STABILIZATION OF BLACK COTTON SOIL USING ULTRA FINE SLAG

A PROJECT

Submitted in partial fulfillment of the requirements for the award of the degree of

BACHELOR OF TECHNOLOGY

IN

CIVIL ENGINEERING

Under the supervision of

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By

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to

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY

WAKNAGHAT SOLAN – 173 234

HIMACHAL PRADESH INDIA

May, 2015

DECLARATION

I hereby declare that the project work presented in this Project entitled "*Stabilization of Black cotton soil using Ultra fine slag*" submitted for the award of the degree of Bachelor of technology in the Department of Civil Engineering, Jaypee University of Information and Technology Wakhnaghat, is original and our own account of work. This project work is independent and its main content work has not previously been submitted for degree at any university in India or Abroad.

Pravar Yadav

Nitesh Mankotia

CERTIFICATE

This is to certify that the work which is being presented in the project title **"STABILIZATION OF BLACK COTTON SOIL USING ULTRA FINE SLAG"** in partial fulfillment of the requirements for the award of the degree of Bachelor of technology and submitted in Civil Engineering Department, Jaypee University of Information Technology, Waknaghat is an authentic record of work carried out by **Pravar Yadav** and **Nitesh Mankotia** during a period from August 2014 to May 2015 under the supervision of **Niraj Singh Parihar** Assistant Professor, Civil Engineering Department, Jaypee University of Information Technology, Waknaghat.

The above statement made is correct to the best of my knowledge.

Date: - ………………………

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ABSTRACT

The quality and life of pavement is greatly affected by the type of sub-grade, sub base and base course materials. The most important of these are the type and quality of sub-grade soil. But in India most of the flexible pavements are need to be constructed over weak and problematic sub-grade. The California bearing ratio (CBR) of these sub-grades are very low and therefore more thickness of pavement. Decrease in the availability of suitable sub base and base materials for pavement construction have leads to a search for economic methods of improvement of locally available problematic soil to suitable construction materials. The improvement of soil properties is one of the main branches of geotechnical science that has been considered by researchers in different countries. In developing country like India due to the remarkable development in road infrastructure, soil stabilization has become the major issue in construction activity. Stabilization is an unavoidable for the purpose of highway and runway construction, stabilization denotes improvement in both strength and durability which are related to performance. Stabilization is a method of processing available materials for the production of low-cost road design and construction. Fine clayey soils properties due to high swelling necessitate the need to improve its geotechnical properties. Black cotton soils when used as a subgrade for pavements has risks of substantial settlements, heave and low bearing capacity.

This project is an investigation carried out to study the effect of Ultra fine slag on engineering and strength properties of the Black Cotton Soils. The properties of stabilized soil such as compaction characteristics, consistency limits, California bearing ratio and swell potential were evaluated and their variations with Ultra fine slag content evaluated.

The interpretation of test results leading to various conclusion and recommendation on the use of Ultra fine slag in soil stabilization to counter the difficulty posed by black cotton soil for subgrade material is discussed.

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CHAPTER 1

INTRODUCTION

1.1 General introduction

Expansive soil also known as Black cotton soil because of their color & suitability for growing cotton swells when the moisture content is increased and shrinks massively when dry. Montmorillonite mineral is mainly responsible for the swell-shrink characteristic of the black cotton soil. The expansive nature decreases the bearing capacity of the soil. The black color in Black cotton soil is due to the presence of titanium oxide in small concentration. (Nyakarura, et. al, 2009)

Black cotton soil is a highly clayey soil. It is so hard that the clods cannot be easily pulverized for treatment for its use in road construction. This poses serious problems as regards to subsequent performance of the road. The softened sub grade has a tendency to up heave into the upper layers of the pavement, especially when the sub-base consists of stone soling with lot of voids. Gradual intrusion of wet Black cotton soil invariably leads to failure of the road. The roads laid on Black cotton soil bases develop undulations at the road surface due to loss of strength of the sub grade through softening during the wet season. The damage will be apparent usually several years after construction. The stability and performance of the pavements are greatly influenced by the sub grade and embankment as they serve as foundations for pavements. There is therefore need to stabilize black cotton soil in order for it to provide a good foundation material. Stabilization denotes improvement in both strength and durability of the material which are related to performance.

1.2 Problem statement

Black cotton soil is an undesirable foundation material. An engineer may choose to remove the undesirable material and replace it with a more desirable material in terms of strength and durability. This may however turn out to be expensive considering pavements cover several kilometers and therefore the need to find out other alternative methods of modifying the properties of the soil in place. These undesirable properties are that:

In rainy season, Black cotton soils become very soft by filling up of water in the cracks and fissures. These soft soils reduce the bearing capacity of the soil hence the decrease of the strength of foundation.

In saturated conditions these soils have high consolidation settlements which are uneven hence the beam deflects which in turn affect the plastering to the wall. Black cotton soil has high swelling nature which causes damages to the pavement.

It is therefore need to increase the bearing capacity and the unconfined compressive strength of the soil, reduce both elastic and inelastic consolidation settlement, prevent weathering and deteriorations of the black cotton soil.

Fig. 1

Fig. 2

1.3 Objective of study

The basic objectives of study of black cotton soil are as following:

- To check the improvement of bearing capacity of Black Cotton Soil on addition of Ultra fine slag.
- To examine the variation of Strength of soil at different slag content.
- To check the effect of Ultra fine slag on CBR value of the soil.
- To check the effect of Ultra fine slag on Compressive strength of soil.

In order to achieve the above objective, the black cotton soil has been arbitrarily reinforced with Ultra fine slag. So the suitability of Ultra fine slag is considered to enhance the properties of black cotton soil. A cycle of experiments such as Liquid limit test, Plastic Limit Test, California bearing ratio test (CBR) test, unconfined compressive strength and swelling test is carried out on black cotton soil sample with different percentages of Ultra fine slag. They are performed to study the variation in bearing capacity and other properties like liquidity and plasticity behaviour, and compaction behaviour are also studied. The CBR test is carried out to access the suitability of this composite for a road sub grade material.

1.4 Methodology

Study is carried out on the challenges of construction on clays and their effect on the engineering structure in areas where these materials exist looked into. Ultra Fine Slag will be used to stabilize the clay. This will entail collection of data from experimentation and use of any available literature.

1.5 Soil Stabilization

In most cases it is expensive to remove large volumes of unsatisfactory soils and replace them with suitable material. This brings about the need to improve the soil in place so that it serves as a good engineering construction material. The improvement of the stability or bearing power of a poor soil and durability which are related to performance of the soil through mechanical, physio-mechanical and chemical methods is referred to as soil stabilization. This is achieved by use of controlled compaction, proportioning and addition of suitable admixture or stabilizer. The stabilization process involves excavation of the in-situ soil, treatment of the in-situ soil and compaction of the treated soil. Increase in strength is expressed quantitatively in terms of:

- Adsorption, softening and reduction in strength
- Direct resistance to freezing and thawing
- Compressive strength, shearing strength or measure of load deflection to indicate the load bearing quality

Stabilization process is ideal for improvement of soils in shallow depth such as pavements and light weight structures as the process essentially involve excavation of the in-situ soil.

CHAPTER 2

LITERATURE REVIEW

2.1 General

This study is done to evaluate the nature and engineering properties of black cotton soils, their behavior under various seasonal conditions and finally use Ultra fine slag to stabilize the soil as a solution to the problems created by these soils in pavement subgrade construction. The physical properties of clays and most soils are often poorer than may be required for a particular project their shear strength is too low and their compressibility, water content and permeability is too high. Application of RBI Grade 81 was carried out by researchers in the past and observations of investigation program are summarized below :

GyanenTakhelmayum et al, *" Experimental Studies on Soil Stabilization Using Fine and Coarse GGBS*" 2003, carried out their studies using fine and coarse ground granulated blast furnance. A series of strength test were carried out for different proportions of GGBS mixtures. The black cotton soil with varying proportion of GGBS mixtures were prepared at the respective optimum moisture content and the characteristic compaction and unconfined compressive strength values were determined for different curing. A series of compaction test were carried out by varying soil and Fine GGBS at respective optimum moisture content and the corresponding maximum dry density. From that it can observed that with increase in fine GGBS content the maximum dry density increases.

PV sivapullaiah et al, *"Use of Solid Waste to Enhance Properties of Problematic Soils of Karnataka"* 2013, carried out their studies using both fly ash and ground granulated blast furnace as a stabilizer in Black cotton soil. They found that Dispersive soils can be stabilised very effectively with fly ash and GGBS. Curing with fly ash increases the strength and reduces the dispersivity. Black Cotton soil which is known to be effectively stabilised with fly ash can be stabilised better with Ground Granulated Blast Furnace Slag (GGBS). Mixtures of Lime, Fly ash and Ground Granulated Blast Furnace Slag (GGBS) can be optimised for Geotechnical Applications.

