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Durability of Commercial Waste Bagasse Ash And Ground Granulated Blast Furnace Slag Stabilized High Plastic Clay

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***Abstract:** In the current work, a problematic expansive high plastic clayey (CH) soil of Surat, Gujarat, India has been treated with commercial waste bagasse ash (BA) and ground granulated blast furnace slag (GGBS) for sustainable development. Swell shrink behavior, California bearing ratio, unconfined compressive strength for different curing period have been studied. As expansive soil is very sensitive to seasonal variation, cyclic drying and wetting study has been carried out on both treated and untreated samples. The optimum blend is observed to be in the proportion of 82.5%CH + 10%BA + 7.5%GGBS. The unconfined compressive test results indicate that strength of 28 days cured samples of optimum mix increases about three times and eight times when compared to untreated sample and uncured sample respectively. The soaked California bearing ratio (CBR) indicate the increase in strength with increasing curing periods from 7 to 28 days. Optimum mix shows the decrease in swelling pressure and an increase in shrinkage limit as compared to untreated soil. The experimental results show good improvement in swell-shrink behavior, unconfined compressive strength, and soaked California bearing ratio when combined with bagasse ash and slag. The findings of this study revealed that bagasse ash in combination with ground granulated blast furnace slag is suitable as a pozzolanic material in stabilization of high plastic clay to reach the target strength for structures with improved swell-shrink behavior.*

***Index Terms:** Bagasse ash, Expansive Clay, Ground Granulated Blast Furnace Slag, Sustainability*

I. INTRODUCTION

Damage causes on light weight structure due to swell-shrink behavior of expansive soils. Volume change occurs in expansive clay due to variation in moisture content because of seasonal variation in arid and semi arid region. This change in volume can exert enough stress on a light weight structure which results in cracks or distortion.

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Expansive clay has high cation exchange capacity and large surface area. Traditional stabilizers like Cement, lime and fly ash used to modify such soil are based on pozzolanic reactions and cation exchange capacity. Pozzolanic reactions arise when siliceous and aluminous materials react with calcium hydroxide resulted in cementitious compounds.
Commercial waste sugarcane bagasse ash and furnace slag can be used to treat the problematic soil like expansive clay due to their siliceous and calcareous nature. Strands of bagasse got after the extraction of the juice from sugarcane. The fiber of bagasse is waste used as fuel in the same industry. The burning of bagasse fibre in boiler produces bagasse ash, which is generally spread or dumped over farms or in ash pond resulted in an environmental issue. From the research study on bagasse ash, it has been stated that the exposure of bagasse ash dust from the processing of bagasse can cause a lung infection known as bagassosis [23]. So, there is a great need for its reuse. James et al (2017) highlighted that In the 2011 -12 Sugarcane production reached to 361.04 million tonnes in India, and became the biggest cane producer in the world. [13]. Currently, India is the second largest sugarcane producer in the globe produces 341.2 million metric tonnes of sugarcane. Bagasse ash is rich in silica and aluminum oxides, and sometimes calcium so considered as pozzolanic material. Kiran et al (2013) carried out a test for CBR, UCS for different percentages vary from 4 to 12 % of bagasse ash mixed with cement. Result shows, UCS and CBR increased on mixing of 8% and 4 % bagasse ash with 8% cement respectively [21]. Kharade et al., (2014) stated that bagasse ash can be used as stabilizing material for expansive soils. He has investigated 6% bagasse ash without any chemical or cementing material and recommended it as an economical method. [3]. Furthermore, it is also proved that with the addition of cementing material with bagasse ash will give a better improvement in properties of expansive soils. Bahurudeen et al. (2015) studied the mineralogical characterization of bagasse ash and explained that bagasse ash is a composition of silica minerals quartz and cristobalite. Other minerals also reported based on the source of the ash in varying content [6]. ASTM C618 recommended that for natural pozzolana, silica, alumina and iron oxide should be at least 70% [5]. Almost all of the studies reported fulfilled this criterion for bagasse ash [12],[13],[16],[19],[22],[24].

Another requirement for natural pozzolana is that SO3 content should be less than 4%. This requirement also met as reported in research. Bagasse ash is a composition of mainly SiO_2, Al_2O_3, Fe_2O_3, MgO, K_2O, and CaO which is similar to fly ash.

