Enhancing the engineering properties of expansive soil using bagasse ash

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Abstract. This paper deals with stabilization of expansive soil on a laboratory experimental basis. The aim of the research was to evaluate the enhancement of the engineering properties of expansive soil using bagasse ash. The soil is treated with bagasse ash by weight (0, 5, 10, 15, and 20\%) based on dry mass. The performance of bagasse ash stabilized soil was evaluated using physical and strength performance tests, namely the plasticity index, standard Proctor compaction, and percentage swelling. An X-ray diffraction (XRD) test was conducted to evaluate the clay mineral, whereas an X-ray fluorescence (XRF) was to the chemical composition of bagasse ash. From the results, it was observed that the basic tests carried out proved some soil properties after the addition of bagasse ash. Furthermore, the plasticity index decreased from 53.18 to 47.70\%. The maximum dry density of the specimen increased from 1.13 to 1.24 gr/cm\textsuperscript{3}. The percentage swelling decreased from 5.48 to 3.29\%. The outcomes of these tests demonstrate that stabilization of expansive soils using bagasse ash can improve the strength.

1. Introduction

Expansive soils cause several problems for civil engineering infrastructure. Various methods are applied to improve the characteristics of expansive soils. Soil stabilization is one of the construction techniques because it improves the engineering properties of soil such as the strength and volume stability. When the soil strength properties cannot be improved by mechanical stabilization, the chemical admixture technique is used to achieve the desired strength. Chemical stabilization is the most popular method utilized to enhance the physical and mechanical properties of problematic soils consisting of soft soil and expansive soil.

In recent years, a considerable number of laboratory experiments have been carried out, and extensive studies have been conducted on reactive soil using various additives such as lime [see references: 1, 2, 3, 4]; sand, and cement [see reference 5]. Several waste by products including fly ash [see reference 6], sugar cane straw ash [see reference 7], eggshell powder [see reference 8], blast furnace slag [see reference 9], marble dust [see references 10], stone dust [see reference 11], and used lubrication oil [see reference 12] have been investigated by employing each material alone or in combination with other additives. Many researchers [see reference: 13, 14, 15, 16, and 17] have performed several studies on bagasse ash to evaluate the stabilization properties of expansive soil. Based on the test results, they indicated that bagasse ash admixture caused significant modification and improvement of the engineering properties of expansive soil. Bagasse is the fibrous residue generated after the juice has been extracted from the sugar cane plant. It is deposited as waste and it
pollutes the environment [4]. The resulting ash is deposited in stockpiles, which are dumped in waste landfills and constitute environmental problems for society.

In this paper, the expansive soil is embedded with different proportions of bagasse ash (0, 5, 10, 15, and 20% based on dry soil mass). Various tests are carried out on the modified expansive soil to find the index properties, maximum dry density, and percentage swelling.

2. Methodology

2.1 Clay Soil
The soil used in this study was obtained from the district of Jono, in Sragen, Central Java from a depth of 0.5 to 1.0 m below the natural ground level. Samples were kept safe and dry in jute bags. They were air dried to allow elimination of water, which may affect sieve analysis. X-ray diffraction (XRD) was conducted to evaluate the soil mineralogy.

2.2 Bagasse Ash
Bagasse ash is a residue obtained from the burning of bagasse in sugar-producing factories. This material contains amorphous silica, which is an indication of cementing properties, which can develop good bonding between grains in the case of weak soil. To stabilize expansive soil, the waste product bagasse ash is collected from Mojo Sugar Company, situated in Sragen Central Java. Bagasse ash is used as a stabilizer to deal with environmental concerns through the reduction of sugar industry waste material. An X-ray fluorescence (XRF) test was conducted to evaluate the chemical composition of bagasse ash material. Figure 1 shows a photograph of bagasse ash material.

![Bagasse ash material](image)

Figure 1. Bagasse ash material.

2.3 Experimental Investigation
In this study, the additive contents are defined by the ratio of the weight of a particular additive to the dry weight of the soil, expressed as a percentage. Experimental oedometer tests were conducted by the authors on selected expansive soil samples with different bagasse contents, that is, 0, 5, 10, 15, and 20%. The soil samples were examined to determine the percentage swelling using Equation 1. Swelling tests were conducted on samples prepared at a water content similar to the optimum moisture content for untreated soil with various dry densities depending on the standard compaction (ASTM D 698-91). In the first step, a series of tests were conducted on untreated expansive soil samples. The second set of tests was associated with bagasse-ash-treated soil. The sample used for the swelling test is illustrated in Figure 2.
Figure 2. Specimen behavior under swelling test.

An oedometer is one of apparatuses used to measure the degree of swelling. The swelling process is the opposite of the consolidation process; that is, the volume of the soil increases gradually because of excess negative pore pressure [19]. The percentage swelling according to SNI 6424:2008 is calculated using

$$\text{Percentage swelling} = \frac{\Delta h}{h_0} \times 100\%$$

3. Results and discussion

3.1 Characteristics of natural soil

The soil samples used in this paper were collected from the district of Jono in Sragen, Central Java, Indonesia. Table 1 shows the physical properties of the soil used in this investigation. In term of the sizes of particles, the soil was classified as clay of high plasticity (CH) according to the Unified Soil Classification System (USCS). The specific gravity of solids (Gs) was 2.62. The grain size distribution showed that 96.23% was fine-grained material (silt/clay). The Atterberg limits of the fine portion of material were a liquid limit (LL) of about 87.35% and a plastic limit (PL) of 33.37%, which resulted in a plasticity index (PI) of 53.98%. Based on the high plasticity index, the soil can be classified as highly expansive soil.

