Impact of Wetting - Drying Cycles on Swelling Behavior and Micro- Structural Analysis of Stabilized High Plastic Clay

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Abstract: Clay minerals of expansive soil are susceptible swelling and shrinkage due tomoisture variation. Distress occur expansive clay soils due to drying and wetting cycle, which directly affect the light weight structures. To effect of cyclic wetting- drying phenomena can be reduced by improving the soil. In this study the high plastic clayey soil was treated with industrial waste granulated blast furnace slag and bagasse ash and the influence of wetting and drying cycle on swelling characteristics of treated soil has been investigated in laboratory condition. Such investigation is needed to check the durability of stabilizer to modify the expansive soil. High plastic clay was stabilized with different proportion of BA and GGBS to get optimum mix. Both untreated and (0 and 28 days cured) treated expansive clay were analyzed for wetting-drying cycles. Variations in consistency limits of both natural and untreated clay were investigated. The micro-structural studies were also conducted by X-ray florescence and scanning electron microscopy (SEM). The finding indicates that these waste products reduces the gradual deformation of stabilized high plastic clayey soil subjected to drying and wetting cycles. The result of this research revealed that bagasse ash can be used in soil stabilizer as a pozzolanic material in combination with ground granulated blast furnace slag to improve swell-shrink behavior.

Keywords: Bagasse ash, Ground granulated blast furnace slag, High plastic clay, Stabilization, Wetting drying cycles

1 Introduction:

Expansive clayey soil is susceptible to variation in a volume due to moisture variation. It is good for agriculture purposes but problematic for the light weight structures such as pavements, runways, embankments and low-rise residential buildings due to high swelling and shrinkage behaviour on moisture variation. This behaviour of this soil is due to the existence of an expanding lattice structure of mineral montmorillonite. Montmorillonite expands when it comes in contact with water. Soil available in arid and semiarid regions worldwide, rich in these minerals, where climate characterised by alternating rainfall and drought periods, is subjected to the wet and dry cycle, causing instability and distress. Due to swelling of expansive clays, cracks and deformation propagates in roads, pavements, building foundations, irrigation structure and reservoir linings, pipe lines [1]. It has been reported by Al-Rawas that more than

15 billion dollars cost damage occur on the structure rested on such soil in the United States [2]. A number of researchers, Day, (1994) and Basma (1996) performed full swell-full shrink cyclic wetting-drying tests on untreated clay, which shows an increase in swell behaviour and constant after 4-5 cycles. This behaviour is explained as destruction of the flocculated clay structure and more swelling & permeable soil formation having a dispersed structure [3,4]. Kalkan discussed the impact of wetting-dryingcycle (full swell-partial shrink) on silica fume stabilized expansive clay. Improved the durability of treated sample against the cycles of wetting-drying. Investigated the effect of cyclic swell-shrink (Partial shrinkage method) on swelling behaviour of polymer-stabilized expansive clays [5]. Fateme Yazdandou discussed that SEM analysis shows particles are moving closer together, forming aggregates and reducing the swelling potential [6]. Rao et al, investigated the wet-dry cycles effect (full swell-full shrink) on theconsistency limits of the lime-treated clay. Swell potential of natural soils decreases after the 1st cycle and reached to the equilibrium after fourth cycle. Also swell potentials of soil treated with lime increased due to disturbance in pozzolanic reaction and partial breakdown of inter-particle cementation [7]. Rao A et.al studied the wetting drying (full swell-full shrink) effect on the swelling behaviour ofexpansive soiltreated with fly ash cushion which were treated with cement and lime. Cement treated fly ash cushions showed decrease in heave when compared with lime[7].