Ground granulated blast furnace slag is a byproduct of the iron industry. The iron mineral is decreased to press and the rest of the materials structure a slag which occasionally tapped off as a liquid fluid must be quickly extinguished in substantial amounts of water. This slag is ground in to a fine powder after drying. Chemically, slag is a mixture of lime, silica, and alumina hence cementitious properties are generated when ground granulated slag reacts with water. GGBS is generally used in concrete to partially replace the cement. Anil Kumar Sharman et al. (2016) studied the effect of ground granulated slag combined with fly ash to treat expansive soil. This study reported that the combined use of slag and ash to bind together and increase pozzolanic activities which reduce the swell potential and enhanced the unconfined compressive strength [2]. Oormila. T. R. et. al. (2014), also studied the effect on strength properties of Tamil Nadu soil treated with varying proportion of fly ash and ground granulated slag. It was reported that 20 % of GGBS gives the maximum increment in the CBR value. [26]. Laximanth Yadu (2013) investigated the probable effect of granulated furnace slag varying to 3 to 9% combined with 3 to 12 % of fly ash to stabilize a soft soil. This study concluded 6 % GGBS with 3 % fly ash considered as an optimum mix. [17].

Bagasse ash and GGBS have a vast variation in the chemical composition. Bagasse ash is rich in silica and alumina and low in calcium oxide [13], while GGBS is high in calcium oxide [7],[17],[20],[28]. The combined effect of this two-waste product can be more effective to stabilize expansive clay than using individually. Each can provide sufficient lime and/or silica to support pozzolanic reaction.

Studies relating to the GGBS and/or Bagasse ash individually with different stabilizer have been carried out by a few researchers. On another hand, no work on the combined activation of Bagasse ash and GGBS as a stabilizer for expansive soils have been published till date. The purpose of this study is to investigate the long-term behavior on swell-shrink and strength properties of stabilized expansive clay. Combine effect of commercial waste bagasse ash and Ground granulated blast furnace slag (GGBS) have been used to modify high plastic expansive clay considering sustainable aspects of development for light weight structure.

II. Materials and Method

The study divided into three phases. In the first phase,
An investigation has been carried out on different waste materials available in the study area and determination of their physical properties for the selected material BA, GGBS, and soil. In the second phase, various laboratory test has been carried out to find the optimum mix for stabilization of the sample. In the third phase, Durability study such as unconfined compression test for different curing period and cyclic drying wetting study has been carried out on optimum mix.

A. *Materials*

Soil sample

The soil samples used in the study have been obtained from Surat, Gujarat, India. The soil sample was extracted at a depth of about 1 to 1.5 m. Soil sample oven dried for 18 hr. at 110° C and then broken by a rubber hammer into small crumbs for testing. Classification of soil has been carried out as per AASHTO classification system. The geotechnical properties of soil such as particle size distribution, specific gravity, and consistency limits were determined as per Indian standard code. The soil was classified as high plasticity clay as per A-line chart. Laboratory test results of the soil sample are shown in me.

Baggase Ash

The sugarcane bagasse ash as shown in fig. 1 was collected from the boiler of Asia's largest sugar factory, Bardoli, Gujarat, India. Ash was ground and sieved through 425 μm sieve for further testing. The specific gravity of BA was measured to be 2.32. Chemical composition SiO_2, Al_2O_3, Fe_2O_3, CaO, K_2O and MgO are 62.43%, 4.28 %, 6.98 %, 11.8%, 3.53 % and 2.51% respectively for bagasse ash (BA) used in the study.

Fig. 1 Sugarcane bagasse ash (Boiler ash)

Table I: Properties of soil, BA, and GGBS

Property	Soil	BA	GGBS
Colour	Black	Grey	White-Grey
Specific gravity	2.6	2.32	2.83
Grain size analysis			
Gravel (%)	0	-	-
Sand (%)	19	25	2
Silt (%)	33	73	98
Clay (%)	48	2	0
Consistency limits			
Liquid limit (%)	65.05	-	-
Plastic limit (%)	28.12	-	-
Shrinkage limit (%)	21.42	-	-
IS Classification	CH	-	-
Strength Properties			
Optimum moisture content (%)	22.7	-	-
Maximum dry density (kN/m^2)	1.58	-	-
Unconfined compressive strength qu (kN/m^2)	245	-	-
CBR (%)	3.31	-	-

Swelling properties			
Swelling Pressure (kN/m^2)	54.92	-	-
Free Swell Index (%)	68	0	0

Ground Granulated Blast furnace slag

The GGBS in powder form as shown in fig. 2 was collected from the Astrox Pvt. Ltd. Surat, Gujarat, India. It is cementitious material consist of CaO, SiO_2, Al_2O_3. It can be used as a binder material due to the high amount of CaO. The specific gravity of GGBS used in this study was measured to be 2.83.

