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AN EXPERIMENTAL INVESTIGATION TO STUDY THE EFFECT OF GGBS ADDITION ON THE INDEX PROPERTIES OF CLAYEY SOIL

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ABSRACT

The by-product of iron obtained from the blast furnace is referred to as ground granulated blast furnace slag (GGBS). Its major composition is silicate and aluminosilicate of melted calcium which gets frequently extracted of blast furnace. Each year, approximately ten to twenty mega tonnes of GGBS is manufactured industrially. If such a huge quantity of GGBS is not utilized or disposed properly, it can cause pollution by degrading the environment. From past researches, GGBS is well known to have good binding properties due to which when GGBS is mixed with soil, it transmits cementitious behaviour along with soil. It behaves like soil stabilizing agent and improves soil properties. The properties of ground granulated blast furnace slag are very much similar to that of cement. Hence, GGBS is well utilized nowadays as an alternative in place of cement. Since GGBS is a waste by-product, its use in construction is economical and reduces the threat to environment pollution. In this research, the optimum dosage of ground granulated blast furnace slag (GGBS) was mixed with clayey soil to make the soil stable and suitable for construction purpose and to improve the soil strength considerably. The maximum dry density, optimum moisture content, liquid limit, plastic limit and plasticity index at varying percentages of GGBS (0%, 8%, 12%, 16% and 20%) addition in the clayey soil were examined. The maximum dry density and the corresponding optimum moisture content for the virgin clayey soil are found equal to 16.43kN/m^3 and 18% respectively. The maximum dry density and the corresponding optimum moisture content for the clayey soil containing 16% GGBS mixture are found equal to 17.42kN/m^3 and 24% respectively.

Keywords: Ground granulated blast furnace slag (GGBS), maximum dry density (MDD), optimum moisture content (OMC), liquid limit, plastic limit, plasticity index.

INTRODUCTION

The properties of the clayey soil used for the investigation were obtained by performing experiments. Ground granulated blast furnace slag (GGBS) was used in the experimentation to stabilize and enhance the soil properties and to improve the soil strength effectively. Multiple experiments were performed on the virgin clayey soil and clayey soil mixed with varying percentages of GGBS (8, 12, 16 and 20%) to find out it's index properties such as liquid limit, plastic limit and plasticity index, optimum moisture content (OMC) and maximum dry density (MDD).

ALKALI ACTIVATOR

The alkali activator is used to enhance GGBS reaction and for early strength gain of GGBS. To prepare a 10 Molar Alkali Activator solution, 400 gram of Sodium Hydroxide (NaOH) is added to 1 Litre water and mixed thoroughly to attain a uniform consistency solution. This Sodium Hydroxide solution prepared is then mixed with Sodium Silicate in the ratio 1:2.5.

LITERATURE REVIEW

Darisi et al., (2021)performed experimental investigation on improvement in the engineering properties of expansive soil (black cotton soil) stabilized with ground granulated blast furnace slag (GGBS) and lime as soil stabilizers. A decrease was observed in liquid and plastic limit and the plasticity index also reduced respectively after soil stabilization using GGBS plus lime. It was found that the optimum moisture content (OMC) of black cotton soil was reduced by 41.17% and the maximum dry density (MDD) improved by 9.9%. It was noticed that the optimum proportion of lime and GGBS was equal to lime (6%) plus GGBS (10%) when used in combination. Soaked and un-soaked compression bearing ratio (CBR) of the soil plus lime (6%) plus GGBS (10%) in combination showed an increment of 9.02% and 8% accordingly. The unconfined compressive strength (UCS) of soil plus lime (6%) plus GGBS (10%) in combination improved by 84.16%. It was hence concluded that the lime and GGBS in combination at optimum dosage can be used to stabilize expansive soil effectively.