Pankaj R. Modak et al, "*Stabilisation of Black Cotton Soil Using Admixtures*" vol 1, May 2012, conducted their studies using lime and fly ash as admixture in stabilizing black cotton soil. The improved CBR value is due to addition of Lime and Fly ash as admixtures to the BC soil. It also reduces the hydraulic conductivity of BC soil. There will be no need of drainage layer after treatment of black cotton soil as sub grade with lime and fly ash. In combination, the admixtures are beneficial for lower plasticity and higher silt content soils. In terms of material cost, the use of less costly fly ash can reduce the required amount of lime.

Nadgouda, K.A et al, **"***The Effect of Lime Stabilization on Properties of Black Cotton Soil*" December 2010, carried out their studies using lime as stabilizer in expansive soil. They found that an immediate benefit obtained by the addition of lime to swelling soils is to reduce the potential for swelling upon contact with water. The plastic nature of the soil decreases and the stiffness of the soil increases as the lime content increases. For improving the properties, the optimum lime content was found to be within the range of 3.5% to 4.5%.

2.2 Soil identification and Description

Soil is the relatively loose mass of mineral and organic materials and sediments produced by the physical or chemical disintegration of rock. It consists of layers of mineral constituents of variable thickness, which differ from the parent material in physical, morphological, chemical and mineral characteristics.

According to the detailed description of the method of describing soils contained in BS 5930, the basic soils are boulders, cobbles, gravels, sand, silt, and clay. Soil identification and description includes the details of both mass and material characteristics.

2.2.1 Mass characteristics

Mass characteristics are best determined in the field. They can also be determined in the laboratory when undisturbed samples are available. Mass characteristics include firmness, details of bending, strength, weathering and discontinuity.

Table 2.1 Field identification test for clay soil [1]

Term	Field test
Very soft	Exudes between fingers when squeezed in the hand
Soft	Molded by finger pressure
Firm	Can be molded by strong finger pressure
Stiff	Cannot be molded by fingers
Very stiff	Cannot be indented by thumb nails

2.2.2 Material characteristics

Material characteristics can be determined from samples having the same particle size distribution as the insitu soil but whose insitu structure has been altered. The principal material characteristics are particle size distribution and plasticity. Secondary material characteristics are color of the soil, shape, texture and composition of the particles.

2.3 Material and method

Black cotton soils are organic clays of medium to high compressibility and form a major soil group in India. They are characterized by high shrinkage and swelling properties. This Black cotton soils occurs mostly in the central and western parts and covers approximately 20% of the total area of India. Because of its high swelling and shrinkage characteristics, the Black cotton soil (BC soils) has been a challenge to the highway engineers.

2.3.1 BLACK COTTON SOIL

Geotechnical properties of black cotton soil are given in Table. Black cotton soil have the tendency to increase in volume when water is available and decrease in volume if water is removed. Black cotton soil is generally black in color. The swelling soils of India have their origin in subaqueous decomposition of basalt rocks or weathering in-situ. The mineral montmorillonite is formed under alkaline environment. The black cotton soil is mostly residual in character and the thickness of the deposit is not large- less than 4 m in most cases. In India, Black cotton soils are common in entire Deccan plateau, western Madhya Pradesh, parts of Rajasthan, Bundelkhand region in Uttar Pradesh and parts of Andhra Pradesh and Karnataka.

Table 2.2 [2]

Color	Specific gravity	Liquid limit(%)	Plastic limit(%)	O.M.C(%)	M.D.D(g/cc)	Free swell index(%)
Black	2.65	40-60	30-60	20-30	1.4-1.6	40-60

2.3.2 ULTRA FINE SLAG

Blast-furnace slag is produced as a by-product of the iron and steel production industries. Its earthy constituents come from iron ore processing, and it consists of the same oxides as Portland cement, but in different proportions. Immediately after its production, slag is usually quenched for rapid cooling in a process known as granulation. The granulation results in a reactive amorphous glass and avoids any crystallization.

Hence an attempt has been made to improve the strength and swell behaviour of expansive black cotton soil using Ultra fine slag in this work.

Table 2.3 [2]

Color	Specific gravity	Liquid limit	Plastic limit	Free swell index(%)
Off-white	2.82	40	Non-Plastic	zero

CHAPTER 3

3.0 PRELIMINARY TESTS

3.1 Investigation of soil properties

Soil samples were collected from Guna, Madhya Pradesh area and transported to the lab. A portion of the soil was taken for the determination of natural moisture content in accordance to BS 1377-2: 1990.

3.2 Classification

The rest of the sample was air dried.500grams of the air dried sample was soaked in water for two hours and washed over 0.075 sieve. The retained soil was oven dried after which it was placed on an already prepared stack of sieve with different aperture sizes arranged in a way that every upper sieve had a larger opening than the sieve below. The test sieves were agitated so that soil samples roll over the test sieves and mass of retained soil in each sieve was determined. The particle size distribution curve is as shown in the graph in section 4.1.1

3.3 Atterberg Limits

An air dry sample passing the 425µm sieve was mixed with water and used to determine the consistency limits of the soil.

Liquid limit was determined using the standard liquid limit apparatus designed by Casagrande. About 120gm of specimen is mixed with distilled water in evaporation dish to form a uniform paste. A portion of the paste is placed in the cup over the spot where the cup rest on the base, squeezed down and spread into position and the groove is cut in the soil pat. The handle is rotated at a rate about 2 revolutions per second, and the number of blows is counted until the two parts of the soil sample come into contact at the bottom of the groove.

Plastic limit was determined by dipping a small portion soil paste in the air dry sample passing 425µm sieve to form a mould. The mould was rolled between fingers then on a smooth plate into a thread of 3mm diameter. This was being repeated until the thread first showed signs of cracking. A portion of the mould was taken for water content determination.

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3.4 Proctor compaction test

The standard proctor test was developed by R.R Proctor (1933). The test consist of

- Cylindrical metal mould, having an internal diameter of 10.15cm, an internal effective /height of 11.7cm and the capacity of about $947cm^3$.
- Detachable base plate.
- Collar effective height of 5cm.
- Rammer 2.5kg in mass falling through a height of 30.5cm.

About 3kg of air dried and pulverised soil, passing a 4.75mm sieve, is mixed with a small quantity of water. The soil is placed in the mould and compacted by giving 25 blows of rammer uniformly distributed over the surface. The bulk density ρ and the corresponding dry density ρ_d for the compacted soil are calculated from following relation:

$$\rho = M / V \ (g/cm^3) \ ; \quad \rho_d = \rho / (1+w) \ (g/cm^3)$$

M = mass of wet compacted specimen (g)

w = water content (ratio)

V = volume of the mould ($947cm^3$)

3.5 California Bearing Ratio (CBR) test

CBR tests were conducted on neat soil as well as stabilized soils. To stabilize the soil Ultra fine slag was added in different percentages i.e. 3%, 6%, 9%, 12%, 15%. The dry weight required for filling the mould was calculated based upon the maximum dry density (MDD) and corresponding optimum moisture content was achieved from standard proctor test. The static method of compacting soil specimen in the CBR mould was used. The correct mass of the wet soil was placed in the mould in five layers and each layer gently compacted with rammer weighing 4.5kg. The mould was compacted by free fall of rammer. The neat soil was tested after soaking in water for four days. The load penetration curve was drawn for the neat soil as well as the stabilized soils and the CBR values were calculated from these curves. The variation of CBR (soaked condition) of the black cotton soil samples with the addition of Ultra fine slag in increasing percentages is shown in Graphs

Fig.3 (Testing of CBR setup)

3.6 Unconfined compression test

The soil samples were prepared by static compaction method to achieve Maximum Dry Density at Optimum Moisture content. The steel split mould having a diameter of 3.6 cms and a height of 7.8 cms is used. The weight of the soil to be taken and the volume of water to be added are calculated by knowing the volume of mould and Maximum Dry Density and Optimum Moisture content of the soil. Once the trial mix is prepared, the mould is oiled thoroughly. The mix is transferred to the mould compacted and then extracted from the mould. Three identical samples were prepared for their Maximum Dry Density and Optimum Moisture content based on the compaction curves obtained. Samples intended for long term testing were kept in desiccators to maintain 100% humidity and to prevent loss of moisture from samples. Water was sprinkled at regular intervals and was cured in the desiccators. All the samples intended for immediate testing were tested immediately. The unconfined compression test was carried out according to IS 2720(part 10) - 1973. The test was conducted using Unconfined Compressive test apparatus at a strain rate of 1.25 mm/ minute. The specimen to be tested was placed centrally in between the lower and upper platform of testing machine. The loading was continued until three or more consecutive reading of the load dial showed a decreasing or a constant strain rate of 20% had been reached