Fig. 2: Powder form of GGBS

limits, standard Proctor test, unconfined compressive strength, California bearing ratio, swelling pressure test, and free swell index were performed for different sample mixes as per IS 2720 specification. Soil sample with different proportion of BA and GGBS mixed thoroughly and kept for 15 min. Special attention was needed as the consistency should decrease while the progress of the experiment. Shrinkage limit was found out as per IS 2720 (Part VI). Sample mix was made using water content equal or greater than the liquid limit and kept for 24 hrs in a humidity chamber to mitigate water evaporation, after filing of shrinkage dish with gentle tapping sample were weighted and kept for air drying first then for oven drying.

The maximum dry density (MDD) and optimum moisture content (OMC) were determined by standard proctor method as per IS 2720: part 7: 1980 (ASTM 698). UCS test sample was prepared as per the optimum moisture content of the respective mix in accordance with ASTM 2166 for three samples. The dimension of the sample used for the unconfined compression test was 50 mm in diameter and 100 mm in length. In order to assess the strength development over time for each mix samples, the UCS was determined after different curing periods 7, 14 and 28 days. Sample curing was done in a humidity chamber maintained at 100% humidity and 32°C

Table II: Detail program of experiments

Sr. no.	Mix Proportion (%)			Index properties				Compaction		UCS (kN/m^2)				CBR (Soaked)		Swelling properties		W/D cycle
	CH	BA	GG BS	SL	PL	LL	PI	OMC	MDD	0	7	14	28	0	28	SP	FSI	After 28 days
1	100	0	0	*	*	*	*	*	*	*				*		*	*	*
2	92.5	5	2.5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
3	90	5	5	*	*	*	*	*	*	*	*	*	*	*		*	*	
4	87.5	5	7.5	*	*	*	*	*	*	*	*	*	*	*		*	*	
5	87.5	10	2.5	*	*	*	*	*	*	*	*	*	*	*		*	*	
6	85	10	5	*	*	*	*	*	*	*	*	*	*	*		*	*	
7	82.5	10	7.5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
8	82.5	15	2.5	*	*	*	*	*	*	*	*	*	*	*		*	*	
9	80	15	5	*	*	*	*	*	*	*	*	*	*	*		*	*	
10	77.5	15	7.5	*	*	*	*	*	*	*	*	*	*	*		*	*	
11	77.5	20	2.5	*	*	*	*	*	*	*	*	*	*	*		*	*	
12	75	20	5	*	*	*	*	*	*	*	*	*	*	*		*	*	
13	72.5	20	7.5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	

*Test conducted

B. *Testing methodology*

These experiments involved the analysis of the performance of various combinations of soil sample with BA and GGBS mix. The detailed program of experiments conducted for the study is given in II. The investigation has been carried out on uniformly mixed soil sample in different percentage by dry weight. The BA varies in range of 5 % to 20 % with 5 % increments and the GGBS varies in range of 2.5 % to 7.5 % with 2.5 % increment. All mixing was done manually with care to make a homogeneous sample. Tests such as Atterberg

temperature. Soaked CBR values were obtained for all mix soaked for 4 days after 0 and 28 days curing in humidity chamber maintained at 100% humidity and 32°C temperature as per ASTM 1883.Swelling pressure test accordance with IS 2720: Part 41 carried out for all mix by making remolded sample as per OMC of the respective mix. The free swell index was carried out using 10 gm sample mix of passing 425 µm sieve as per IS 2720: Part 40.

Durability under cyclic wetting and drying has been checked for three untreated samples and 28 days cured treated optimum mix samples of 50 mm diameter and 100 mm length. In the wetting phase, cured samples were immersed in potable water for five hours then their weight and height were recorded. These samples were oven dried for 42 hr.

at a temperature of 70° C and were cooled at room temperature. Then their weight and height were measured. This completes the one cycle; the same procedure of wetting and drying were repeated for twelve cycles. Alternate wetting and drying cycle of 5 hrs and 42 hrs respectively with the one-hour gap for cooling and air drying was given in accordance with IS:4332 (Part-5).