| Properties                        | Value   |
|-----------------------------------|---------|
| Natural water content (%)         | 53.87   |
| Specific gravity (Gs)             | 2.62    |
| Unit weight (kN/m³)               | 14.2    |
| Percentage passing 75-μm sieve (%)| 96.23   |
| Liquid limit (%)                  | 87.35   |
| Plastic limit (%)                 | 33.37   |
| Plasticity index (%)              | 53.98   |
| USCS                              | CH      |

3.2 XRD test of clay soil from Jono district

XRD was conducted to evaluate the mineralogy of the clay soil. Table 2 shows the XRD results.
Table 2. Major peaks found by XRD test.

| No. | Peak no. | 2Theta (°) | d (Å) |
|-----|----------|------------|-------|
| 1   | 22       | 20.12      | 4.40979 |
| 2   | 30       | 26.8194    | 3.32151 |
| 3   | 3        | 5.8283     | 15.1516 |

3.3 XRF test of Mojo Sugar Company bagasse ash
The chemical composition analysis of the bagasse ash was carried out by XRF test, and the results were as shown in Table 3. The bagasse ash was found to contain mainly silicon, calcium, potassium, and aluminum.

Table 3. Chemical composition analysis of the bagasse ash.

| Abbreviation | Ash (%) | Abbreviation | Ash (%) |
|--------------|---------|--------------|---------|
| SiO2         | 67.33%  | MnO          | 0.27%   |
| CaO          | 12.51%  | ZnO          | 0.05%   |
| K2O          | 4.11%   | Nd2O3        | 0.05%   |
| Al2O3        | 3.45%   | CuO          | 0.05%   |
| Fe2O3        | 3.39%   | V2O5         | 0.02%   |
| P2O5         | 3.10%   | ZrO2         | 0.02%   |
| SO3          | 2.81%   | Rb2O         | 0.02%   |
| MgO          | 2.04%   | Cr2O3        | 0.01%   |
| Cl           | 0.46%   | Bi2O3        | 0.01%   |
| TiO2         | 0.28%   |              |         |

(Source: XRF test, Lab. MIPA Terpadu UNS)

3.4 Result of Atterberg Limit for Treated Soil
Atterberg limits were found, and grain size tests were conducted on the natural and treated soil in the investigation to determine LL, PL, and PI. Figure 3 shows the variation of LL, PL, and PI with the percentage of bagasse ash.

![Figure 3. Effect of bagasse ash on Atterberg limit of soil-bagasse ash mixes.](image)
The PI of the clay sample treated by bagasse ash showed a decrease with increases in the quantity of bagasse ash added, as illustrated in Figure 3. The addition of bagasse ash has a remarkable effect on the plasticity of cohesive soils. The general decrease in the liquid limit for the combination of bagasse ash is attributed to the fact that the compounds formed possess cementitious properties due to calcium silicate with soil particles.

3.5 Compaction Behavior
Light compaction tests were conducted on the natural and treated soil in the investigation to determine the maximum dry density (MDD) and optimum moisture content (OMC) values. Figures 4 and 5 show the variation of OMC and MDD with the percentage of bagasse ash, respectively.

![Figure 4](image-url)

**Figure 4.** Effect of bagasse ash the optimum moisture content of soil/bagasse-ash mixes.

![Figure 5](image-url)

**Figure 5.** Effect of bagasse ash the maximum dry density of soil/bagasse-ash mixes.

Figure 4 shows that the OMC decreased with increases in the percentage of bagasse ash mixture, and Figure 5 shows that the MDD increased with increases in the percentage of bagasse ash mixture. Bagasse ash causes the soil particles to flocculate. Thus the soil becomes more easily workable and its strength and stiffness increase.
3.6 Percentage Swelling of Treated Soil
A consolidation test according to the ASTM D 2435-02 setup was used to determine the percentage swelling of the soil. The percentage swelling of the soil was calculated with Equation 1. Table 4 and Figure 6 show the results of the treated soil.

Table 4. Test results of swelling behavior of treated soil.

| Percentage of bagasse ash (%) | $H_0$ (cm) | $H_1$ (cm) | Percentage of swelling (%) |
|-------------------------------|------------|------------|---------------------------|
| 0                             | 1.8        | 1.90       | 5.48                      |
| 5                             | 1.8        | 1.90       | 5.28                      |
| 10                            | 1.9        | 1.97       | 3.54                      |
| 15                            | 1.9        | 1.96       | 3.08                      |
| 20                            | 1.9        | 1.96       | 3.29                      |

![Figure 6](image.png)

Figure 6. Variation of percentage swelling value with the percentage of bagasse ash.

The addition of 5, 10, and 15% bagasse ash led to a reduction in the percentage swelling. A bagasse ash dose of 15% led to the smallest percentage swelling, so we can say that this was the optimum dose. At a bagasse ash dose of 20%, the percentage swelling tended to increase by a small value.

4. Conclusion

Use of the soil stabilization method by applying waste product bagasse ash was able to successfully improve the expansive soil. The addition of bagasse ash reduces the plasticity index and the percentage swelling and increases the maximum dry density. Bagasse ash is cost-free and available locally; hence it proved economical too. Further research needs to be conducted to find the optimum percentage of bagasse ash that should be applied as a stabilizer and used in combination with other additives, that is, slag furnace, plastic waste, and so on.

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