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Effect of Curing Period on Strength Development in High Plastic Expansive Clay Stabilized with Industrial Waste

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***Abstract*—A key layer of any pavement, subgrade must be able to support loads transmitted from top without excessive deformation under adverse conditions. Researchers and pavement designer have adopted combined treatment techniques to improve the strength and stability of this layer or foundation soil of problematic site. In this study, investigation has been carried out to check the effect of curing time on strength development of problematic high plastic expansive clay stabilized with commercial waste material bagasse ash (BA) and blast furnace slag (BFS). Laboratory studies were carried out to evaluate the influence of combine effect of bagasse ash (BA) and blast furnace slag on high plastic clay soil of study area. Preliminary tests such as Atterberg limits, compaction parameter test together with a series of unconfined compression strength (UCS) and California bearing ratio (CBR) were obtained on different mix proportion to get optimum mix of different proportion. Number of UCS sample were prepared for untreated and optimum mix for different curing period such as 0, 7, 14, 28, 56, 112, 140, and 180 days and tested. It was observed that UCS values were improved for treated soil, with curing periods and also with respect to untreated samples. Study revealed that the curing duration exerted a significant influence on the stress–strain behavior of bagasse ash and blast furnace slag mixed clay. From the experimental results, it can be concluded that this industrial waste can be used to enhance the subgrade strength of high plastic clay. Such combined waste material in its optimum content can be used by pavement designers and engineers in the field on any construction works on expansive clay site**.

***Index Terms*— bagasse ash; blast furnace slag; curing period; high plastic clay; stabilization.**

I. INTRODUCTION

Soil available in the arid and semi-arid region across the world rich in expansive clay minerals where climate characterized by alternate periods of rainfall and drought, subjected to wetting and drying cycle and cause instability and distress. Cracks and deformation occur due to swelling of expansive clays in roads, pavements, building foundations, irrigation structure, and reservoir linings, pipelines. Combined treatment techniques have been adopted by many pavement designers and site engineers to improve the strength and stability of subgrades or foundation soils of expansive sites. For problematic soils such as expansive soil, a single additive may not result in maximum improvement in the required properties of the soils[1][2] [3]. Combining the two treatment

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techniques has the potential to provide an improved strength and stability of subgrade soils or foundation soils thereby presenting a sustainable and cost effective solution to the engineering problems associated with this soil. In such cases soil stabilization using waste materials such as rice husk ash, blast furnace slag, fly ash, bottom ash and cement kiln are having been carried out as they are pozzolanic in nature and reduce the water absorption by binding the clay particles[4][5]–[7] [8]. Studies relating to the Bagasse ash and ground granulated blast furnace slag individually with some admixture have been carried out by few researchers[9]–[22][23]–[33]. However, no studies on the joint activation of Bagasse ash and ground granulated blast furnace slag as stabilizing agents for expansive soils have been published to date. The purpose of this study is to investigate the effect of combined mix sugarcane industrial waste Bagasse ash and GGBS on s strength properties of low to high plastic expansive clay. Work focus on curing period effect of combine mix bagasse ash & ground granulated blast furnace slag (GGBS) for the stabilization of high plastic expansive clay to check durability. In general, the longer the curing period, the better is the strength development, due to the pozzolanic reaction.

II. Materials and Methodology

A. Material

Clayey soil

The soil samples used in the study have been obtained from a Vesu, Surat, Gujarat, India. Disturbed clayey soil was extracted at a depth of about 1 m from the ground level. The sample has been classified as high plastic clay as per A-line chart from the laboratory results. The geotechnical and chemical properties of the soil sample are summarized in Tables I and II respectively. The specific gravity of the sample is measured to be 2.69 Soil sample of study area has been identified as high plastic expansive clay.

Baggase Ash:

The sugarcane bagasse ash was collected from the boiler of Asia's largest sugar factory. In this study collected ash oven-dried and passed through 425 µm sieve was used. The specific gravity of BA was measured to be 2.32.

Ground granulated Blast furnace slag:

The GGBS was collected from the Astrox Pvt. Ltd. Surat, Gujarat, India. It is made by inter grinding of high-quality clinker, slag, and gypsum. It is cementitious material consist of CaO, SiO_2, Al_2O_3. The high amount of CaO in GGBS reflects it as a binder material. The specific gravity of GGBS was measured to be 2.9.