Unconfined compression strength was determined after each cycle of wetting and drying.

C. Mix proportion

The common coding system used for the mix in this paper as described: The term CH is for high plastic clay; the term BA is for Bagasse Ash and term GGBS is for Ground Granulated Blast Furnace Slag. Hence, a mix of 82.5 % high plastic clay, 10 % Bagasse Ash and 7.5 % Ground granulated blast furnace slag is designated as 82.5CH + 10BA+ 7.5GGBS.

III. RESULT AND DISCUSSION

A. Effect on Atterberg Limits

It has been found from the test results that Bagasse ash content is directly related with the reduction in the liquid limit and plasticity index as shown in fig. 3. It has been observed that with an increase in the content of bagasse ash from 10 % to 20 %, liquid limit and plasticity index decreases almost 30 % and 60 % respectively with less percent of GGBS. The shrinkage limits of soil – BA mixtures increasing with binder content as shown in fig. 4. Shrinkage limit of optimum mix increased by 40 % as compared to the untreated sample. Increase in shrinkage may be due to the development of interaction between bagasse ash – GGBS mix surface and soil matrix with time, which could be beneficial for strength gain. Cation exchange and flocculation occur due to a reduction in the diffused double layer thickness, immediately after soil is mixed with pozzolanic material and enhanced plasticity property of clay [15],[21],[28]. Liquid limit and plasticity also decrease due to a reduction in the surface area and water affinity of the clay particles. Results indicate 25 % and 43 % reduction in liquid limit and plasticity index respectively for optimum mix 82.5CH + 10BA+ 7.5GGBS as compared to the untreated sample. The high plastic soil is converted into low to medium plastic for optimum mix samples as per A-line chart.

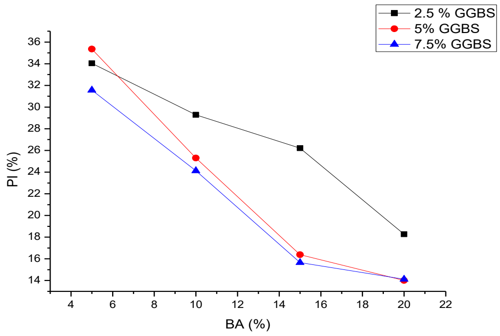


Fig. 3: Variation in plasticity index with BA content for GGBS treated sample

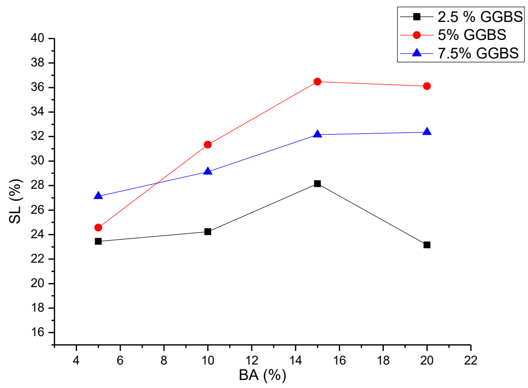


Fig. 4: Variation of SL with BA content for GGBS stabilized soil

B. Effect on compaction characteristics

The change in optimum water content (OMC) and the maximum dry density (MDD) for the optimum mix are shown in Fig. 5 and 6 respectively. Generally, with an increase in stabilizer, OMC decreases and MDD increases. But in this study different trend has been observed. With increasing bagasse ash content, OMC increased while MDD decreased. The same trend has been reported by some researchers for another type of ashes like rising husk ash, fly ash [8],[16],[26]. Test results indicate an increase in MDD with increasing GGBS content and decrease with BA content and OMC increase with BA and GGBS content. Reduction in MDD may be due to the flocculation and agglomeration of fine clay particles covering large spaces leading to the reduction in dry density. Change in dry density attributed due to a stabilizing agent like BA filled the voids of the mix because of the specific gravity's variation of soil and stabilizer [20]. The lower specific gravity of BA caused a reduction in dry density. The increase in OMC is due to the change of the surface area of the mixed sample and pozzolanic reaction of lime of GGBS with clay fraction of the soil. This different pattern observed due to a reduction in clay content and increased friction resistance also.