Many researchers studied and well documented the wetting and drying cycles impact and expansive behaviour of natural expansive clay and traditional chemicals such as lime and cement stabilized clay. Studies related to influence of wetting & drying cycle on the swelling behaviour of waste material stabilized soils and after 28 days cured period are very limited. Generally, traditional stabilizers relay on capacity of ion exchange and pozzolanic reactions of soil. Pozzolanic reactions happens when aluminous and siliceous materials form cementitious compounds after reaction with calcium hydroxide. Industrial waste, bagasse ash and blast furnace slag can be used to modify the clay because of siliceous and calcareous source. Most of sugarcane bagasse is used as a source of fuel in the same sector, whereas GGBS is primarily used as partial cement replacement for concrete. There is also excellent potential for using these industrial by-products as stabilizing agents. James et al 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 [8]. Currently, India is the world's second biggest producer of sugarcane, produces 341.2 million metric tonnes of sugarcane. This ash is act as pozzolana which is rich in oxides of alumina and silica. Kiran et al, Chittaranjan and Keerthi and Kharade et al. discussed the bagasse ash as a stabilizer for expansive clay and revealed that it can be used to improve the swelling behavior of expansive soil [9-11]. Wani et al., 2015 discussed the mineralogical characterization of bagasse ash, which stated thatbagasse ash is composed of silica mineral such as quartz. Other minerals also reported in varying percent depending on the source of ash [12]. ASTM C618 suggest that for any natural pozzolana; alumina, iron oxide and silica should be at least 70% and also SO_3 content should be less than 4% [13]. It has been reported in almost all the studies related to bagasse ash. The chemical properties of bagasse ash and GGBS are vary widely. GGBS is high in calcium oxide whereas bagasse ash is rich in silica and alumina butlow in calcium oxide. When used as a stablelizing agent, the combination of these two products may be mor e useful instead individual. One will provide enough calcium or silica to react as pozzolana. Several researchers conducted studies on GGBS and/or bagasse ash separately with different stabilizer [14-16]. However, any work has not been released to date on the impact of the wetting drying process on the combine activation of bagasse ash and GGBS as stabilizers for expansive soils. The aim of this research is to explore the long-term behavior on swell-shrink characteristics of stabilized high plastic expansive clay.

2 Materials and Methods:

2.1 Material:

Clayey Soil

The soil samples used in the research have been taken from a Surat, Gujarat, India. Soil available in local region is low to high expansive black clay. The disturbed clayey soil sample was extracted 1 m deep from the ground level. Laboratory tests to classify the soil were performed. Grain size analysis shows the sample content 46 % clay, 33% silt and 21% sand. Sample has been classified as high plastic clay according to the A-line chart. The different geotechnical and chemical characteristics of the soil sample are summarized in table 2 and 1 respectively. Clay sample's specific gravity is evaluated to be 2.6. X-ray diffraction (XRD) analysis and scanning electron microscopy (SEM) images of the clay soil sample are discussed in further section.

Baggase Ash:

The sugarcane bagasse ash was taken from the boiler of sugar factory, Bardoli, which is Asia's largest sugar factory. Bagasse ash is an industrial waste material, generally dumped in farms. In this study collected ash oven dried and passed through 425 µm sieve was used. The measured specific gravity of BA was 2.32. These bagasse ashes (BA) have been chemically studied as shown in Table 1, to evaluate the possibility of their use as stabilizing the material.

Fig. 1 Bagasse ash sample

Ground granulated Blast furnace slag:

The GGBS was taken from the locally available market of Surat, Gujarat, India. It forms from high-quality clinker, slag and gypsum after grinding. It is cementitious waste consist of oxides of calcium, silica and aluminum. GGBS represents the elevated quantity of calcium oxides as a binder material. The specific gravity of GGBS used in this research was measured to be 2.83.

Fig. 2 Powder form of GGBS

Chemical and Mineralogical properties:

The x- ray fluorescence analysis was carried out to obtain the concentration of exchangeable cations which reflects its effect on swelling behavior. The chemical compositions of untreated clay and bagasse ash have been determined using wavelength dispersive x-ray fluorescence method as shown in table 1. Chemical constituent of ground granulated blast furnace slag has been obtained from the cement manufacturer.

Table 1: XRF results of CH, BA and GGBS

Component/ Metal Oxides	Concentration (%)		
	CH	**BA**	**GGBS**
SiO_2	34.71	51.361	26.43
Al_2O_3	5.265	2.005	9.36
Fe_2O_3	44.384	21.267	2.51
CaO	4.92	3.32	41.02
K_2O	1.244	4.074	1
M_gO	1.439	1.127	6.5
Na_2O	0.354	0.319	0.3
SO_3	1.533	6.594	-
TiO_2	3.028	1.791	2.1
Cr_2O_3	0.105	1.207	-
MnO	0.623	0.445	-

Mineralogical analysis was performed using X- ray diffraction (XRD). The X were obtained with the help of X- ray diffractometer advance -8 instrument using Cu Kα radiation. As a result of XRD analysis, Smectite identified in the untreated clay sample which shows existence of montmorillonite mineral. Bagasse ash contains quarts. XRD analysis shows small amount of impurities also due to presence of silt and sand content. Untreated clay shows high liquid and plastic limit due to presence of smectite, which has high water absorption capacity. The analysis has been performed with the help of Joint Committee on Powder Diffraction Standards after comparing with the results of samples.