Chowdhury & Patra, (2021)performed numerical investigation on the settlement behaviour of circular footing on pond ash bed imposed by combined static and cyclic loading and studied the effect of geogrid layers(single and double), geocell with geogrid layer and geocell layer on the settlement behaviour of circular footing. PLAXIS 2D software was used for the investigation. With and without water table were the two conditions considered. It was observed that for the geogrid layers reinforcement, maximum settlement reduction noted was 27 to 49.7% as compared to unreinforced case. For the single layer geocell reinforcement, maximum settlement reduction observed was 27.4 to 33.5% as compared to unreinforced case. For the geocell-geogrid reinforcement, maximum settlement reduction observed was 35.4 to 61% as compared to unreinforced case. The lowest settlement was noticed at an optimum spacing of 0.18d between geocell and geogrid layer (where, d= diameter of circular footing). The top geocell layer's optimal depth observed was 0.1d and optimal width of geocell and geogrid layer observed was 3.2d and 4.1d respectively. It was hence concluded in the investigation that the geocell-geogrid reinforcement gave better result than other reinforcement combinations.

Useche-Infante et al., (2019)examined bearing capacity response of circular footing placed over sand reinforced with geogrid. For the investigation, some of the parameters taken into consideration were first geogrid reinforcement depth, vertical spacing in between geogrid reinforcement layers, geogrid diameter and number of geogrid layers. It was found that, for single geogrid layer ($N = 1$), the optimum depth for geogrid placement was between 0.25B to 0.40B i.e. ($0.25 < u/B < 0.40$) where, u equals to depth of first geogrid layer and B equals to footing diameter. For two geogrid layers arrangement ($N = 2$), the optimum depth for second geogrid layer reinforcement was $h = 0.25B$ taken from beneath the first geogrid reinforcement vertically. Optimal diameter for geogrid reinforcement was found as 3 to 5 times of circular foundation's diameter. It was observed that at three number of geogrid reinforcement layers, the optimal value of bearing capacity ratio was noted. It was hence concluded that geogrid used as reinforcement layers in sand beds effected in significant improvement of load settlement response.

Thomas et al., (2018)studied the effect of alkali-activated ground granulated blast furnace slag (GGBS) and enzyme as compared to ordinary portland cement (OPC) on the geotechnical characteristics of soil through atterberg limits, shear strength test, compaction test and unconfined compression test. It was concluded that increase in stabilizer dosage caused an increase in OMC and decrease in MDD. It was seen that the treated soil's cohesion increased significantly. The alkali (1M NaOH solution) activated GGBS stabilized soil's (UCS) unconfined compressive strength and shear strength parameters gave better results as compared to OPC stabilized soil. UCS of alkali activated GGBS stabilized soil was 1.15 times compared to OPC stabilized soil and it was 5.5 times compared to enzyme stabilized soil. Hence, it was concluded that alkali activated GGBS is more efficient than enzyme in increasing strength for the selected soil.

METHODOLOGY

Table 1: TESTS PERFORMED

S. No.	Soil Characteristic/ Arrangement	Tests Performed	No. of Tests Performed
1.	Virgin Soil (Soil + 0%GGBS)	LL, PL, (MDD & OMC), Sp. Gravity	4
2.	Soil + 8% GGBS	LL, PL, (MDD & OMC)	3
3.	Soil + 12% GGBS	LL, PL, (MDD & OMC)	3
4.	Soil + 16% GGBS (optimum)	LL, PL, (MDD & OMC) & Sp. Gravity	4
5.	Soil + 20% GGBS	LL, PL, (MDD & OMC)	3

TEST PROCEDURES

Proctor Test (OMC and MDD)