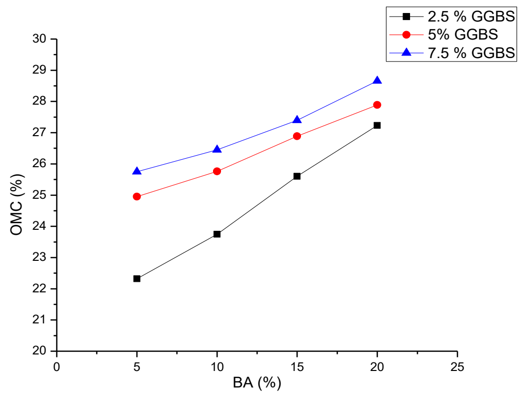


Figure 5: Variation of OMC with BA for GGBS treated sample

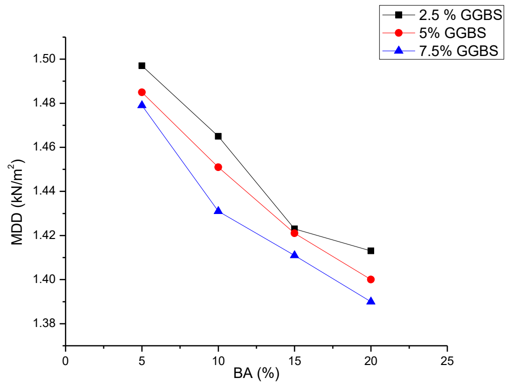


Figure 6: Variation of MDD with BA content for GGBS treated sample

C. Effect on strength characteristics

The unconfined compressive strength of treated soil enhanced due to increase in GGBS content and curing period. UCS test has been performed on 0, 7, 14 and 28 days cured samples of all mixes. Initially, the addition of bagasse ash after certain limit strength has been reduced for 0 days cured samples but had gained strength with the combination of GGBS content. The twenty-eight days cured 82.5CH + 10BA+ 7.5GGBS samples show the three times increase in strength compared to untreated soil and eight times increases with compared to zero days curing period. Fig. 7 shows the failure pattern of optimum mix sample subjected to unconfined compressive load.

Fig. 7: Failure of 28 days cured sample of an optimum mix

Variation in unconfined compressive strength for different GGBS content with a varying percent of bagasse ash is shown in fig. 8. Test resultsshow that 7.5 percent GGBS with 10 % BA mixed in a CH soil gives maximum strength.

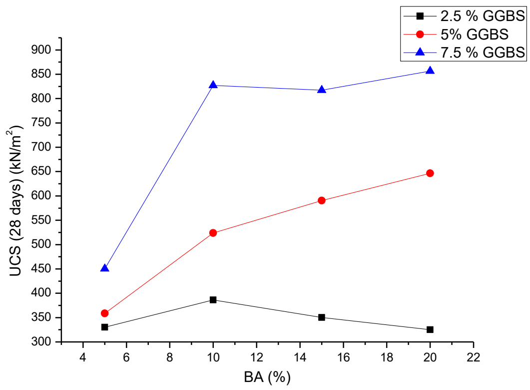


Fig. 8: Variation of 28 days cured UCS with BA content for GGBS treated sample

Fig. 9 shows the change in an unconfined compressive strength (UCS) of 7.5 % GGBS with 5-10 % BA content treated expansive soil for different curing periods. It is seen that strength increases up to 10% of the BA content then no increase in strength observed due to an increase of BA content. A similar pattern is observed for all the curing periods. For each mix, the strength was found to be directly related to the curing period.

