# Soil Stabilization Using Agro-industrial Waste

**K. L. Anaslal, P. A. Gopika, Sneha S. Menon, and R. Sujana**

**Abstract** Stabilization of soil is essential to create strong foundations for infrastructure. Studies are being conducted to evaluate the efficacy of existing methods and to develop novel methods in the domain of soil stabilization. Though economy, efficiency and sustainability are the key aspects to be considered in any stage of a project, most of the existing practices fails to fulfil these altogether. Using refuse and industrial wastes as additives in ground improvement can help preserve the environment and promote sustainable practices. The present study aims at using agro-industrial wastes viz. eggshell powder and sugarcane bagasse ash as stabilizing materials. Due to the pozzolanic characteristics of these materials, they can be used as a good substitute for industrial lime also. The effect of adding eggshell powder and bagasse ash on the strength and settlement properties of soft soil will be evaluated based on various laboratory tests such as unconfined compressive strength test, permeability test, compaction test, CBR test etc. The best additive proportion was determined based on test outcomes, which assisted in analyzing how soil qualities improved in the presence of additives.

**Keywords** Soil stabilization · Bagasse ash · Eggshells · Agro-industrial wastes

## 1 Introduction

This study aims to understand the effect of stabilizing additives such as egg shells and sugarcane straw ash on the soil properties. The materials were used since they were affordable and easily accessible in the area. Sugarcane bagasse ash is a pozzolanic material because it is a burned product of sugarcane bagasse, which has a high silica concentration. Egg shell powder can be used as a substitute for lime-based soil stabilizers due to its high level of calcium, protein, and lime. Studies were carried out using a series of laboratory experiments, including fundamental soil tests and strength tests, which determined the soil to be weak soil. Repeating the same tests

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with a mixture of eggshell powder and bagasse ash in different ratios (3%, 6%, and 9%) of plain soil was necessary to determine the various strength properties of the soil with the additives and compare them to those of plain soil. Stabilization of soils using Agro-industrial waste products results in safe disposal and increased strength and stability of soil.

Carlina et al. (2021) found that adding bagasse ash and eggshell powder increased the CBR value of clay soil, due to their silica content and calcium content binding water to clay [1]. Kiran et al. (2013) found that bagasse ash and additives increased the CBR and UCS values of black cotton soil [10]. Kharade et al. (2014) found that partial replacement of Bagasse Ash improved maximum dry density, but increased moisture content, leading to weak bonds and less strength [7]. Wubshet et al. (2016) found that additives such as 3% lime, 15% bagasse ash and 3% lime plus 15% bagasse ash increased the optimum moisture content of soil mixes from 32.2% to 41.0%, 43.2% and 52.2% respectively [6]. Hitesh et al. (2016) found that the addition of bagasse ash can significantly improve the engineering properties of black cotton soil, making it a viable option for stabilization in construction projects [3]. Basack et al. (2021) studied the geotechnical properties of soil treated with bagasse ash and stone dust, including compaction, shear strength, and permeability. Additionally, they analyzed the cost-effectiveness of using these additives for soil stabilization and for transport infrastructure projects [4]. Beegom et al. (2017) found that egg shell powder can be a potential alternative to lime for soil stabilization, offering favorable engineering properties and environmental benefits [5]. Ali et al. (2014) found that the addition of marble dust and bagasse ash can effectively improve the engineering properties of expansive soils, reducing their susceptibility to volume changes and also contributes to sustainable and cost-effective methods for stabilizing expansive soils in construction projects [9].

## 2 Materials and Methodology

### *2.1 Materials*

**Clay soil**. The required laboratory tests were carried out on soil utilized in the study in order to ascertain its fundamental characteristics a strength. Table 1 displays the results of various index and engineering properties of the soil. From the sieve analysis and gradation data, it can be inferred that soil is poorly graded sand.