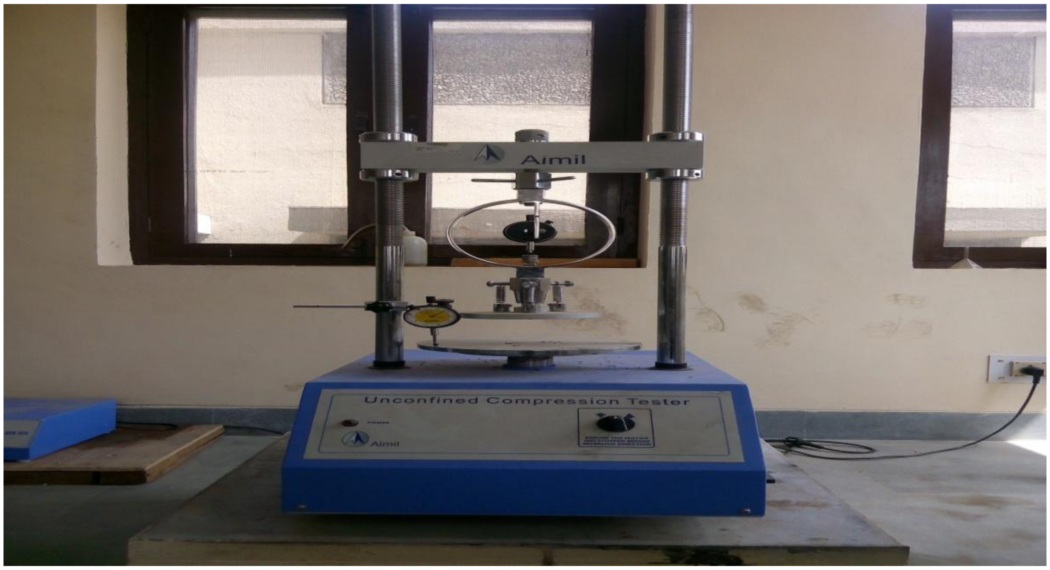

Fig.4 (**Setup for unconfined compression test)**

3.7 Swell test

For swell purpose the initial height (H) of specimen was determined in mm. A dial gauge was mounted the on the edge of the mould and the initial dial gauge reading (L) recorded. The final reading of the dial gauge at the end of soaking period (K) was also recorded.

Calculations for Swelling

$(S) = (K - L) * F * 100 / (H)$

Where

S = swell expressed as a percentage of the height of the moulded material before soaking

K = dial gauge reading after soaking

L = dial gauge reading before soaking

F= dial gauge reading factor

H= Initial height of specimen

Fig.-5 (Setup for Swelling test)

CHAPTER 4

RESULTS, DATA ANALYSIS AND DISCUSSION

4.1 Results and data analysis

4.1.1 Sieve Analysis

Dry and Wet Sieve Analysis of the soil was performed in accordance with IS 2720 (Part 4)-1985 and were classified in accordance with IS 1498-1970.

Table 4.1 Classification of soil

Sieve No	75micron
Wt. of Soil retained above (W_1)	327gm
Wt. of Soil that passed (W_2)	673 gm

% of mass passing = $W_2/(W_1 + W_2)$

= 67.3 %

- Since percent of passing is more than 50% so it can be classified as Fine soil according to IS:1498-1970.

4.1.2 Liquid Limits

The Liquid Limit (LL) of the samples were determined and plotted against the Ultra Fine Slag content.The liquid limit of untreated soil was determined as 65% whereas it varied between 63.4% to 75.43% after ultra fine slag was added. The liquid limit of the soil decreases with increase in ultra fine slag content up to 6% after that it goes on increasing with increase in ultra fine slag content. Thus the optimum ultra fine slag content is between 6-9%for maximum effect on liquid limit.

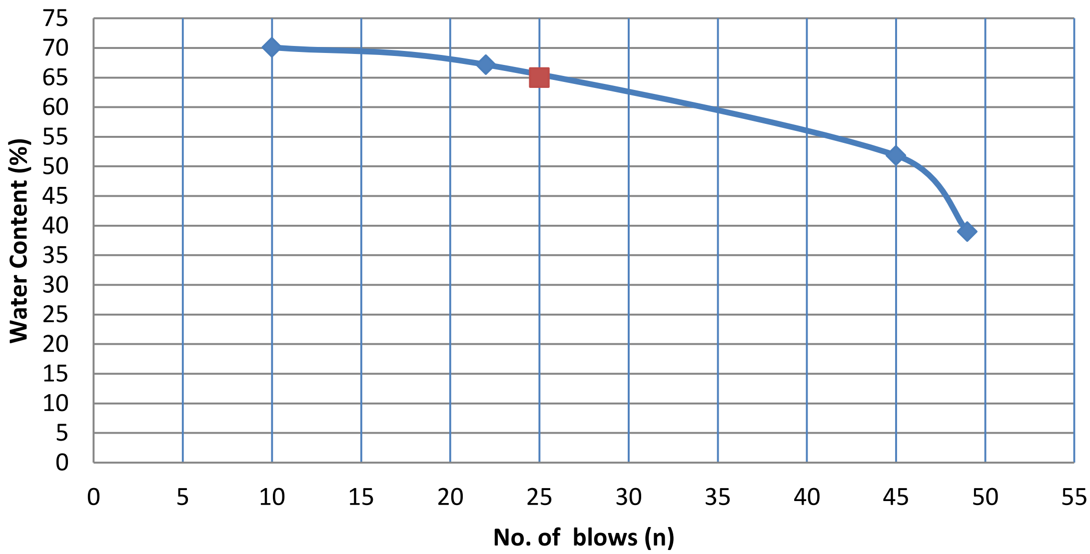

Fig No- 6

RESULT:- From the graph we obtained the liquid limit corresponding to 25 blows.
Liquid limit is = 65%

4.2 Plastic limit of Original clay Sample

Table 4.2

Container No.	1	2
Wt. of container, W_1(gm)	19.35	19.60
Wt of container +Wet soil ,W_2 (gm)	20.67	22.45
Wt of container +dry soil sample ,W_3 (gm)	20.25	21.60
Water content (%)= $\{(W_2-W_3)/(W_3-W_1)\}*100$	46.67	42.5

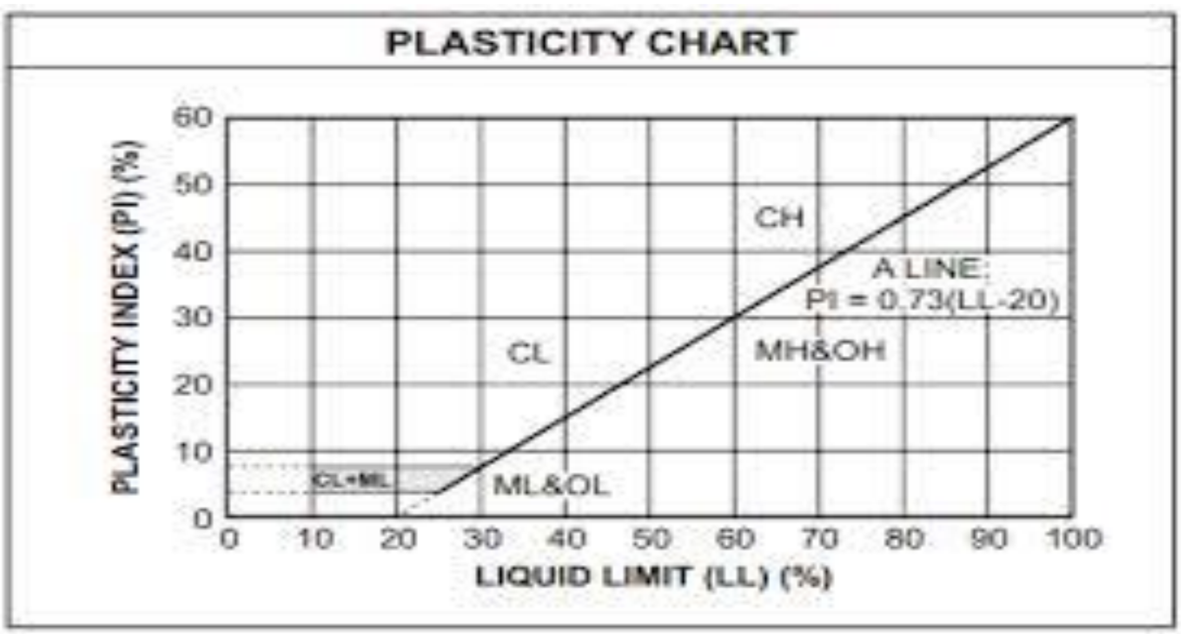

Fig. 7

PLASTIC LIMIT of the Black cotton soil comes out to be 44.58

PLASTICITY INDEX = Liquid Limit –Plastic limit =20.42

- As per the plasticity chart we obtained that the soil is below A- line and also the soil has high swelling characteristics.
- Oven dried method is used to distinguish between organic and inorganic soil. If the liquid limit of the soil decreases by 30% or more, it is classified as organic soil otherwise inorganic. So after oven drying the liquid limit decreases from 65% to 33% .
- Conclusion: soil can be classified as **organic clay of high plasticity(OH)**.