2.2 Methodology: Preparation of sample:

The collected sample of clay was dried for 24 hrs before at 70°C before grinding. To get optimum mix for durability test, investigation has been carried out using bagasse ash and blast furnace slag in different percentage by dry weight. All three materials are mixed manually in dry state in different proportion using required water. Mixing was done till uniform mixture obtained. Mix prepared for Clay soil with GGBS content varying from 2.5% to 7.5% and bagasse ash varying for 5 to 20% at 2.5 % and 5 % interval respectively to obtain optimum mix sample. Liquid limit & plastic limit (as per IS 2720: PART 5: 1985), shrinkage limit (as per IS 2720: PART 6: 1972), free swell index (as per IS 2720: Part 40) and swelling pressure test (as per IS 2720: Part 41) have been carried out for untreated and treated samples per Indian standard. Optimum water content of mix has been found using proctor test (as per IS 2720: PART 7: 1980) to make remolded sample for swelling pressure analysis as per Indian standard. The optimum mix was selected for cyclic wetting-drying study to check the durability of stabilized soil.

Consistency Limit Tests

After identification to know the degree of expansive soil; plastic limit & liquid limit test performed on untreated and different mix content treated soil as per Indian standard code. Special attention was needed as consistency should decrease while progress of experiment. Shrinkage factors were found out using Part VI of the IS 2720. All sample were prepared by adding water equal to or greater than liquid limit of sample and kept for 24 hrs in humidity chamber to mitigate water evaporation. After filing of shrinkage dish with gentle tapping sample were weighted and kept for oven drying first then for oven drying.

Compaction tests

In order to make a remolded sample to evaluate swelling pressure and wetting-drying cycles; optimum moisture content of untreated and treated samples was found out using light compaction test as per Indian Standard. 5 kg oven dried sample passed through 4.75 mm sieve has been used with different water content on interval of 2-4 % were used depending upon sample. The compaction curves have been plotted to get maximum dry density and optimum water content for every representative samples.

Swelling pressure tests

Swelling pressure test performed on remolded samples of different mix using optimum water content and maximum dry density. Constant volume method has been used as per Indian standard code to determine swelling pressure of 60 mm diameter and 20 mm height samples of all mix. Samples were confined from all direction to measure swelling pressure. Free swell index was carried out using 10 gm oven dried sample passing through 425-micronsieve. Samples were put to swell freely in cylinder filled using distilled water and kerosene for 24 hrs.

Preparation of specimens for Durability study: Wetting-Drying Cycles tests:

This test has been carried out to analyze the impact of stabilizer on the swell behavior of soil subjected to alternate wetting and drying cycles which reflect the durability of stabilized soil on seasonal change. Wetting –drying cycle has been applied to untreated clay sample, 0days cured optimum mix sample and 28 days cured optimum mix sample. During the test, the samples have been submerged at room temperature in potable water to allowing wetting for five hours; wetted specimens were dried at 70°C in the thermostatically controlled oven for 42 hours. In between wetting and drying period, sample is allowed to dry at room temperature for 12 to 18 hr. This constitutes one cycle of wetting and drying as per IS 4332: Part IV. At the end of every cycle, swelling pressure has been measured. Swelling pressure test were carried out on swelling pressure apparatus using control volume method. This procedure was repeated till six cycles.

Scanning Electron Microscopy (SEM):

SEM study reported till date shows effect of wetting-drying cycle on treated uncured samples, no study reported for 28 days cured sample SEM analysis. To check the effect of wetting drying cycle on 28 days cured optimum mix sample, specimen were given for scanning electron microscopy. Samples for this test were prepared for the following conditions. (a) 28 days cured remolded sample with zero wetting-drying cycle (b) 28 days cured remolded sample after two wetting-drying cycles (c) 28 days cured remolded sample after six wetting-drying cycles.

The samples were kept for dry at room temperature. Then samples were taken for scanning electron microscopy analysis at the Bombay textile research association, Mumbai. The samples were analyzed using instrument named JEOL JSM IT 200. Magnification from 50 X to 2000X was used to analyze the sample.

3 Results and Discussion:

The experimental work was divided into three phases. In the first phase, the geotechnical and chemical characteristics of the soil, BA and GGBS were identified. In the second phase, the optimum content was determined to modify the soil sample and durability tests were carried out on untreated and optimum mix sample. In third part Scanning electron microscopy analysis performed and analyzed. In this paper durability study- wetting drying analysis and mineralogical study for untreated and optimum sample were presented.

