Stabilization of expansive soil by using industrial waste

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Abstract. The production of sugarcane bagasse ash (SBA), glass fiber (GF) and ceramic dust (CD) in developing countries at very large scale usually poses a severe disposal problem. The purpose of this research is to determine whether these three waste products are suitable for improving the engineering characteristics of expanding soil. The study has been carried out by varying the content of SBA (0-20%), CD (0-20%) and GF (0-4%) in black cotton soil. Optimization was carried out to find out the composition of the ideal quaternary blend. The use of these materials was found to decrease the maximum dry density and swelling of soil with increase in optimum moisture content. In addition, the liquid limit was found to decline with increment in CBR and unconfined compressive strength. The study confirms the use of these waste materials as soil stabilizers in addition to provide a solution for waste reuse.

Keywords: Expansive soil, Ceramic dust, Sugarcane Bagasse Ash, Liquid limit, OMC, MDD, CBR.

1. Introduction
Black cotton soil is a typical expansive soil that covers more than over 20% of topographical space of India including Andhra Pradesh, Maharashtra, Tamil Nadu, Gujarat, and Madhya Pradesh[1]. Expansive soil presents several hidden threats. This soil contains an enormous amount of montmorillonite and illite minerals that result in expansion and shrinking with absorption and discharge of water[2]. As a result, the foundation, pavement, rail, road, and channel structures constructed on such soil type may face contraction stress due to changes in volume of soil which in turn may lead to fracture and severe loss[3]. Since expansive soil has a very unfavorable nature, geotechnical engineers have been using different methods to reduce its effects through soil stabilization practices[4]. The goal of the engineers that specialize in expansive soil stabilization is to have the soil remain stable without substantially changing its volume or plasticity, as well as greatly improving its strength qualities[5]. Although the techniques for stabilizing expansive soil have evolved through time, one of the issues is concerned with using sustainable practices aiming at recycling and waste minimization[6].

Generally, the studies are based upon use of lime as the prime soil stabilizer but with the advent of rapid industrialization leading to overuse and scarcity of resources, researchers are trying for innovative solutions[7]. India is a developing country with high population rise and enormous agricultural, construction and industrial activities that results in generation of various type of wastes that are generally discarded as such and cause pollution[8–10]. Literature reports many studies on use of industrial and agricultural waste as soil stabilizers[11]. These materials include sugarcane bagasse ash, fly ash, sawdust, alccofine, ground granulated blast furnace slag, natural as well as synthetic fibers, and ceramic dust etc. [12] Experts across the globe are strengthening soil by improving the
mechanical and physical characteristics using natural and synthetic fibres in recent years[13]. Glass fibres have garnered the significant interest with its random distribution in soil leading to reinforcement. Rabab’ah et al. observed that glass fiber (GF) is more efficient in stabilizing at large strains in subgrade soil [14]. Sujatha et al. varied GF content from 0.25 % to 1.0 %, and better results were obtained at 1% fiber content [15]. Abbey et al. determined the effect of incorporation of GF in presence of polypropylene fibres on the microstructure of clay [16].

Bagasse is the fibrous waste left behind after sugarcane juice extraction. Burning of bagasse as fuel in sugarcane industries results in the generation of sugarcane bagasse ash (SBA), which is usually dumped into pits or discarded as such[17]. James and Pandian have reported that SBA with its pozzolanic action due to presence of enormous content of silica, has been found more viable in lessening the swell index than lime alone[18]. The cation exchange between clay, SBA, and lime provides additional stability. Using lime mixed with SBA forms new cementation compounds-calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH) due to the pozzolanic reaction between portlandite and silica that helps to improve soil stability. Kumar Yadav et al. have used optimized content of SBA for stabilization of alluvial soil[19].

A majority of the waste materials produced during construction and demolition of buildings is made up of ceramic wastes, including tiles, sanitary goods, and marble. The disposal, recycling and reuse of this waste with potential environmental hazards is also a major issue[20]. Many studies have been conducted by using ceramic wastes as replacements in concrete manufacturing, paving, and soil stabilization owing to their pozzolanic action. Cabalar et al. found that adding waste ceramic dust (CD) to a Clay soil decreased its plasticity index and swell potential while increasing the workability and CBR of the soil[21]. Likewise, Okeke observed a positive impact of addition of CD on engineering properties of expansive soil in presence of lime[22]. Keeping in consideration of the beneficial applications of SBA, GF and CD along with cost-effectiveness, this study is aimed to examine the effect of addition of these soil stabilizers on the index as well as engineering properties of the black cotton soil.