Fig.1. Bagasse ash

Fig.2. Ground granulated blast furnace slag

B. Methodology

The investigation has been carried out on GGBS in combination with BA to stabilize high plastic clay in different percentages by dry weight. The artificial soil mixed prepared for GGBS for CH soil mixed with BA. Tests such as consistency limits, standard proctor test, unconfined compressive strength, California bearing ratio, swelling pressure test and free swell index were performed for different sample mixes. The study has been carried out for different combinations of CH soil + Bagasse ash (0%, 5 %, 10%, 15%, 20%) + Ground granulated blast furnace slag (0 %, 5% 7.5%).

Mix prepared for GGBS content varying from 5% and 7.5% with bagasse ash varying for 5 to 25% at 5 % interval to obtain high strength for a combination. Then sample with very good improvement in unconfined compression strength and swelling behavior were considered as optimum mix, which is 82.5% CH+ 10% BA + 7.5% GGBS mix to stabilize high plastic clay of study area. Paper focuses on effect of curing period on optimum mix to check the durability with the comparisons of untreated clay of study area.

Table I: Results of optimum mix of each combination

Soil property	CH	82.5 % CH+10 % BA+7.5 % GGBS
Plasticity Index (%)	42	19.44
Shrinkage limit (%)	19.53	32.89
Optimum moisture content (%)	20.8	29.23
Maximum dry density (kN/m^2)	1.49	1.403
CBR (%)	3.86	13.55
Swelling Pressure (kN/m^2)	32.36	19.74
Free Swell Index (%)	52.45	12.00

C. Influence of Curing period on Unconfined compression Strength

To check the durability of optimum mixes and untreated soil, the UCS sample of 38 mm diameter and 76 mm height were prepared and cured in humidity chamber for 0,7, 14, 28, 56, 112, 140 and 180 days. The Unconfined compression test was carried out as per IS 2720 (part 10) 1991. To prepare the specimens, UCS mould was coated with lubricant in order to lessen the chance of fracturing the specimen during removal. Moist soil was compacted into three equal layers. Between each layer the surface was scoured to provide bond between the layers. After removal of each sample from the mould, it has been wrapped with plastic to avoid evaporation of water and kept into the humidity chamber. At the end of each period three samples of untreated and optimum mix samples were tested to find its unconfined compressive strength at the end of curing days. The specimen was compressed until failure surface are definitely developed, or the stress-strain curve was passed the peak, or until an axial strain of 20 percent is reached. The average UCS value of three samples was considered as unconfined compressive strength.

Fig. 3. Cured UCS sample of an untreated and optimum mix

D. Chemical properties

The X-Ray Fluorescence analysis has been carried out to obtain the concentration of exchangeable cations which reflects its effect on swelling behavior. The chemical properties of untreated clay and bagasse ash were obtained using Wavelength Dispersive X-ray Fluorescence method as shown in table II. The sample was sent to Sophisticated Instrumentation Centre for Applied Research and Testing (Sicart), V.V. Nagar for the XRF analysis Chemical composition of ground granulated blast furnace slag and cement slag have been obtained from the manufacturer.

TABLE II: XRF RESULTS OF CLAY AND ADMIXTURES

Component/ Metal Oxides	CH (%)	BA (%)	GGBS (%)
SiO_2	34.71	51.36	26.43
Al_2O_3	5.26	2.01	9.36
Fe_2O_3	44.38	21.26	2.51
CaO	4.92	3.32	41.02
SO3	1.53	3.59	-

From the XRF analysis of the material, it has been seen that bagasse ash is high in oxides of silica and iron (more than 70 %) and low in calcium oxide which has good binding properties, whereas ground granulated blast furnace slag and cement slag are rich in silica and calcium oxide (more than 70 %) and low in iron and silica oxides.

The result shows bagasse ash can combine with slag and a chemical reaction occurs. The reactions result in the formation of Calcium Aluminate Silicate Hydroxide (CASH), Calcium Silicate Hydroxide (CSH) and Calcium Aluminate Hydroxide(CAH) which has cementitious properties, that strengthens gradually over several years. As long as there is sufficient calcium from the slag to combine with the soluble silica and alumina, the pozzolanic reaction will continue as long as the pH remains high enough to maintain the solubility of the silica and alumina[26]. Lees, Abdelkader, and Hamdani, (1982) said that strength gain also largely depends on the amount of silica and alumina available from the clay itself; thus, it has been found that high calcium oxides of lime stabilization are more effective for montmorillonite soils than for kaolinitic soils. Due to limited silica in clay soil, there is always free calcium form additive like lime or cement that is not utilized[34]. Hence Calcium oxide riched slag can chemically combine with clay and bagasse ash (clay and BA combined act as super – Pozzolans, are materials having a high silica content of above 85 %) which is rich in silica enhances the pozzolanic reactions.