Table 4.3 Relationship between swelling potential and plastic index by Peck Hanson and Thornburn (1974) [3]

Swelling Potential	**Plasticity index percentage (%)**
Low	0-10
Medium	10-20
High	20-35
Very High	35 and above

- As it can be concluded from our calculation that black cotton soil has the high swelling potential because plasticity limit comes out to be in the range of 20-35.

4.1.3 TESTS AFTER ADDING ULTRA FINE SLAG

Liquid limit after adding 3% (w/w) Ultra Fine Slag

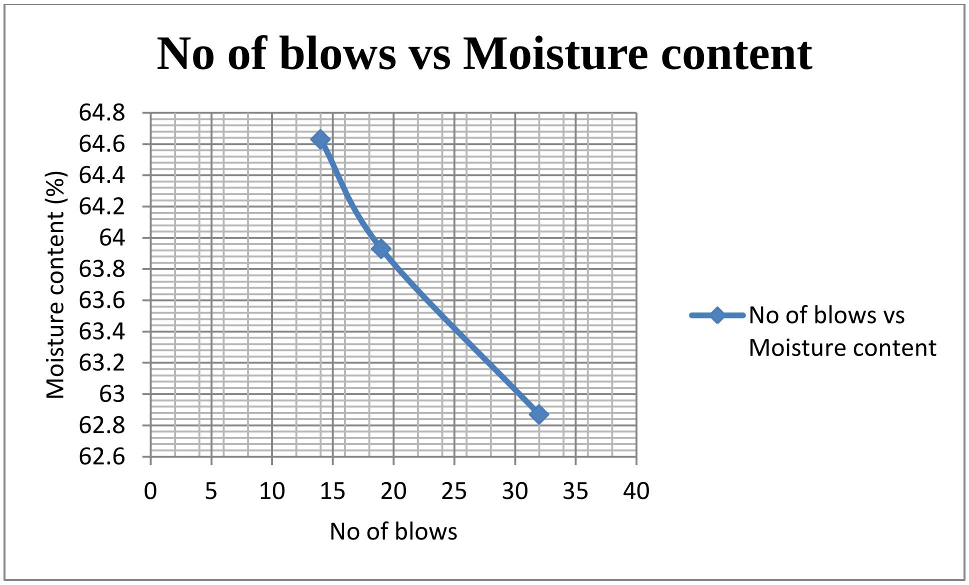

Fig. 8

Liquid limit with 6% (w/w) Ultra fine slag

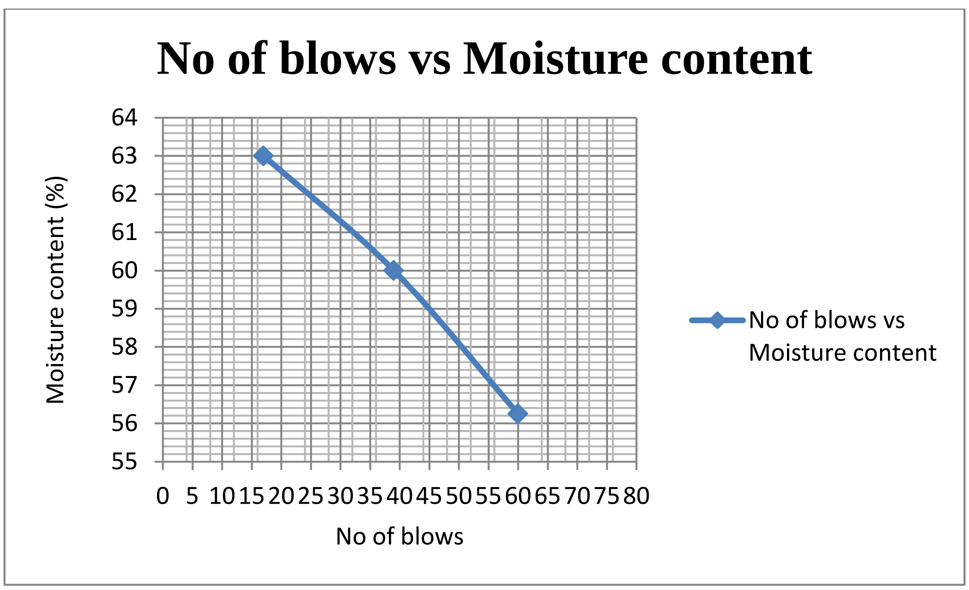

Fig.9

Liquid limit with 9% (w/w) Ultra fine slag

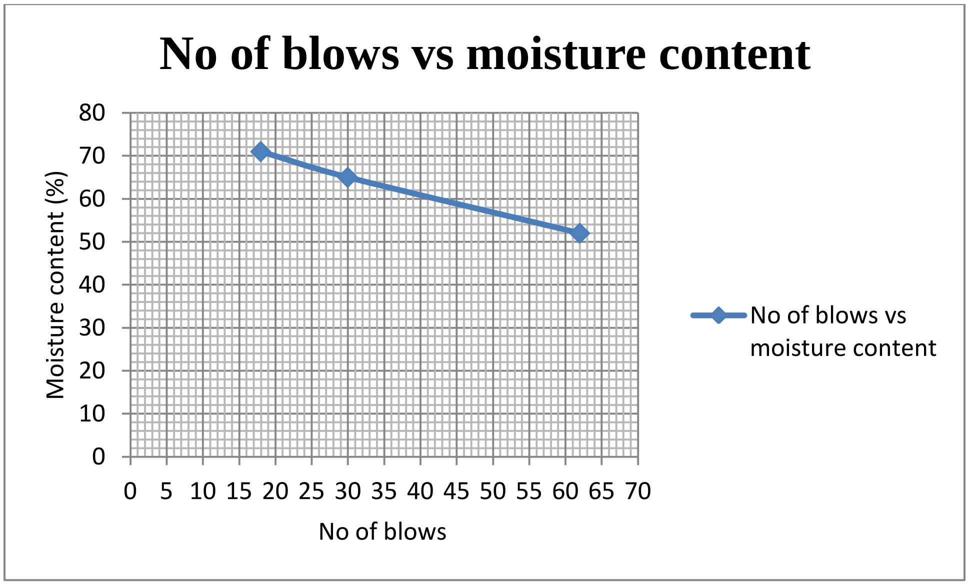

Fig. 10

Liquid limit with 12% (w/w) Ultra fine slag

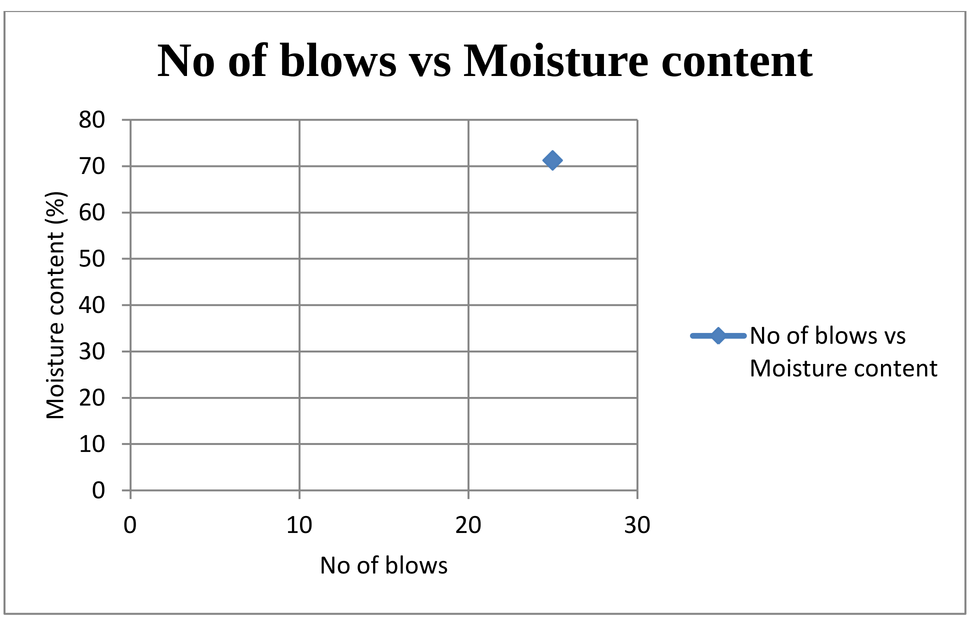

Fig. 11

Liquid limit with 15% (w/w) Ultra fine slag

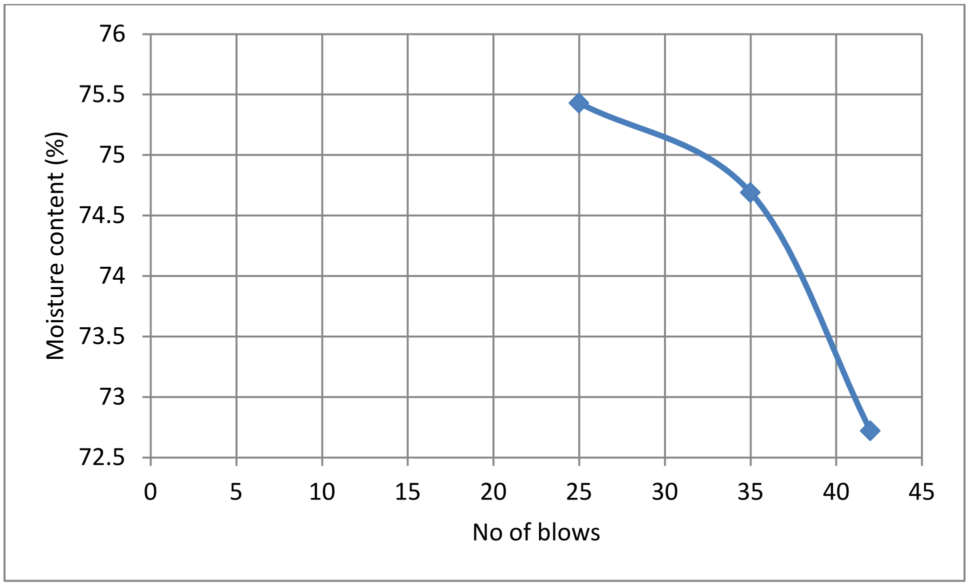

Fig. 12

Table 4.4 Variation of liquid limit with ultra fine slag

Slag Content %(w/w)	Liquid limit
3	63.4%
6	62%
9	66.5%
12	71.25%
15	75.43%

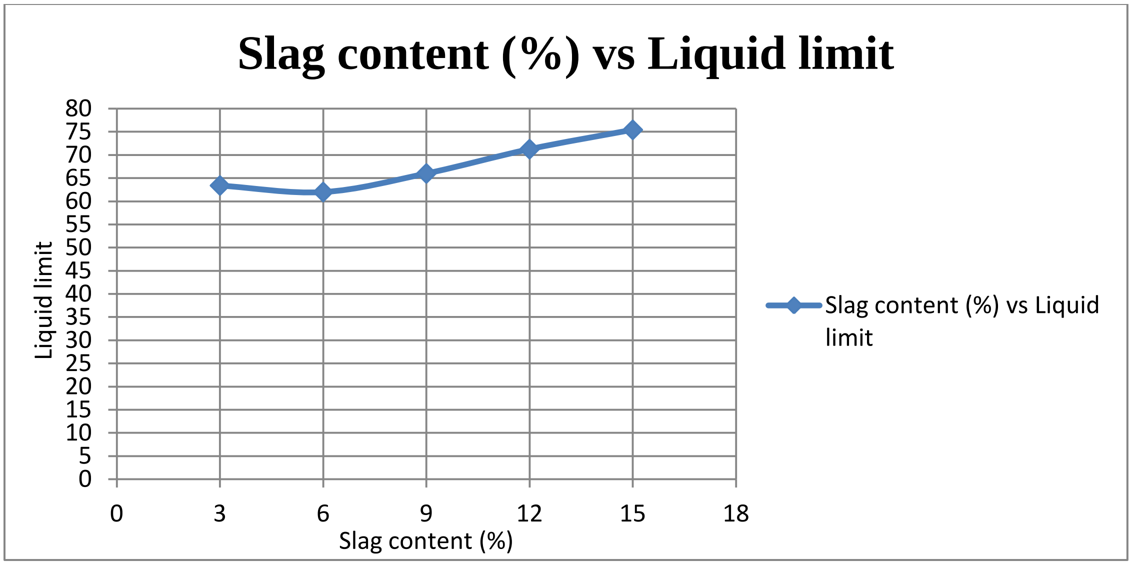

Fig. 13

Liquid limit: The liquid limit decreases with the addition of Ultra fine slag. The results show a considerable decrease in the liquid limit up to 6% Ultra fine slag content increase and then after the decrease is observed to be marginal for further increase of slag content to 15%. The liquid limit of the black cotton soils is essentially controlled by the thickness of