Take a suitable amount of representative soil and crush it with a rubber mallet after allowing it to air dry. Sieve the soil using No. 4 sieve and remove the coarser particles. Take approximately 3 kilograms of soil and add water to bring its initial water content to 10% (preferable) for fine grained soil and blend the mixture thoroughly. After cleaning the mold, measure the diameter, height and weigh the mold without the collar. The cylindrical mold's internal diameter is 100 mm and the mold has a detachable base plate and a collar of 2 inches. Mass of the rammer is 2.5 Kg and has a fall of 12 inches (30.5 cm), and has a flat circular face of 2 inches diameter. Attach the collar and use the rammer to compact the moistened soil into three equal layers with uniformly distributed blows given in each layer. 25 number of blows are applied to each layer with the rammer. After compacting the soil, the collar is removed and the extra soil over the top of mold is trimmed using straight steel edge. The outer surface of mold and base plate is cleaned and then its mass is noted. The soil is removed from mold and soil is split and then approximately 100 grams of this soil sample is taken for determining the water content. The soil lumps are broken and are mixed with the remaining soil in tray. The water content is increased by 2 % to 3 % by adding more water and the compaction procedure is repeated for each increase in water content until the compacted soil mass reduces. For each trial, the water content and the corresponding dry density is calculated. Then a compaction curve is plotted between water content (abscissa) and dry density (ordinate). After performing the proctor test on virgin clayey soil, the same procedure was repeated to perform the proctor test on clayey soil mixed with varying percentages of GGBS (8, 12, 16 and 20 %) to determine the effect of varying dosages of GGBS mixed with clayey soil on the optimum moisture content and maximum dry density. The water content corresponding to the maximum dry density (peak of the compaction curve) is known as optimum moisture content. Note down the values of maximum dry density and the corresponding optimum moisture content.

Liquid Limit Test

250 gram air dried soil is taken into evaporating dish after passing from 425 mm IS (Indian Standard) sieve. Distilled water is added in soil and mixed thoroughly so that a uniform paste is formed. (The consistency of the paste should be such that it takes 30 to 35 cup drops for causing closure of standard groove upto 12 mm length). A part of this paste is placed in Liquid Limit Device's cup and spread using few spatula strokes. At the maximum depth point, the paste is trimmed for getting a depth of 1 cm and the extra trimmed soil is returned to the dish. Take a grooving tool and along centre line of soil paste, cut a groove such that a sharp groove of exact dimension (11mm wide at top, 2 mm at bottom and 8 mm deep) is formed. The cup is lifted and dropped by revolving the crank at a speed of two revolutions per second until the two halves of soil cake combine with each other for approximately 12 mm length by flowing and not by sliding. Count the number of blows (N) and note it down. For the determination of the moisture content, a representative part of the soil is taken from the cup. The test is repeated for different moisture contents minimum three more times with blows between 10 to 40. After performing the liquid limit test on virgin clayey soil, the same procedure was repeated to perform the liquid limit test on clayey soil mixed with varying percentages of GGBS (8, 12, 16 and 20 %) to determine the effect of varying dosages of GGBS mixed with clayey soil on the liquid limit respectively.

Plastic Limit Test

20 gram of soil passing 425 micron IS sieve is taken in evaporating dish, add distilled water to it and mix it until soil gets plastic such that it gets moulded firmly by fingers. Take around 8 gram of the plastic soil prepared and roll the soil beneath the fingers on a glass plate applying a slight pressure for rolling of soil in the thread of 3 mm diameter uniform along the length of thread. The rate at which the rolling of thread should be done is eighty to ninety strokes in a minute.

Then this thread is kneed together and is then again rolled as described before. This process is repeated till thread gets crumbled on reaching a diameter of three millimetre. Pieces of crumbled thread are taken for moisture content measurement and the procedure is repeated for minimum three times. Average of these measurements is equal to the liquid limit.

PROPERTIES OF MATERIALS USED

The clayey soil used for the experimentation was oven dried for 24 hours at 100°C to 110°C and smashed using a wooden hammer and was sieved through IS (Indian Standard) sieve of 4.75 mm.

Table 2: PROPERTIES OF CLAYEY SOIL

PROPERTIES	VALUE FOR CLAYEY SOIL
Liquid Limit (%)	50
Plastic Limit (%)	24
Plasticity Index	26
OMC (%)	18
MDD (kN/m^3)	16.43
Cohesion (kN/m^2)	49.9
Angle of Internal Friction (degree)	17.9
Specific Gravity	2.51
Classification as per IS	CH

The GGBS (Ground Granulated Blast Furnace Slag) was oven dried for 24 hours at 100°C to 110°C and was sieved through IS (Indian Standard) sieve of 4.75mm. The GGBS dosages selected for experimentation are as 0, 8, 12, 16 and 20% of the soil's dry weight.