Table 2: Geotechnical characteristics of Clay and Optimum mix sample

Soil property	Clay	Optimum Mix
Liquid limit (%)	64.05	46.55
Plastic limit (%)	27.12	29.61
Plasticity Index (%)	42	19.44
Shrinkage limit (%)	22.42	46.32
Optimum moisture content (%)	22.7	29.23

Maximum dry density (kN/m^2)	1.58	1.431
Swelling Pressure (kN/m^2)	54.917	19.74
Free Swell Index (%)	66	27

Different tests such as Atterbeg limits, swelling pressure test, compaction, CBR, UCS were performed on different proportion of CH, BA(5 to 20 %) and GGBS (2.5 %, 5%, 7.5%) mix. Based on swelling and strength properties, 82.5 % CH, 10 % BA and 7.5% GGBS mix was considered as optimum mix for the soil of study area. Good bonding and pozzolanic reactions occur between BA, GGBS and CH soil for this proportion which increases enough compression strength and decreasing swelling pressure, adding more GGBS may cause over-safe design for light weight structure.

Effect on Atterberg Limits:

Bagasse ash content was found to be directly associated with the reduction of liquid limit and plasticity index as shown in fig 3. Plasticity is good swelling potential measure, reduction in plasticity index represent the reduced swelling potential. Same as the shrinkage limit of clay and bagasse ash mixtures increasing with binder content as shown in fig. 4. Increase in shrinkage may be due to the development of interaction between bagasse ash – GGBS mix surface and soil matrix. It is known that significant modification in the index characteristics of soil occur with the addition of non-swelling material such as Bagasse ash, which reduces the thickness of diffuse layer and so that clay particle flocculated [17]. The consequent reduction in the affinity towards water and the particle surface area resulted in reduction in the plasticity. High plastic clay is converted into low to medium plastic for optimum mix samples.

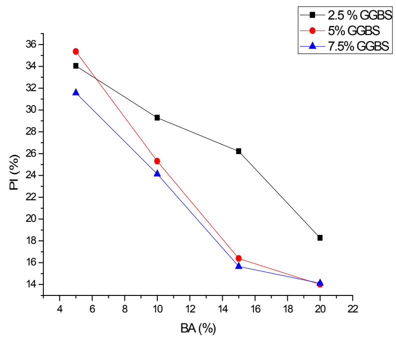

Fig. 3 PI with varying percent of BA for GGBS stabilized clay

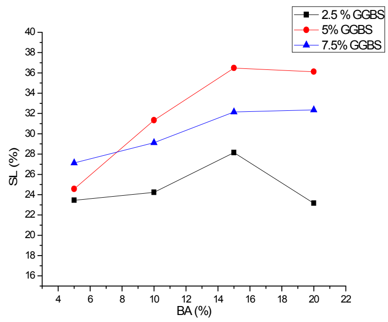

Fig. 4 SL with varying percent of BA for GGBS stabilized clay

Effect on compaction characteristics:

Figure 5 and 6 shows the impact of the mix on the optimum water content (OMC) and the MDD respectively. Generally, with increase of mix content, OMC decreases and MDD increases. 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 also for other type of ashes like rise husk ash, fly ash [18-20]. The reduction in dry density explained as varying specific gravities of soil and stabilizer [21]. 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.

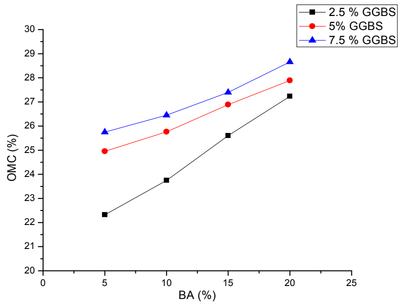

Fig. 5 OMC with varying percent of BA for GGBS stabilized clay

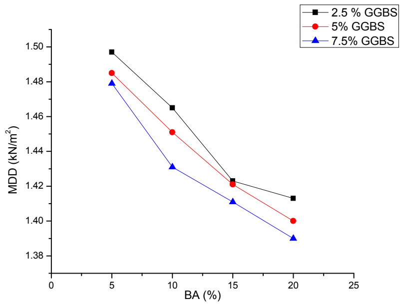

Fig. 6 MDD with varying percent of BA for GGBS stabilized clay

Effect on swelling characteristics

Swelling characteristics in this study is defined by swelling pressure and differential free swell index. Reduction in swelling pressure observed as shown in figure 7. with the increase of bagasse ash.