the diffused double layer and the shearing resistance at particle level. The addition of Ultra fine slag results in the decrease of liquid limit due to the effect of reduction in the diffused double layer thickness as well as due to the effect of dilution of clay content of the mix. The decrease of liquid limit becomes very marginal at 6% ultra fine slag content of due to the increased dilution effect i.e. due to the increased percentage of coarser size particles in the mix because of the increased percentage of Ultra fine slag.

In some cases addition of slag may result in an increase in liquid limit. The increase in the liquid limit of the soil may be attributed to prolonged equilibrium of the slag–soil mixture which results in formation of more flocculated particle arrangement. Possibly, the water has been entrapped in the large void spaces of the flocculated structure of the soil fabric, thereby showing increase in liquid limit

4.2.1 Variation of plastic limit after adding ultra fine slag

Table 4.5

Slag content % (w/w)	Plastic Limit
3	**47.46%**
6	**50.94%**
9	**48.44%**
12	**47.4%**
15	**45.2%**

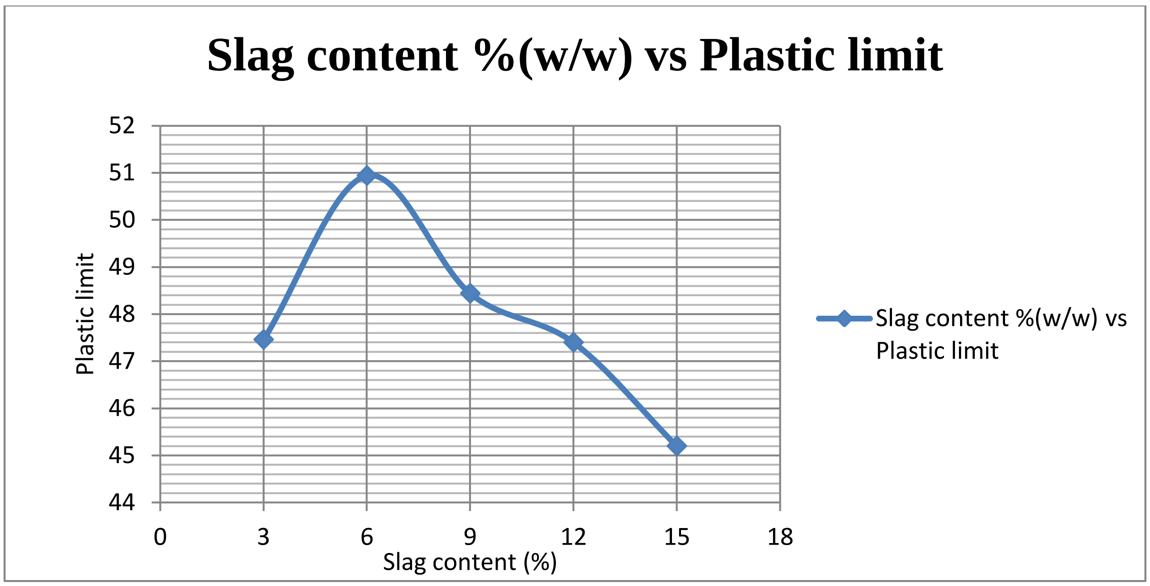

Fig.14

Plastic Limit: The addition of Ultra fine slag results in a steady increase in the plastic limit of the soils. Immediately on addition of 3% slag, the plastic limit of black cotton soil increases from 44.58% to 47.46%. The plastic limit increases to 50.94% for the soil with 6% slag content.