Table 3: Chemical Composition of GGBS

Element	Weight (%)
CaO	36.02
MgO	7.9
SiO_2	34.43
Al_2O_3	9.36
Fe_2O_3	0.94
Loss on Ignition	0.1

RESULTS

PROCTOR TEST (MDD & OMC)

VARIATION OF DRY DENSITY WITH WATER CONTENT (VIRGIN CLAYEY SOIL)

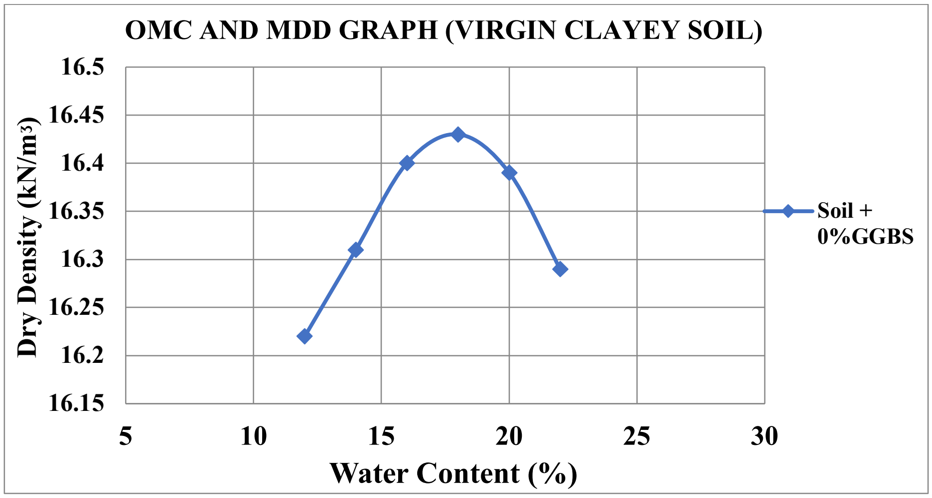

Figure 1: OMC AND MDD GRAPH (VIRGIN CLAYEY SOIL)

It can be seen from figure 1 that the maximum dry density and the corresponding optimum moisture content for the virgin clayey soil are found equal to 16.43kN/m^3 and 18% respectively from standard proctor test.

VARIATION OF DRY DENSITY WITH WATER CONTENT (SOIL + 16% GGBS)

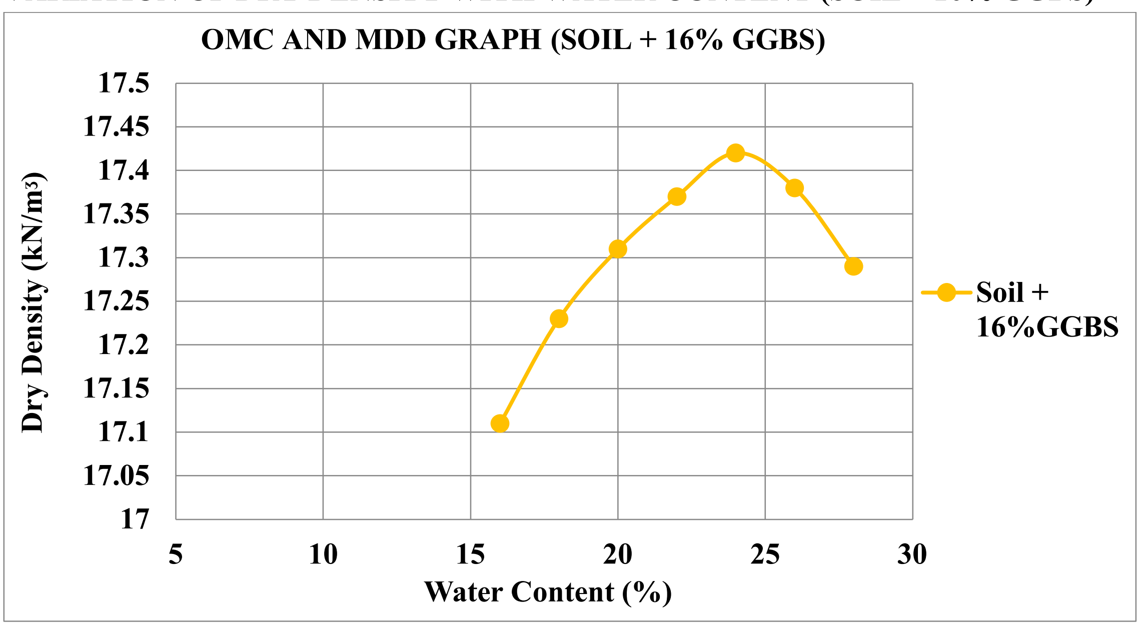

Figure 2: OMC AND MDD GRAPH (SOIL + 16% GGBS)