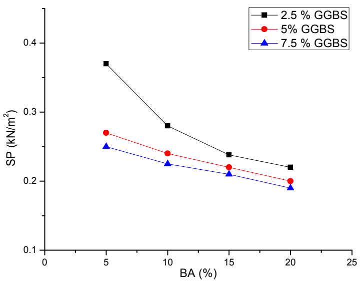

Fig. 7 SP with varying percent of BA for GGBS stabilized clay

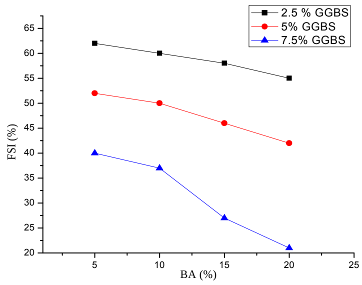

Fig. 8 FSI with varying percent of BA for GGBS stabilized clay

Decreasing rate of pressure is less in case of addition of GGBS when compared with bagasse ash. Free swell index is also decreasing as increase percent of bagasse ash as per figure 8. Swelling pressure and free swell index reduced on addition of BA due to increase of exchange of ions and flocculation. Also, non-expansive material bagasse ash replaces the expansive clay which reduces the swelling pressure and free swell index. 10 % to 20% bagasse ash recommended for soil available in study area, after that it became constant with the combination of 5 to 7.5 % GGBS.

Effect of Wetting and drying cycles:

Wetting – drying cycle has been performed on untreated clay sample and (0 days cured and 28 days cured) optimum mix sample. Figure 9 shows the swelling pressure decreases for untreated and 0 days cured optimum mix sample after every wetting drying cycle. It has been found that with increasing wetting-drying sample swelling pressure is decreasing for both the sample and became constant after fourth cycle for untreated sample. 0 day cured optimum mix sample shows continuous decreasing rate with each wetting-drying cycle. It has been observed that 28 days cured sample converted into non swelling due to flocculation and pozzolanic bonding between clay and BA particles with GGBS. Wetting-drying results shows zero swell pressure when measured by constant volume method using swelling pressure apparatus. Six wetting-drying cycle has been applied on the same sample which results shows zero swelling pressure for each cycle.

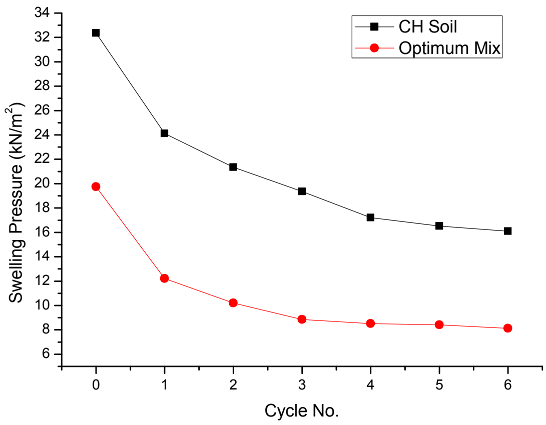

Fig. 9 Swelling pressure with no. of wetting drying cycles

Image Analysis:

Scanning electron microscopy images of natural high plastic clay and 28 days cured optimum mix sample after 0, 2nd and 6th wetting – drying cycle has been presented in figure below.

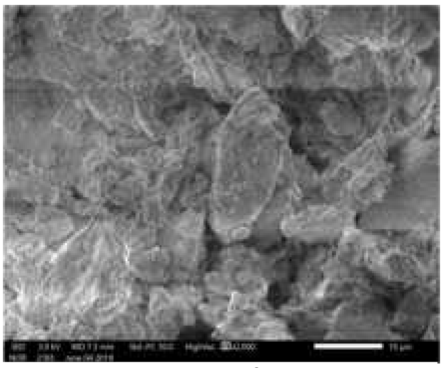

Fig. 10. SEM of CH Soil

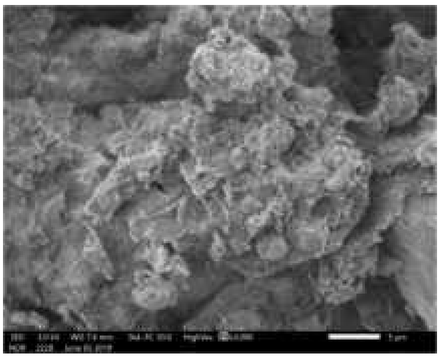

Fig. 11. 28 days cured mix sample (0 Cycle)