The increase in plastic limit is due to decrease in diffused double layer thickness of clay particles and flocculation owing to the presence of free lime in the slag. Decrease in diffused double layer leads to increase in shearing resistance. The soil fabric varies with changes in exchangeable cation and cement concentration. The pores vary depending upon the particles arrangement, size and shape. Thus the flocculated structure will have higher plastic limit .

4.3 Standard Proctor Test

The Standard Proctor test was performed on black cotton soil and the result was plotted on graph between dry density and water content.

Result -The optimum moisture content comes out to be 18.75%

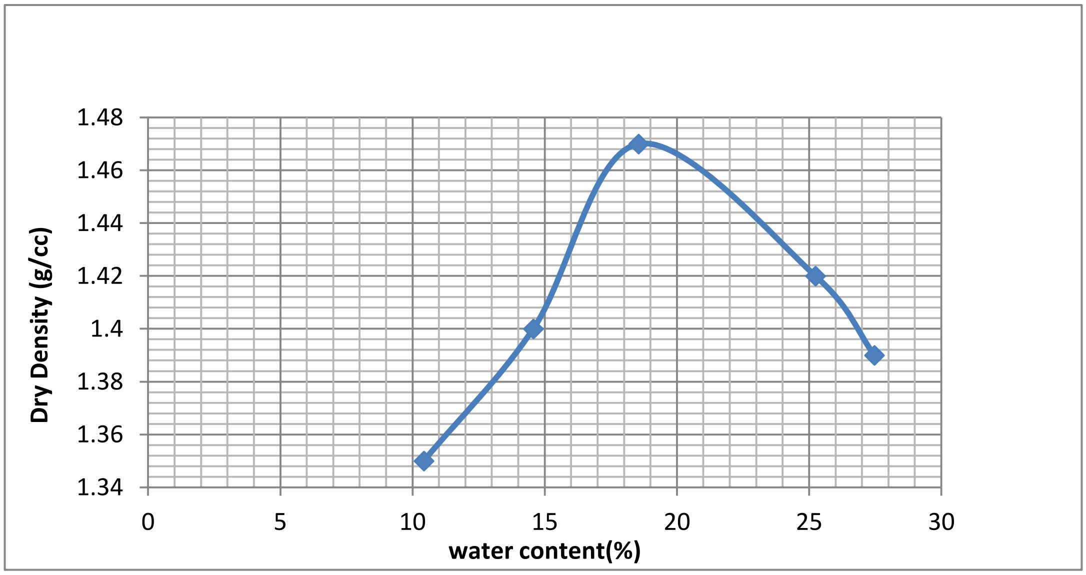

Fig.15

Standard Proctor Tests results after adding Ultra Fine Slag

4.3.1 Variation of O.M.C with slag (%)

Table 4.6

Slag %	O.M.C
0	18.75
3	18.65
6	18.40
9	18.15
12	17.72
15	17.45

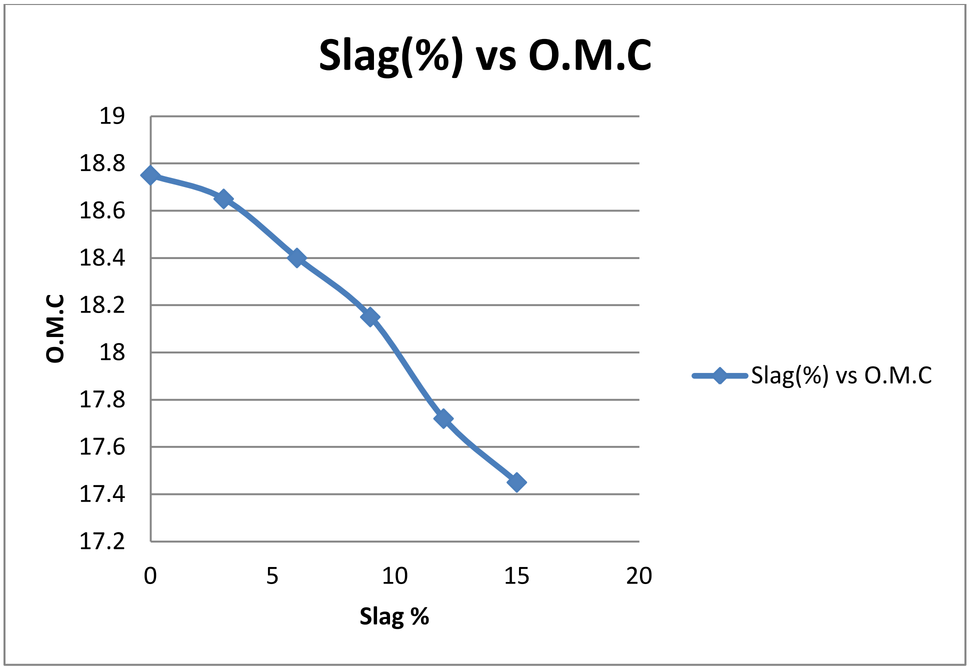

Fig.16

- With increase in slag content, optimum moisture content decreases.

4.3.2 Variation of Maximum Dry Density vs Slag %

Table 4.7

Slag (%)	Dry density(g/cc)
0	1.47
3	1.53
6	1.55
9	1.59
12	1.64
15	1.67

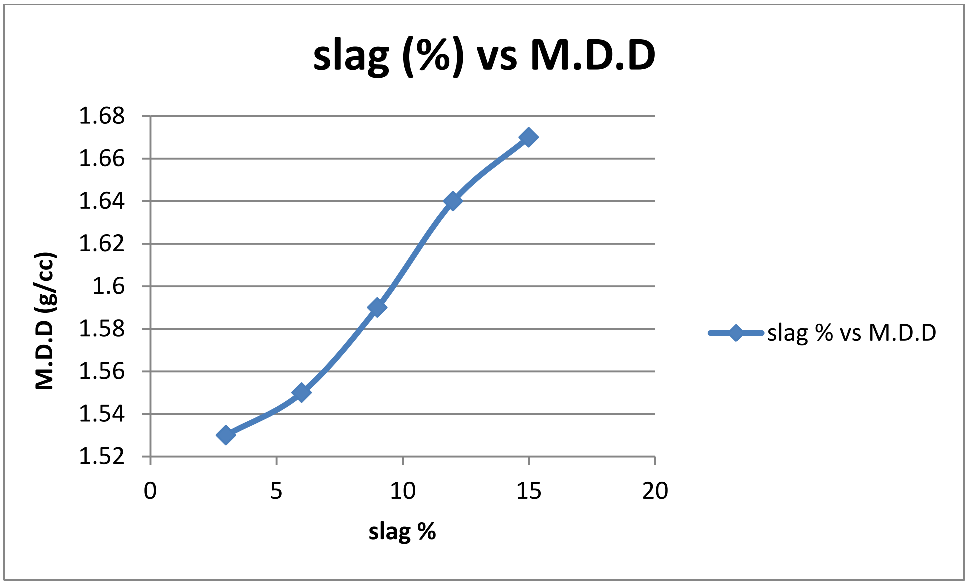

Fig. 17

- With increase in percent of slag content, Maximum dry density is also increasing.

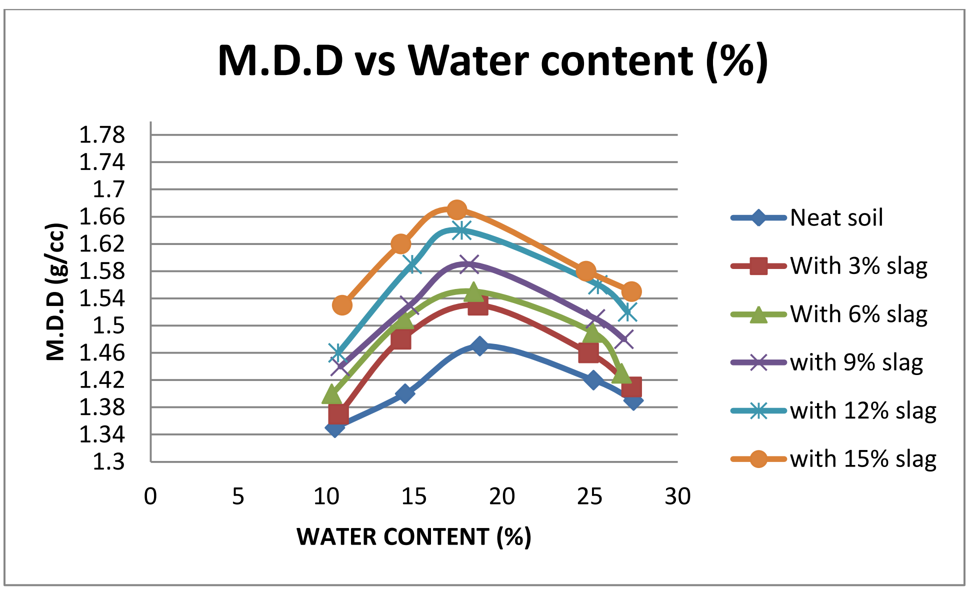

Fig. 18

- From above graph we can conclude that with increase in slag content O.M.C. is decreasing and Maximum dry density is increasing.