It can be observed from figure 2 that the maximum dry density and the corresponding optimum moisture content for the clayey soil containing 16% GGBS mixture are found equal to 17.42kN/m^3 and 24% respectively.

Table 4: OMC AND MDD VALUES FOR VARYING GGBS DOSAGE PERCENTAGES

GGBS (%)	OMC (%)	MDD (kN/m^3)
0	18	16.43

8	20	16.71
12	22	16.95
16	24	17.42
20	26	17.51

The OMC and MDD values for varying dosage percentages of GGBS are given in table 4. It was observed that as the GGBS dosage percentage in clayey soil increases from 0 to 20 percent, the maximum dry density value increases from 16.43 kN/m³ to 17.51 kN/m³ respectively and the optimum moisture content increased significantly from 18% to 26% respectively.

MAXIMUM DRY DENSITY VALUES OF CLAYEY SOIL WITH VARYING GGBS PERCENTAGES

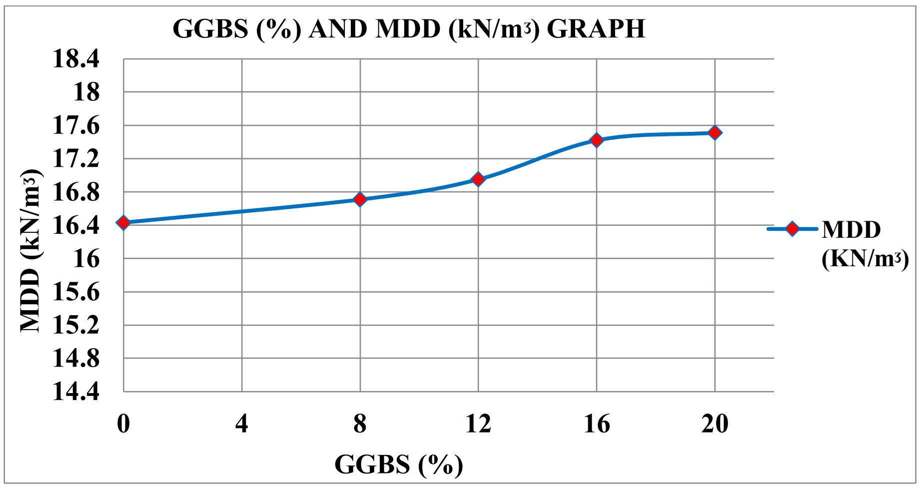

Figure 3: MAXIMUM DRY DENSITY VALUES OF CLAYEY SOIL WITH VARYING GGBS PERCENTAGES

From figure 3, it can be observed that as the GGBS percentage within the clayey soil increases from 0 to 20 percent, the maximum dry density value increases from 16.43 kN/m³ to 17.51 kN/m³ respectively.