2. Materials and methods

The black cotton soil taken for the current examination was obtained from Totadayallapur, Haveri District, Karnataka. Table 1 summarises the characteristics of the used soil. Three stabilizers namely, sugarcane bagasse ash (SBA), glass fibre (GF) and ceramic dust (CD) were obtained from a nearby vendor and their sieve size was made up to size of soil particles (0.08 mm). The effect of incorporating SBA in soil was studied by using various proportions by weight of soil mass with SBA (5%, 10%, 15%, 20%) and CD (5%, 10%, 15%, 20%). The optimum content of GF was ascertained by varying content from 0 to 4% during the soil failure test and 3% of GF was obtained as optimized content as after this content, the GF started oozing out. The specimens were completely blended by employing a mechanical mixer and tested further with standard compaction in agreement with IS: 2720(Part 7). Free swelling index (FSI) and Unconfined compressive strength (UCS) were analyzed in agreement with IS: 2720 (Part 40):1977 and IS 2720 (Part 10):1991 respectively. Atterberg’s limit (liquid limit) and CBR (California Bearing Ratio) were analyzed in agreement with IS: 2720 (Part-5)-1985 and IS: 2720 (Part-16) respectively as outlined in Figure 1.

| Parameter | Specific gravity | Liquid limit | Plastic limit | Shrinkage limit | Maximum dry density | Plasticity index |
|-----------|-----------------|--------------|---------------|----------------|---------------------|-----------------|
| Value     | 2.61-2.63       | 54-60 %      | 18-20 %       | 10-11 %        | 1.45 g/cc           | 36-40 %         |
Table 2. Variation of stabilizers in soil specimens

| Designation of Specimen | SBA (%) | CD (%) | GF (%) |
|-------------------------|---------|--------|--------|
| S1                      | -       | -      | -      |
| S2                      | 5       | -      | -      |
| S3                      | 10      | -      | -      |
| S4                      | 15      | -      | -      |
| S5                      | 20      | -      | -      |
| S6                      | 15      | 5      | -      |
| S7                      | 15      | 10     | -      |
| S8                      | 15      | 15     | -      |
| S9                      | 15      | 20     | -      |
| S10                     | 15      | 10     | 1      |
| S11                     | 15      | 10     | 2      |
| S12                     | 15      | 10     | 3      |
| S13                     | 15      | 10     | 4      |

3. Results and discussion

3.1 Free Swell Ratio (FSR)

The inclusion of SBA, CD and GF, the non-expansive materials has been reported to reduce FSR as per literature reports [17,22]. Figure 2 displays the variation of FSR with addition of SBA. As the proportion of SBA increased, the FSR values declined significantly till inclusion of 15% SBA resulting in a reduction of 22% (Table 3). Since SBA has abundant cation exchange and flocculation capacity, it helps to improve the FSR [17]. More effective than SBA alone was addition of CD, which reduced the FSR by 28% at 10% CD. However, the better results were obtained with inclusion of GF.
As the proportion of GF increased, the FSR values dropped. The minimal FRS for specimen S12 corresponds to SBA 15%, CD 10% and GF3%. The increased strength of the fiber-soil matrix results in less mobility of the soil and controls the swell behaviour[14].

### Table 3. Soil expansion behaviour of specimens

| Specimen | FSR | Soil Expansion |
|----------|-----|----------------|
| S1       | 2.43| High           |
| S2       | 2.17| High           |
| S3       | 1.94| High           |
| S4       | 1.89| Moderate       |
| S5       | 1.96| High           |
| S6       | 1.87| Moderate       |
| S7       | 1.75| Moderate       |
| S8       | 1.78| Moderate       |
| S9       | 1.85| Moderate       |
| S10      | 1.83| Moderate       |
| S11      | 1.69| Moderate       |
| S12      | 1.48| Low            |
| S13      | 1.53| Low            |