The variation of maximum dry unit weight with Ultra fine slag content in soil mixtures is presented in fig. It is observed that with the increase in water content the dry density also increases up to 15% moisture content and with further increase in water content the dry density Increases gradually. Hence the addition of Ultra fine slag to black cotton soil in various percentages affects the compaction characteristic which is primarily due to alteration of gradation of soil mixtures. The increase of the maximum dry unit weight with the increase of the percentage of Ultra fine slag is mainly due to the higher specific gravity of the fine Ultra fine slag compared with expansive soil and the immediate formation of cemented products by hydration which increases the density of soil. It can also be observed that the optimum moisture content was decreased with further increase in Ultra fine slag content. The lowest dry density was observed to be about 1.53g/cc for 3% Ultra fine slag mixture and highest dry density was about 1.67g/cc. for 15% Ultra fine slag mixture. There is enhanced C-S-H formation as compared to use of soil alone. This enhanced C-S-H occupies pore spaces, normally occupied by calcium hydroxide in the hydration of pozzolanic reaction taking place in mixtures which uses the excess SiO from the slag source, Ca (OH) produced by the hydration of the silicates, and water to produces more of the desirable CSH making slag a beneficial mineral admixture to attain increase in strength. This leads to reduced porosity and permeability of GGBS hydrates compared to fly ash hydrates. The reduced porosity and permeability reduce the volume of voids and this, together with the resultant stronger structure, provide resistance to damage. Ultra fine slag has a low reactive potential. Its hydraulic reactivity depends on chemical composition, glass phase content, particle size distribution and surface morphology.

4.4 California Bearing Ratio Results

Unsoaked CBR test result: The following results are obtained for soaked condition are

Load value at 2.5mm penetration = 95.49 kg

$$\text{CBR \%} = \frac{\text{load sustained by specimen at 2.5mm penetration}}{\text{load sustained by standard aggregate at corresponding penetration level}}$$

$$= \frac{95.49\ X\ 100}{1370} = 6.97\ \%$$

Soaked CBR test result: The following results are obtained for soaked condition are ;

Load value at 2.5mm penetration= 39.46 kg

$$\text{CBR \%} = \frac{\text{load sustained by specimen at 2.5mm penetration}}{\text{load sustained by standard aggregate at corresponding penetration level}}$$

$$= \frac{39.46\ X\ 100}{1370} = 2.88\ \%$$

CALIFORNIA TEST RESULTS AFTER ADDING ULTRA FINE SLAG

4.4.1 Variation of C.B.R with ultra fine slag

Table 4.8

SLAG (%)	CBR (UNSOAKED)	CBR (SOAKED)
0	6.97	2.88
3	11.63	3.10
6	20.86	3.86
9	7.2	3.20
12	7.71	2.62
15	8.0	2.27

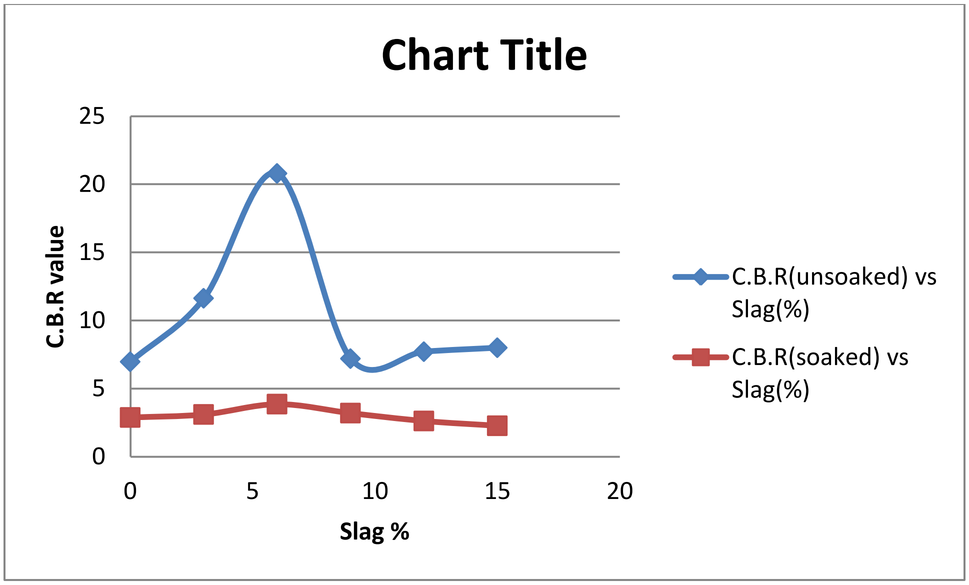

Fig 19

With following results it is observed that, the low CBR of untreated black cotton soil as compared to the black cotton soil-slag mixes is attributed to its inherent low strength which is due to the dominance of the clay fraction. Addition of ultra fine slag to the black cotton soil increases gradually the CBR of the mix up to a peak value of addition of 6% of ultra fine slag. This is due to the frictional resistance contributed from the ultra fine slag in addition to the cohesion from the black cotton soil. Further increase in the ultra fine slag to 9% causes a reduction in the CBR due to the reduction in the cohesion because of the decreasing black cotton soil content in spite of increase in strength due to increase in ultra fine slag content. It is hence observed that, a suitable mix proportion of 6% ultra fine slag content optimizes the frictional contribution of ultra fine slag and the cohesive contribution from black cotton soils; leading to the maximization (peak value) of the CBR. The relatively low unit weight of ultra fine slag makes it well suited for placement over soft or low bearing strength soils. Its low specific gravity, freely draining nature, ease of compaction, insensitiveness to changes in moisture content, good frictional properties, etc. can be gainfully exploited in the construction of embankments, roads, reclamation of low-lying areas, etc

4.5 UNCONFINED COMPRESSION TEST:

Fig. 20

The following the result of unconfined compression test are

Failure load (P) = 30 kg

Dia. of the specimen = 3.8 cm

Area of the specimen (A_1) = 11.34 cm2

Change in length in specimen at failure = 1cm

Area of failure (A_2) $= \frac{A1}{1-\frac{\Delta l}{l}}$ cm^2

Failure stress = P/A = 1.95 kg/cm^2

Shear strength (Cu) = 0.975 kg/cm^2

UNCONFINED COMPRESSION TEST RESULTS AFTER ADDING ULTRA FINE SLAG

4.5.1 Variation of U.C.S. after adding ultra fine slag

Table 4.9

SLAG%	U.C.S
0	1.95
3	3.90
6	5.01
9	4.90
12	4.30
15	5.65

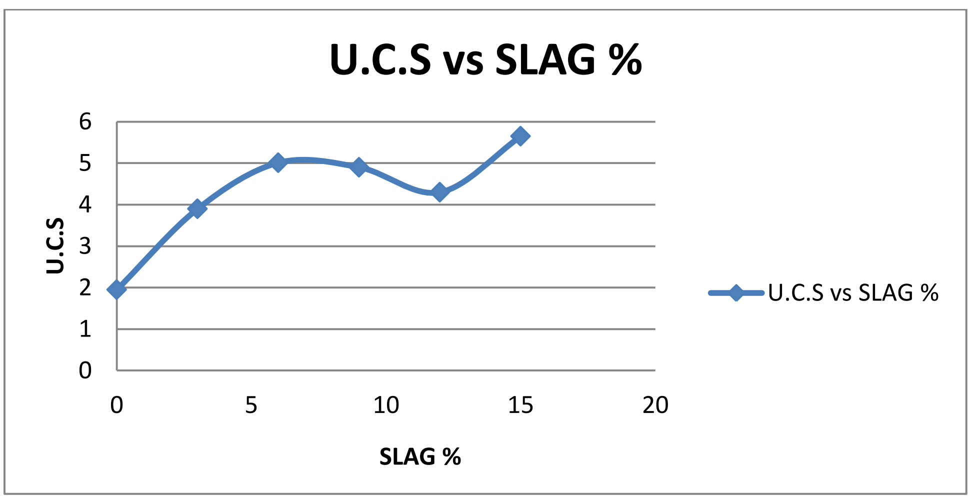

Fig.21

The variation of the unconfined compressive strength test with ultra fine slag content for different curing periods has been shown in the Fig. From the figure it can be seen that the unconfined compressive strength (UCS) of BC soil increases with the addition of small amount of about ultra fine slag which remains constant up about 6% addition of ultra fine slag. With further addition of ultra fine slag the UCS decreases continuously and reaches lowest value with the addition of 12% of ultra fine slag.