LIQUID LIMIT TEST

LIQUID LIMIT TEST FOR VIRGIN CLAYEY SOIL

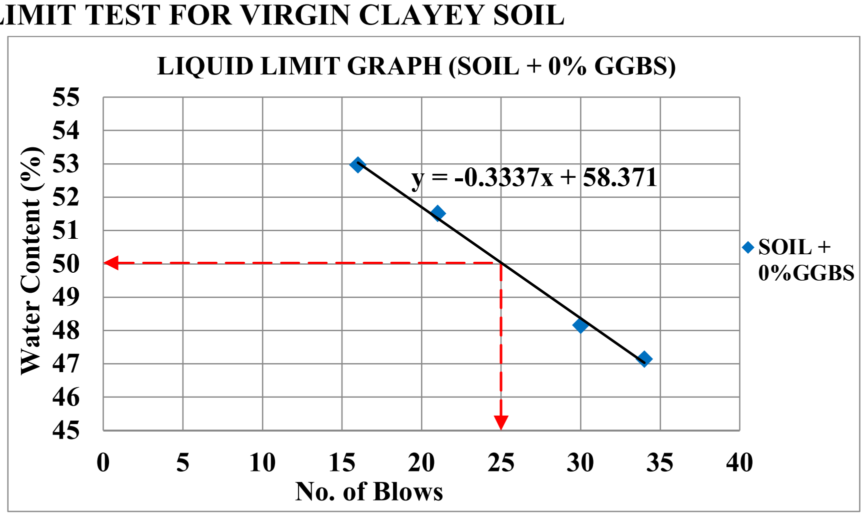

Figure 4: WATER CONTENT AND CORRESPONDING NUMBER OF BLOWS FOR VIRGIN CLAYEY SOIL

The liquid limit graph (figure 4) representing the water content and the corresponding number of blows for the virgin clayey soil shows that at 25 number of blows, the corresponding water content (Liquid Limit) was found equal to 50 %.

LIQUID LIMIT TEST FOR CLAYEY SOIL WITH 16% GGBS

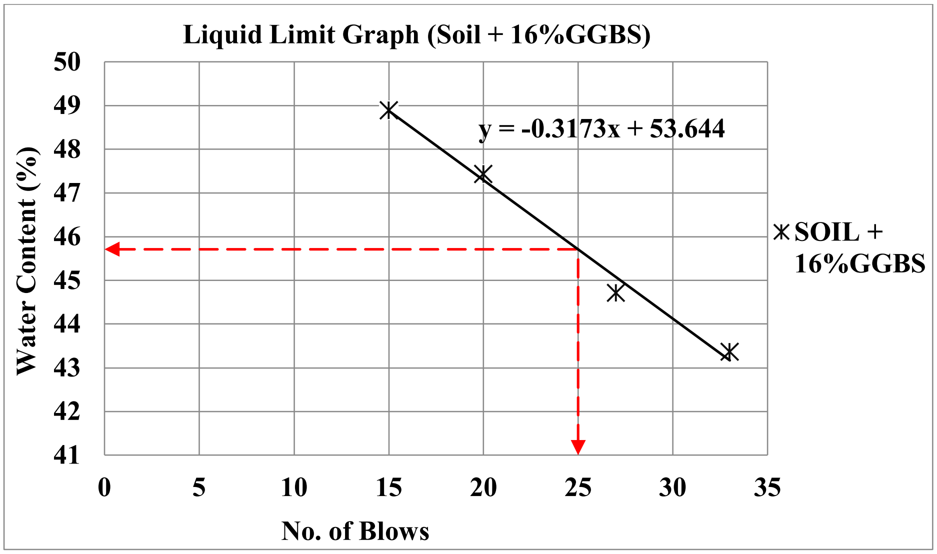

Figure 5: WATER CONTENT AND CORRESPONDING NUMBER OF BLOWS FOR CLAYEY SOIL WITH 16% GGBS

The water content and the corresponding number of blows for clayey soil with 16% GGBS are shown in the liquid limit graph in figure 5. The water content (Liquid Limit) corresponding to 25 number of blows was found equal to 46 % for the case of clayey soil with 16% GGBS.