Sodium, magnesium, and other cations are replaced by the calcium cations from the available calcium hydroxide. Baser (2009) stated that the thickness of the diffused double layer decreases as replacing the divalent ions (Ca^{2+}) from stabilizers with monovalent ions (Na^{+}) of clay. Thus, swelling potential decreases[35]. Yazici (2004) said that cation exchange reaction results in the flocculation and agglomeration of the soil particles with a consequent reduction in the amount of clay-sized materials and hence the soil surface area, which inevitably accounts for the reduction in plasticity[36]. Flocculation and agglomeration change the clay texture from that of a plastic, fine-grained material to that of granular soil.

III. Results and Discussion

A. Effect of binder on compaction characteristics

The effect of the binder on the optimum water content (OMC) and the maximum dry density (MDD) of the soil have been studied. Generally with increase of binder content, OMC decreases and MDD decreases. But in this study different trend has been observed. With increasing bagasse ash content, OMC increased while MDD decreased. Same trend has been reported by some researchers for other type of ashes like rise husk ash. Prabakar et al. (2004) observed a decrease in the MDD and an increase in the OMC for some typical soils stabilized with Fly ash[37]. Basha et al. (2005) found that both cement and rice husk ash resulted in a reduced MDD and increased OMC[6]. Kolias et al.(2005) also reported a decrease in the MDD and an increase in the OMC with increasing Fly ash content. The decrease in MDD may be attributed to the difference in the specific gravities of soil and the stabilizing agent.[38]. Light compaction test results indicate increase in MDD with increasing GGBS content and decrease with BA content and OMC increase with BA content and GGBS content.

B. Effect of binder on CBR

The CBR test indirectly measures the shearing resistance of a soil under controlled moisture and density conditions. The CBR is obtained as the ratio of load required to affect a certain depth of penetration of a standard penetration piston into a compacted specimen of the soil at some water content and density to the standard load required to obtain the same depth of penetration on a standard sample of crushed stone.

CBR tests were conducted on the compacted specimens at the optimum moisture content using standard compaction test. The compacted soil samples of the CBR mould are soaked for 4 days in a water bath to get the soaked CBR value. CBR test was carried out to check feasibility of mix as improved sub-base of pavement. Soaked CBR test was carried out for 0 days curing and 4 days soaking for all the mixes. The mix with 10%- 20% BA with 7.5% GGBS was found to be suitable as sub-base material of pavement. CBR 2.5 value was increased to 41% for optimum mix. The increase in CBR value is due to the progressive cementation of soil-BA-GGBS as a result of hydration and pozzolanic reaction.

C. Effect of binder for different curing period on Unconfined Compression Strength

UCS results for samples of all mixes after 0, 7, 14, 28, 56, 112, 140 and 180 days were carried out. Figure 5 shows the axial strain vs. deviator stress for untreated and optimum mix. The deviator stress of untreated soil was found to be less than that of both optimum samples. Even for each mixed deviator stress is increasing with the curing period. Time – strength development is crucial in the study of strength characteristics of soils treated

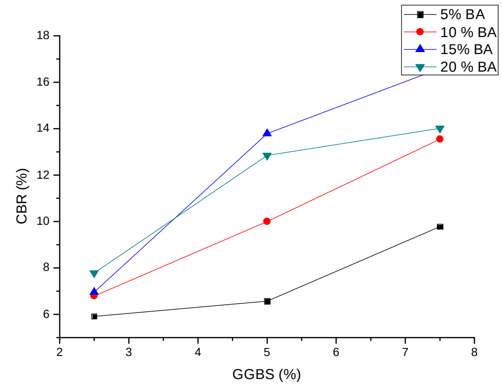

Fig. 4. CBR for different percent of GGBS and BA mix

with stabilizers as the structure of such materials evolves with time due to continuing hydration/ pozzolanic reactions [39]–[42]. Optimum mix GGBS (82.5% CH+ 10% BA + 7.5% GGBS) shows remarkable increase in a strength as compared to the untreated sample.