The variations in strength can be explained by the following factors:

1. Reduction in cohesion of the soil due to addition of coarser materials
2. Increase in strength of soil due to cementation by pozzolanic compounds produced
3. The effect of compaction parameters as the soil ultra fine slag mixtures are compacted to their respective optimum conditions.
4. Occupation of ultra fine slag particles by finer soil particles.

The reduction in cohesion of soil is least with the addition of 3% of ultra fine slag because of soil particle cohesion is disturbance is minimum which however increases with increasing ultra fine slag content. With increase in ultra fine slag content the available pozzolanic material i.e. ultra fine slag increases but the available water for pozzolanic reactions becomes less due to decrease water content. Further the moulding densities are also lower with increasing GGBS content. With ultra fine slag content higher than 6% all the effect of decreased moulding water content and density dominate and the strength decrease. Thus the effect of pozzolanic reactions is nullified by lower densities and water contents.

4.6 FREE SWELL TEST :

Table 4.10

INITIAL DIAL GAUGE READING K	FINAL DIAL GAUGE READING L	DIAL GAUGE FACTOR (mm) F	HEIGHT OF SPECIMEN (mm)	FREE SWELL (%)
0	60	0.2	210	5.7
0	62	0.2	210	5.9
0	59	0.2	210	5.6

$$s = \frac{(K - L) \times F \times 100}{H}$$

- From above results, the average swell of soil as percentage of the height of the moulded material before soaking is 5.73 %.

SWELLING PRESSURE RESULTS AFTER ADDING ULTRA FINE SLAG

4.6.1 Variation of swelling pressure with slag %

Table 4.11

SLAG %	Free swell (%)
0	5.73
3	4.96
6	3.20
9	2.80
12	2.2
15	2.03

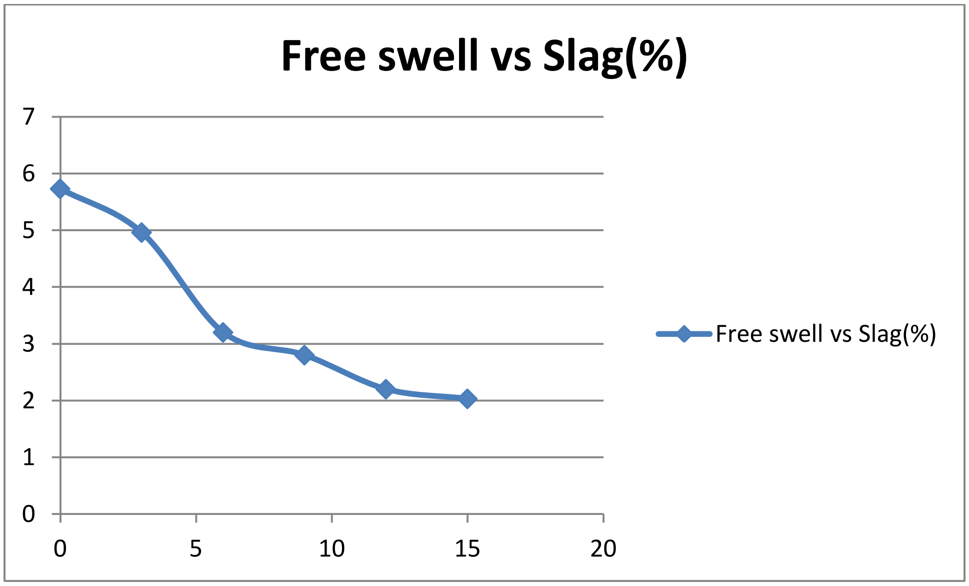

Fig 22

The swell potential of the samples follow a steady decrease with the addition of ultra fine slag in increasing percentages. When ultra fine slag is added to expansive clays in presence of water, two important reactions take place: one is flocculation and the other is cementation. The decrease is mainly due to the flocculation of clay particles caused by the free lime present in ultra fine slag resulting in the reduction of friction between the particles. The second reaction taking place upon the addition of cement is cementation. As an effect of this reaction, cementitious products in the form of calcium alumino-silicates develop in the blend. Stabilizing agents like ultra fine slag reacts with reactive silica present in the fly ash to produce cementitious bonds that help in arresting swell.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The problems associated with black cotton soil in pavement construction have been identified to arise out of water saturation as well as design based problems. The road surfacing must be impervious, side berms paved and sub grade well treated to check capillary rise of water. Ultra fine slag stabilization reduces permeability, helps keep moisture out and maintains high level of strength and stiffness even when saturated. An approach to the design problem can be in having semi rigid sub-base or the CBR value of the BC soil being used as subgrade is improved by giving asuitable treatment with the appropriate technology.

It was also establish that cement can be used as an effective stabilizer for improving the geotechnical characteristics of black cotton soils for use in sub-grades or sub-base layers. The BC soil parameters are seen to have improved i.e. decreased plasticity, volume change and increased bearing strength of the BC soils.

Addition of Ultra fine slag significantly improves the index properties of soil. Plasticity index is one of the important criteria for selection of soil as construction material. The relative decrease in the plasticity index of the soils is a favorable change since it increases the workability of these soils.The decrease in linear shrinkage of the soils with the addition of cement facilitates in checking the volume change behavior of the soils over a large variation in the moisture content as the season changes.

California bearing ratio of the study soil increases gradually with the addition of ultra fine slag. The improvement in the California bearing ratio value of the black cotton soil upon the addition of ultra fine slag suggests that cement can be effectively used in bulk as sub-grade material in combination with the study soils, for the road construction works. The increase in CBR values indicates an increase the bearing strength. Bearing strength provides a stable working platform on which pavement layers may be constructed.

The decrease in linear shrinkage and swell of the black cotton soil with addition of ultra fine slag shows that ultra fine slag reduces the heaving potential of the soil. Stabilizing expansive soils with admixtures like ultra fine slag has been found to be effective but uniform blending of large quantities of soils with admixtures is difficult.

The study of variations of different parameters viz. liquid limit, plastic limit, plasticity index, shrinkage limit, maximum dry density, optimum moisture content, swell and California bearing ratio with the addition of ultra fine slag suggest that the effects of slag treatment vary depending upon the quantity of ultra fine slag that is mixed with the black cotton soil and therefore for each parameter of the study soil samples, there exists an optimum ultra fine slag percentage for mixing with the soil under consideration; at which the respective parameter attains its most desirable value from geotechnical point of view.

Ultra fine slag soil stabilization technology has been found useful, cost-effective and suited to manual methods of construction

5.2 RECOMMENDATIONS

The use of ultra fine slag should be embraced in the construction industry as an alternative method of stabilizing weak subgrades. The ultra fine slag treatment can be utilized for the following purposes:

- To overcome the susceptibility of foundations to volume change and to increase their shearing resistance and bearing capacity
- To consolidate sub grades and base courses for concrete pavement in order to make them resistant to volume changes and displacement or erosion in the presence of moisture even under the rocking action of curled slabs, if any.
- To provide a pavement foundation of marginally weaker in strength than that of concrete pavement, but much improved strength than natural Black cotton soil.

There is a possibility of using industrial wastes such as fly ash which pose problems when it comes to their disposal in geotechnical applications such as arresting heave in black cotton soils.This study was limited in scope and hence further research should be done to establish the additives to cement that could be used to lower the percentage of ultra fine slag required without compromising on the strength.

5.3 PURPOSE AND SCOPE OF THE STUDY

There are ways of keeping expansive soils from either expanding or shrinking too much when used as a subgrade. These help minimize the problems associated with black cotton soil. The challenges of construction on clay were carried out and their effect on the pavement looked into. Ultra fine slag will be used for its suitability to improve the properties of black cotton soil and use this soil as a foundation material for pavement subgrade construction and foundation design. The data is analyzed so as to obtain the best design for the local conditions.

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