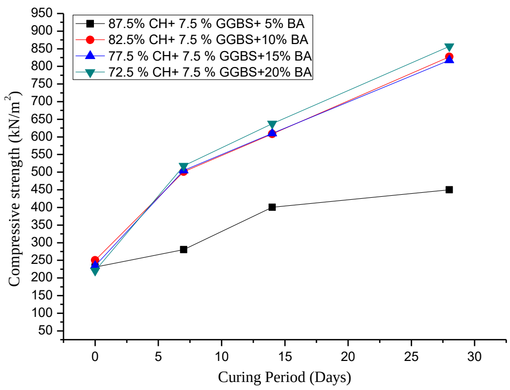


Fig. 9: Compressive strength variation with curing period for different mix

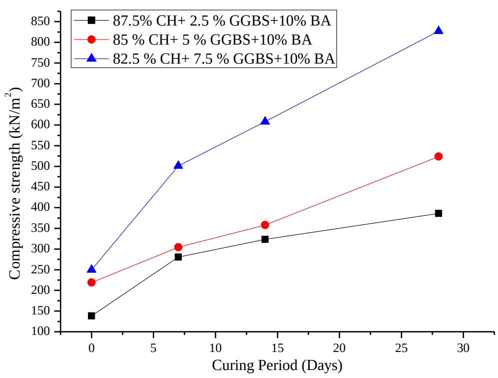


Fig. 10: Compressive strength variation with curing period for different mix

The pozzolanic reaction occurs with time in between calcium and silica-alumina present in GGBS and bagasse ash and/or CH soil respectively which forms cementitious compounds like calcium silicate hydrates (CSH), calcium aluminate hydrates (CAH) and calcium aluminum silicate hydrate (CASH). These cementitious compounds increase the unconfined compressive strength of the soil. Frictional resistance from BA and cohesion of the CH also responsible for an increase in compressive strength. It has been observed that the addition of BA beyond 20% reduces the strength. Many research studies show the reduction in the compressive strength of soil after a certain limit of binder content [4], [8-10]. For stabilized soils with more binder, it acts as unbounded particles because the pozzolanic reaction does not occur and the added particles reduce the overall strength. [1],[11].

D. Effect on California Bearing Ratio

CBR test has been conducted to check the feasibility of mix as improved sub-base of pavement. Two high strength design mix (82.5CH + 10BA+ 7.5GGBS) and (72.5CH + 20BA+ 7.5GGBS) tested for soaked CBR after 0- and 28-days curing period. The mix with 10%- 20% BA with 7.5% GGBS was found to be suitable as sub-base material of pavement. CBR value was increased up to 41% for mix 82.5CH + 10BA+ 7.5GGB. Fig. 11 shows the variation of Soaked CBR with BA content for different GGBS content. CBR value increases with time due to pozzolanic reaction resulted in to the cementation of Clay-BA-GGBS.

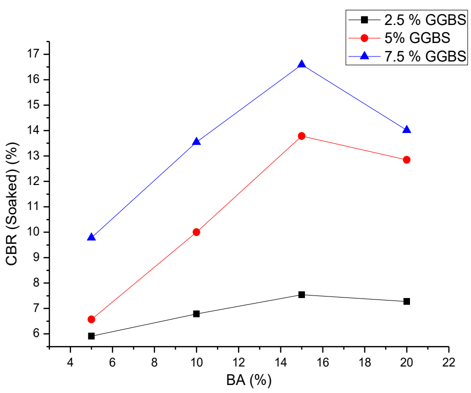


Fig. 11: Variation of soaked CBR with BA content for GGBS stabilized soil

E. Effect on swelling characteristics

Test results show that swelling pressure decreases rapidly with the bagasse ash content. Decreasing rate of pressure is less in case of addition of GGBS when compared with bagasse ash. The free swell index is also decreasing as increase percent of bagasse ash. Swelling pressure and Free swell index of untreated CH soil 54.92 kN/m^2 and 66 % reduces to 19.78 kN/m^2 and 27 % respectively for Optimum mix (82.5CH + 10BA+ 7.5GGBS) shows almost 64 % and 60% reduction. Variation of swelling pressure and free swell index with BA content for GGBS treated sample are shown in fig. 12 and 13.

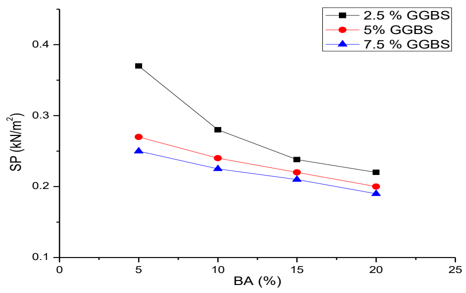


Fig. 12: Variation of SP with BA content for GGBS treated sample

Swelling pressure and free swell index reduced on the addition of BA due to flocculation and cation exchange. Bagasse ash particles replace the expansive clay particles is responsible for the reduction in swelling pressure and free swell index.