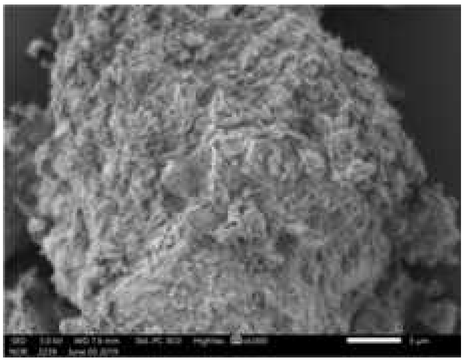

Fig. 12. 28 days cured sample after 2nd cycle

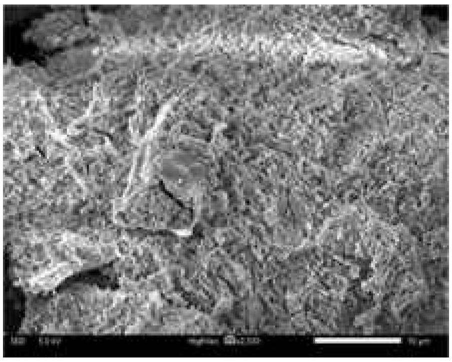

Fig. 13. 28 days cured sample after 6th cycle

Figure 10 shows that large size pores and unbounded clay particles increase the total void spaces and also pores are not connected with each other properly. Figure 11 shows the decrease in pore spaces and bonding due to aggregation and flocculation of bagasse ash and GGBS content with the soil after 28 days curing period. These microscopic images and experimental outcomes show the possible reaction occur between BA -GGBS mix with clay particles. It has been seen that after second wetting-drying cycle (Figure 12) minimum voids observed which represent, mix sample not affected by wetting drying cycle. Stabilizer covers the surrounding clay soil particles and fill the voids of the stabilized clayey soil samples. Figure 13 shows the microscopy images after sixth sample, flocculated structure observed and surface area of particle decreases which reduce the water affinity of sample which may be responsible for the improvement in swelling pressure. A detailed study shows maximum flocculation structure observed on the surfaces of the soil particle.

4 Conclusion:

The aim of this study is to evaluate the impact of waste material bagasse ash-GGBS based mix on the swell shrink characteristics of high plastic expansive clay and to find the optimum mix to stabilize it. The study attempted to analyze the impact of wet and dry cycles on swelling behavior of natural high plastic clay and optimum mix sample. The following conclusions are drawn from the outcomes of the different experiments performed.

1. Use of bagasse ash and GGBS mix to the soil reduced liquid limit and plasticity index while increasing the shrinkage limit. It is found that the addition of binder causes flocculation of clay particles and increases the number of coarser particles which help in reducing the plasticity.
2. Reduced MDD and increased OMC observed on addition of mix. It can be explained due to lower specific gravity of BA caused reduction in dry density and flocculation and agglomeration of particles occupying larger spaces leading to

corresponding decrease in dry density. This is due to predominant effects of reduced clay content and increased frictional resisting respectively.

3. Swelling pressure and free swell index reduced on addition of BA due to replacement of expansive clay with non-expansive material. 10 to 20 % BA recommended with the combination of 5 to 7.5 % of GGBS. It has been observed that Bagasse ash content directly affect the swell-shrink behavior of sample various GGBS improve the strength characteristics of clay. So combine mix of Bagasse ash and GGBS improved the all characteristics of high plastic clay.
4. From the experimental results, 82.5 % CH, 10 % BA and 7.5% GGBA mix has been chosen as an optimum mix for the soil of study area and wetting – drying cycle are given to untreated and (0 day and 28 days cured) optimum mix sample to check its durability against seasonal variation. Untreated sample shows reduction in swelling pressure for each wetting drying cycle and reached to equilibrium after fourth cycle, whereas 0 day cured optimum mix sample shows reduction pressure for all cycle. Results indicates non swelling behavior for 28 days cured optimum mix sample. Scanning electron microscopy images of 28 days cured sample after 0, 2^{nd} and 6^{th} wetting drying cycle shows agglomeration and flocculation of structure. It has been seen that pore space and particle surface area reduces which reflect the less water affinity of particle.

The findings of the test showed that industrial waste bagasse ash able to protect low to high plastic expansive clay from the adverse effect of swelling. Furthermore, bagasse ash reduced the swell pressure of expansive clay after replacing clay minerals. Combine effect of BA- GGBA mix on high plastic clay proved to be a good pozzolanic material against seasonal variation and gives good durability. It is very essential to use it as a step towards sustainable development in the current world, where a range of industrial waste is accessible in large amount.

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