COMBINED GRAPH OF LIQUID LIMIT, PLASTIC LIMIT AND PLASTICITY INDEX WITH VARYING GGBS PERCENTAGES IN SOIL

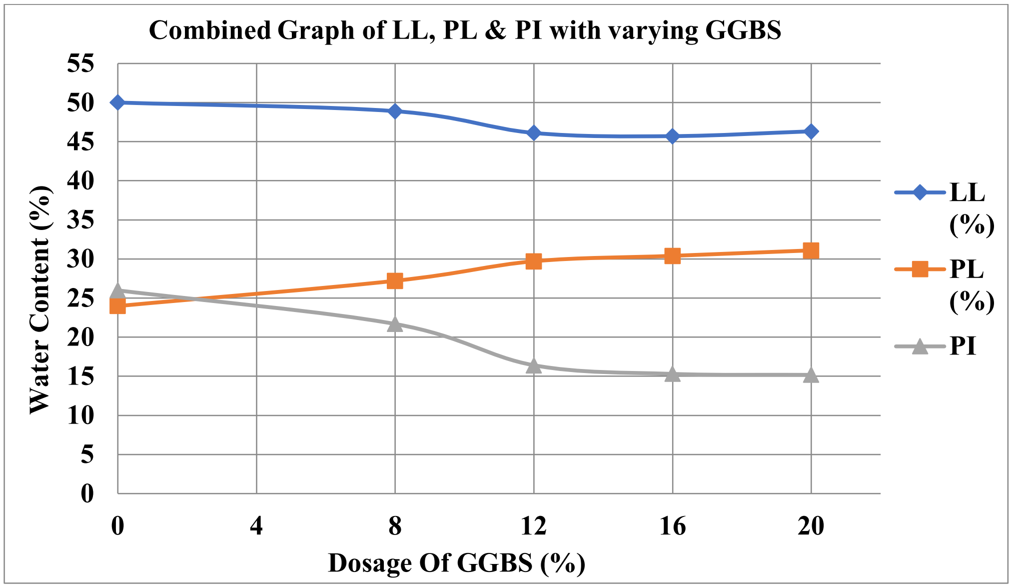

Figure 6: COMBINED GRAPH OF LIQUID LIMIT, PLASTIC LIMIT AND PLASTICITY INDEX WITH VARYING GGBS PERCENTAGES IN SOIL

An increment in the plastic limit of clayey soil was observed with the increase of GGBS percentage in the soil GGBS mixture. The liquid limit and the plasticity index reduced with the increase of GGBS percentage in the soil GGBS mixture. The initial values of the liquid limit, plastic limit and plasticity index for virgin clayey soil were found equal to 50%, 24% and 26 respectively. The GGBS content was added to the clayey soil at 0%, 8%, 12%, 16% and 20% by weight to the clayey soil. At 20% dosage of GGBS to the clayey soil, the liquid limit, plastic limit and plasticity index were found equal to 46 %, 31 % and 15 respectively.

Table 5: LIQUID LIMIT, PLASTIC LIMIT AND PLASTICITY INDEX WITH VARYING GGBS PERCENTAGES IN SOIL

GGBS %	LL (%)	PL (%)	PI
0	50	24	26
8	49	27	22
12	46	30	16
16	46	30	16
20	46	31	15

GGBS was added to the virgin clayey soil in varying percentages (0%, 8%, 12%, 16% and 20%) to study its effect on the liquid limit, plastic limit and plasticity index of the clayey soil. The values of the atterberg limits (LL, PL and PI) for varying percentages of GGBS addition in clayey soil are given in table 5.

CONCLUSIONS

1. The maximum dry density and the corresponding optimum moisture content for the virgin clayey soil are found equal to 16.43kN/m^3 and 18% respectively. The maximum

dry density and the corresponding optimum moisture content for the clayey soil containing 16% GGBS mixture are found equal to 17.42kN/m^3 and 24% respectively.

2. It was observed that as the GGBS dosage percentage in soil increased, the maximum dry density value increased and the optimum moisture content increased significantly up to 20% GGBS addition in clayey soil.
3. An increment in maximum dry density was observed with the addition of GGBS to the clayey soil. The maximum dry density increased because of high specific gravity and sudden creation of the cemented products due to hydration. The optimum moisture content increased with the addition of GGBS because of the hydration process.
4. Since GGBS composition contains significantly high amount of calcium oxide (CaO) which undergoes hydration in the presence of water leading to the formation of hydrated calcium oxide which causes more absorption of water by the soil GGBS mixture.
5. The liquid limit, plastic limit and plasticity index for virgin clayey soil were found equal to 50 %, 24 % and 26 respectively. And for clayey soil mixed with 16% GGBS (optimum dosage), the liquid limit, plastic limit and plasticity index were found equal to 46 %, 30 % and 16 respectively.

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