### Figure 2. FSR of specimens

3.2. **Liquid limit (LL)**

The LL variation greatly influences soil compression and swelling, i.e. reduced LL implies less compression and swelling[17]. Figure 3 illustrates the effect of addition of SBA, CD and GF in varying dosages on the liquid limit (LL) of the used soil. It can be seen that with addition of SBA, the LL continuously decreases. It has been documented in the literature that in the process of ash soil stabilisation, a decrease in the LL and rise in the plastic limit are both seen [19]. Addition of CD resulted in further decrease in LL continuously indicating better results with presence of both SBA and
CD. The general decrease in LL for all specimens is due to the production of cementitious compounds, namely calcium silicates, as a result of the interaction of silica particles in SBA and CD with soil particles [1]. However, more reduction in LL was observed with addition of GF from 1-3%. The decrease in LL specifies that the incorporation of GF in presence of SBA and CD improves the overall behaviour of the soil. The slight increase at 4% GF can be assigned to the oozing out of GF from soil at higher content.[14]

![Figure 3. Variation of Liquid limit](image)

3.3. Standard Proctor Compaction Test

Figure 4 displays the variation in optimum moisture content (OMC) on adding SBA, CD and GF in varying combinations. OMC was observed to enhance with increase in SBA dosage in binary blends. This may be explained by the increased proportion of coarser materials in the blends as a consequence of the addition of SBA, which reduces clay and free silt [5]. Further, inclusion of CD in the ternary blends and GF in quaternary blends improved the OMC. This indicates that more water will be needed to compress the mixture. The variation in maximum dry density (MDD) due to the incorporation of SBA, CD and GF in various proportions is obvious in Figure 5. MDD is observed to diminish when stabilizer concentration increases in specimens. The decrease in MDD may be accredited to the soil particles in the mixture being replaced with particles of stabilizers[23]. Better results were obtained with GF. Because GF particles have a lower special gravity than soil particles, they serve as a filler in soil gaps[7].

3.4. CBR Test

The CBR test analyses the bearing limit of soil[24]. Figure 6 shows the evaluation of soaked CBR values at a curing age of 7 and 28 days with varying dosage of SBA, CD and GF in the specimens. As can be seen, there is an increase in CBR values up to a 10% dose of SBA and thereafter a drop is detected in case of binary blends. Similarly, the further increase in soaking CBR from 0-15% with the addition of CD in presence of 15% SBA may be owing to the production of calcium silicates as a result of a soil-silica interaction [22]. The subsequent reduction in the soaking CBR shows that excess silica does not react with soil particles and therefore has a detrimental effect on particle binding [4,25].

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The CBR further improved with inclusion of 1-3% in presence of 15% SBA combinations with slight decrease later on possibly due to friction between GF at high concentrations and decreased binding in blends[14].
Figure 6. Variation of CBR

3.5. Unconfined compression strength (UCS) Test

The result of UCS test on treated soil with SBA, CD and GF after curing for 7 and 28 days is shown in Figure 7. UCS was found to improve from 7 days to 28 days of curing for all the specimens. Maximum value of UCS was obtained for specimen with addition of GF in presence of SBA and CD. According to earlier reported results, the expansion in UCS can be identified with the hydration and pozzolanic response among soil and silica present in stabilizers forming calcium-silicate hydrate (CSH) that consequently fills the inward holes, and holds the particles together thereby improving the strength\[14,17\]. Thus, optimized combination of these waste materials comprising of SBA, CD and GF can be used to improve the soil quality with simultaneously solving the issues of waste disposal by effective reuse.

Figure 7. Variation of UCS
4. Conclusion

The study was designed to determine the impact of SBA, CD, and GF additions on the engineering characteristics of expansive soil. The addition of these three waste materials was found to positively impact the soil properties as concluded here.

1. The blending of SBA, CD and GF in soil diminishes its FSR and MDD while improves the OMC, because of their non-plastic behavior and tendency to replace the various cations in clay minerals.
2. The optimized combination of 3% GF, 10% CD and 15% SBA was found to decrease the liquid limit with improvement of CBR value.
3. UCS of specimen with optimized stabilizers was found to improve significantly due to onset of pozzolanic reaction.

Thus, the optimized content of usually discarded waste materials SBA, CD and GF can be used for stabilization of the soil as well to solve the pollution issue.

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