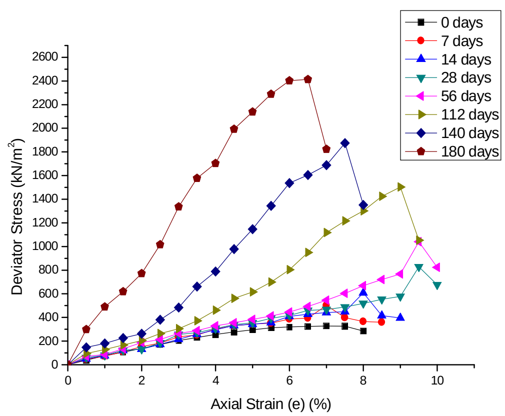

Fig. 5. Axial strain Vs. Deviator stress of optimum mix (GGBS) sample for different curing period

For optimum mix, unconfined compressive strength after 180 days curing period has been increased almost more than eight times as compared to untreated samples of 0 days curing which shows notable durability of mix. It shows almost 6 times increase in strength when compares with treated 0 days cured sample.

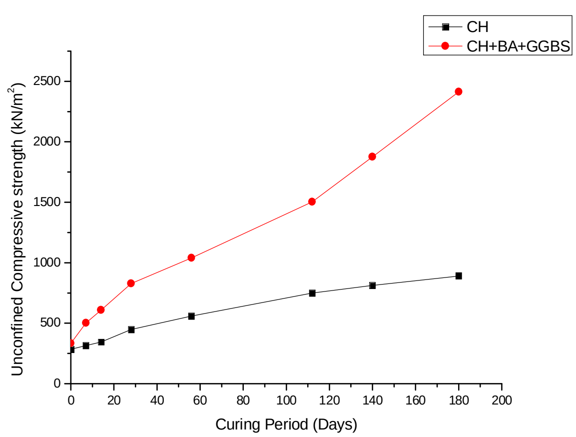

Fig. 6. Variation of UCS with different curing period for untreated and optimum mix samples

Based on these results, it is obvious that curing time exerts a strong effect on the development of strength of the CH soil –mixed with the bagasse ash and GGBS. Maximum shear stress occurred at very low strain for the optimum mix specimens especially for the longer curing periods which were generally followed by a sudden drop in the post-peak stress. It has been seen that; compressive strength is increasing with the curing period for all three mixes.

It can be observed from Figures 6 that as on the curing time increases, the strength increases, and the gain in strength till 180 days may be attributed to the increased pozzolanic reactivity with the time between the GGBS and the siliceous pozzolanic materials from both the BA and Clay. The enhancement in strength may also attribute to hydration and cementation between particles resulted in a reduction of pore spaces with curing time increases. The considerable increase of UCS from 0 to 7 days may be attributed to the reason that cementitious products are formed at an early stage and thereafter major increase in strength from 7 days to 180 days may be due to pozzolanic reaction due to addition of either bagasse ash and slag. Thereafter minor increase may possible after 180 days followed by a slow rate of reaction involving the formation of long term cementitious compounds. A similar trend was reported by Jalali et al. (1997) for lime – fly ash soil stabilization. After that The increase in strength is probably due to fast pozzolanic reactions that resulted in the formation of various cementing compounds such as calcium silicate hydrates (CSH), calcium aluminates hydrates (CAH) and calcium aluminum silicate hydrates (CASH). Based on these results, it is obvious that curing time exerts a strong effect on the development of strength of the expansive soil – binder and is therefore identified as a major variable affecting the strength development of the stabilized soil mixtures.

IV. CONCLUSION

The study tried to utilize ground granulated blast furnace slag with bagasse ash to stabilize high plastic clay. BA-GGBS based binders have been tested for different proportion and 82.5% CH+ 10% BA + 7.5% GGBS mix has been considered as optimum mixes to enhance strength properties. The objective of this work is to assess the durability of the optimum mix samples considering effect of curing period. Based on the results of the various tests carried out, the following conclusions are drawn.

1. Reduction in MDD could be a result of the flocculated and agglomerated fine particles occupying larger spaces leading to corresponding decrease in dry density. The increase in OMC was mostly due to pozzolanic reaction of lime in slag with Silica of BA and clay fraction of the soil. This is due to predominant effects of reduced clay content and increased frictional resisting respectively.
2. Soaked CBR of optimum mix increased with respect to untreated sample shows the improvement in subgrade characteristics. Soaked CBR value increases as GGBS- BA content increasing due to progressive cementation process.
3. The influence of curing time on the unconfined compressive strength of high plastic clay stabilized with an optimum mix shows remarkable enhancement of strength after each curing period as compared to untreated high plastic clay. The increase in UCS can be related to the hydration and pozzolanic reaction between soil, BA and GGBS forming CSH and CAH, they fills the voids, and binds the particles of soils together and improving strength of expansive soils.

The study revealed that high plastic clay stabilized with GGBS combined with bagasse ash have the potential for a time-dependent increase in strength and therefore with additional curing time, further strength may develop.

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