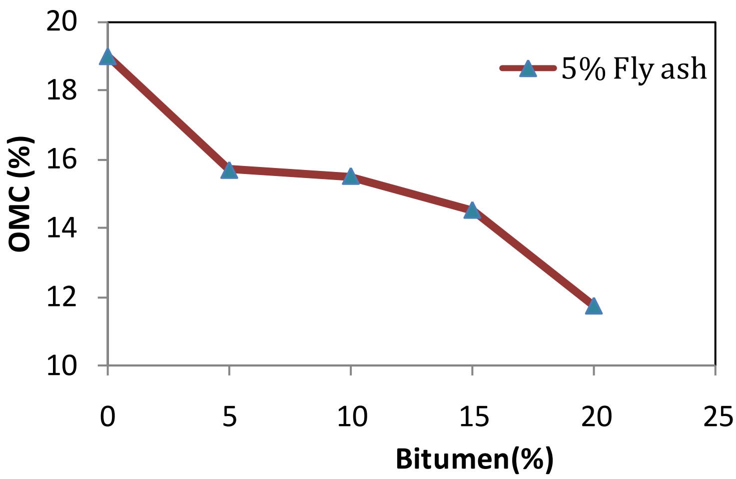


*Figure 4: Variation of Optimum Moisture Content (OMC) with bitumen-fly ash content*

**Effect on Unconfined Compressive Strength**

The unconfined compressive strength (UCS) of the stabilized soil is influenced by addition of bitumen-fly ash admixture as shown in Fig. (5). From this figure, it is observed that the UCS increased with higher rate up to 5% bitumen and 5% fly ash additive and then decreased with rapid rate to a value much less than the initial one. The UCS of stabilized soil with 5% bitumen and 5% fly ash showed 60% increment as compared to natural soil, while the reduction in UCS with addition of 20% bitumen and 5% fly ash is around 70% of the natural soil. The justification of this result may be due to considerable decrease in dry density occurred with addition of bitumen-fly ash above 5% which resulted in rapid reduction in UCS values.

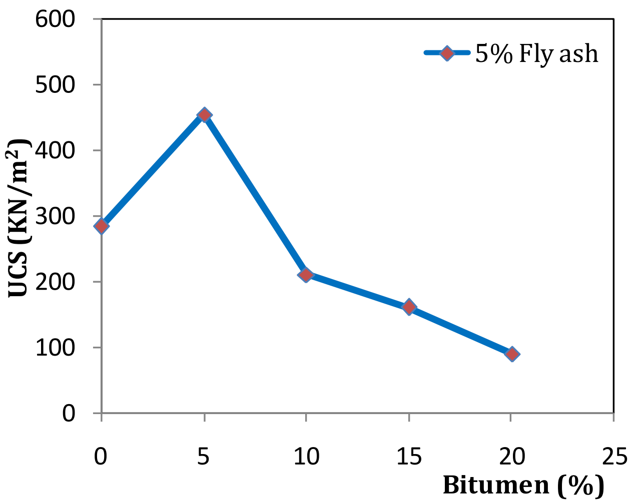


*Figure 5: Variation of Unconfined compressive strength with bitumen-fly ash content*

**Effect on California Bearing Ration (CBR)**

The influence of varying bitumen content (5 to 20%) and constant amount of fly ash (5%) of stabilized soil on CBR is shown in Fig. (6). The plot in this figure clearly demonstrated that the unsoaked CBR value increased from 42% of natural soil to 66% with addition of 5% bitumen-fly ash to the soil. Also, there is an increase in soaked CBR from 1.2% to 6% with 5% bitumen-fly ash additives. This result verified the presence of bitumen material responsible for the strength gain. The reduction in the CBR values was observed at 10% bitumen-fly ash and continues decreasing with addition of bitumen-fly ash. This reduction in the CBR might be due to the excess bitumen-fly ash in the clay not required for the early strength gain as a result of flocculation.

Overall from the results, it is understood that the strength of expansive soil stabilized with bitumen-fly ash are increasing significantly up to the optimum content of stabilizer at 5% bitumen-fly ash and then decreases with addition stabilizer. Therefore, bitumen-fly ash can be used to improve the strength characteristics of expansive soil.

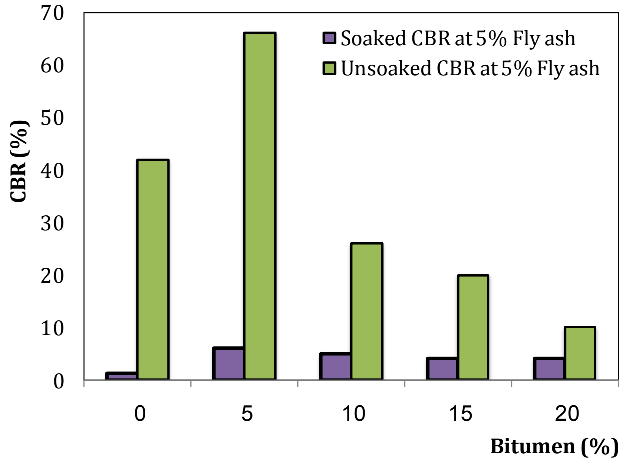


*Figure 6: California Bearing Ration (CBR) versus bitumen-fly ash admixture*

**Conclusions**

An experimental study was conducted to investigate the influence of using bitumen-fly ash admixture on the properties of expansive soils. The following conclusions can be drawn:

- The soil studied is classified as silty clay (CH) of high plasticity (LL 63% and PI 33%), highly expansive soil of free swell index (FSI) 133%, swell potential and pressure 14% and 165 kN/m2 respectively with very low strength, soaked CBR is 1.2%.
- Varying bitumen contents (5%, 10%, 15%, and 20%) with constant amount of fly ash (5%) were used to investigate their influence on soil properties, namely plasticity, free swell, compaction characteristics, unconfined compressive strength and CBR.
- Addition of bitumen-fly ash to the expansive soil has significant effect on swelling and strength properties. A significant decrease in plasticity and swelling of stabilized soil with increasing percentages of bitumen-fly ash admixture. The reductions in PI and FSI values with addition of 15% bitumen-fly ash were found to be 64% and 86% respectively.
- There is significant decrease in optimum moisture content (OMC) values with increasing percentages of bitumen-fly ash admixture. Addition of 20% bitumen-fly ash to the soil results in a considerable reduction in OMC about 40% as compared to the natural soil. The reason of this reduction may be due to high bitumen content increases the waterproofing property and decreases the water absorption of the soil.
- The strength characteristics such as maximum dry density, unconfined compressive strength (UCS), soaked and unsoaked CBR increase up to 5% bitumen-fly ash; beyond this percentage there is a rapid decrease. The increment in soaked CBR is almost three times the initial value, while unsoaked CBR and UCS increment is around 60%.
- The findings indicated an increasing trend for soil strength and decreasing in swelling with addition of bitumen-fly ash, suggesting its potential applications in stabilization of expansive soils.

**Acknowledgment**

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