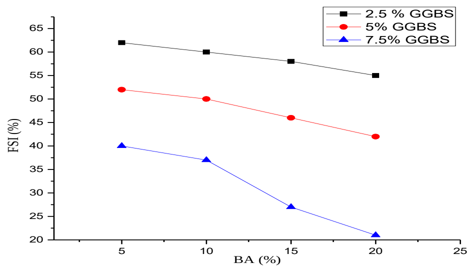


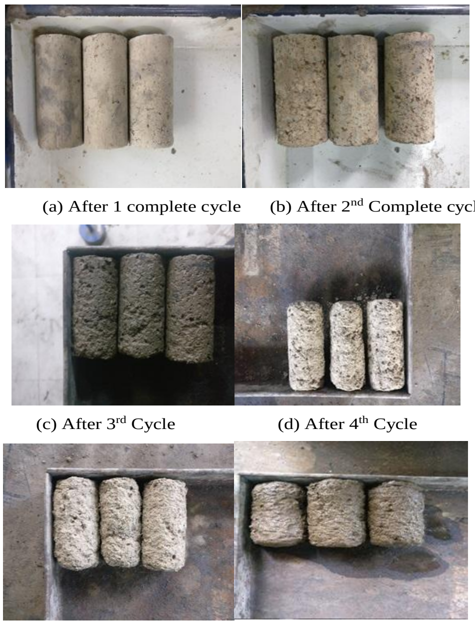
Fig. 13: Variation of FSI with BA content for GGBS treated sample

Bagasse ash and GGBS combine effectively reduce the swelling pressure of soil almost 50 % for all mix proportion. 15 % to 20% bagasse ash recommended for soil available in the study area, after that it became constant with the combination of 5 to 7.5 % GGBS.

F. Effect of wetting-drying cycles

Wetting and drying cycles (W/D cycle) have been performed on 28 days cured samples of the stabilized mix (82.5% CH + 10% BA + 7.5% GGBS) and for untreated soil by giving 5hrs wetting cycle and 42hrs drying cycle at 70 degree Celsius.

Fig.14: First wetting cycle of untreated soil



(a) After 1 complete cycle (b) After 2nd Complete cycle

(c) After 3rd Cycle (d) After 4th Cycle

(e) After 5th Cycle (f) After 6th Cycle

Fig. 15: UCS Sample after each cycle (a-f) for an optimum mix

It has been observed that untreated samples were not sustained even one complete w/d cycle. All untreated samples were demolished after the formation of cracks within 1 to 2 hours of submergence in water as shown in the fig. 14. The optimum mix samples were sustained for more than 6 cycles of wetting-drying after twenty-eight days curing period. As shown in the fig. 15, treated sample are deteriorated as increasing wetting-drying cycle, but no cracks observed which shows the good durability of the mix.

IV. CONCLUSION

The study focused to reuse the commercial waste Bagasse ash and GGBS to improve the high plastic expansive clay for sustainable development. Experimental results of the various tests reveal the following conclusions.

1. The High plastic clay (CH) stabilized in varying percent with bagasse ash and ground granulated blast furnace slag. The percent of CH soil, BA and GGBS which gives the optimum mix is 82.5, 10 and 7.5 respectively.
2. On addition of BA and GGBS binder in the CH, soil decreases plasticity index and liquid limit while increases the shrinkage limit. The maximum dry density decreases and optimum moisture content increases with the addition of BA and GGBS content due to frictional resistance and flocculation.
3. BA content directly affects the swell-shrink behavior of CH soil, whereas GGBS improve the strength characteristics of clay. Combine a mix of Bagasse ash and GGBS improved the overall characteristics of high plastic clay. Swelling pressure and free swell index decreased by 64% and 60% of the optimum mix with compared to untreated CH soil.
4. Optimum mix shows the three times increase in unconfined compressive strength after 28 days curing compared to untreated soil and eight times increases compared to 0 days curing period. Soaked CBR value also increased to 41% for the optimum mix as compared to untreated soil.
5. The optimum mix cured samples were sustained for more than 6 cycles of wetting-drying while untreated CH soil samples were not sustained even for one complete cycle which shows the good durability of the optimum mix.which shows the good stability against moisture variation.
6. Based on swell-shrink behavior, strength characteristics and durability study; a combined mix of bagasse ash and ground granulated blast furnace slag are suitable to stabilize high plastic clay of study area to fulfill the three aspects cost, durability and reuse of waste for sustainable development.

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