**Egg Shell Powder**. Due to its chemical similarity to lime, eggshell powder (ESP), which has not been used as a stabilizing material, could be a potential replacement for industrial lime. Chicken eggshell is a domestic waste product and egg shell powder largely contains the minerals CaO, $Al_2O_3$, $SiO_2$, Cl, $Cr_2O_3$, MnO, and CuO [8]. The waste eggshell that would be utilized in the test was initially washed, dried, and crushed. From the specific gravity test conducted, the specific gravity of the eggshell powder was determined as 1.86.

**Table 1** General properties of soil

| Properties | Results |
|---|---|
| Specific gravity of soil | 2.15 |
| Effective size, $D_{10}$ | 0.286 mm |
| Uniformity coefficient, $C_U$ | 3.185 |
| Coefficient of curvature, $C_c$ | 0.815 |
| Coefficient of permeability, K | 0.0246 cm/s |
| Optimum moisture content | 9% |
| Maximum dry density | 18.63 kN/m$^3$ |
| CBR value | 1.74 |
| Unconfined compressive strength, | 1.765 kN/m$^2$ |
| Liquid limit | 48.5% |
| Plastic limit | 33.33% |
| Plasticity index | 15.17% |

**Bagasse**. Bagasse is the fibrous, dry substance that is left over after the juice from sugarcane or sorghum stalks has been extracted. It was first sun-dried for two days before being reduced to ashes and utilized for the test. From the specific gravity test conducted, the specific gravity of the Bagasse ash was determined as 1.82.

## *2.2 Methodology*

**Preparation of sample**. For the collected soil sample, fundamental laboratory tests (Atterberg's limit, specific gravity, sieve analysis were performed to determine the basic soil properties. Then the stabilization of soil with bagasse ash (BA) and egg shell powder is accomplished by blending the soil with various proportions of these two ingredients (3%, 6%, and 9%), after which the optimum percentage of bagasse ash and egg shell that can be added has been established [2]. Then laboratory experiments (compaction, California bearing ratio, unconfined compressive strength, and permeability test) were carried out to evaluate the strength behavior of the soil containing bagasse ash and egg shell powder.

Table 2 displays the various percentage combinations that are used when conducted the laboratory tests:

**Table 2** Percentage combinations for determining the strength characteristics

| Percentages | Composition of materials in soil sample |
|---|---|
| 3 | Soil + 1.5% BA + 1.5% ESP |
| 6 | Soil + 3% BA + 3% ESP |
| 9 | Soil + 4.5% BA + 4.5% ESP |

**Table 3** Results obtained after specific gravity test

| % composition of additives | Specific gravity |
|---|---|
| 0 | 2.15 |
| 3 | 2.21 |
| 6 | 2.34 |
| 9 | 2.43 |

# 3 Results and Analysis

## *3.1 Specific Gravity*

Specific gravity is a fundamental property of soils and other construction materials. This dimensionless unit is the ratio of material density to the density of water and is used to calculate soil density, void ratio, saturation, and other soil properties.

The soil's Specific Gravity without additives was 2.15, which is a relatively low value. As demonstrated in Table 3, the specific gravity value rises with the addition of Bagasse ash and Eggshell powder.

## *3.2 Light Compaction*

The purpose of the IS light compaction test is to ascertain the relationship between the water content and the dry density of compacted soil and to derive the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) from this test.

Figure 1 and shows the change of optimum moisture content with different percentage of sugarcane bagasse and eggshell powder. It is found that the optimum moisture content increases with addition of sugarcane bagasse ash and eggshell powder.

Figure 2 shows the variation in dry density with different percentage addition of sugarcane bagasse ash and egg shell powder. It is found that dry density drops down with increase in the additives.

## *3.3 Atterberg Limits*

Atterberg limits experiments measure the moisture contents at which fine-grained clay and silt soils change between the solid, semi-solid, plastic, and liquid phases. Table 4 shows the Atterberg limit values obtained in various percentage of additives.

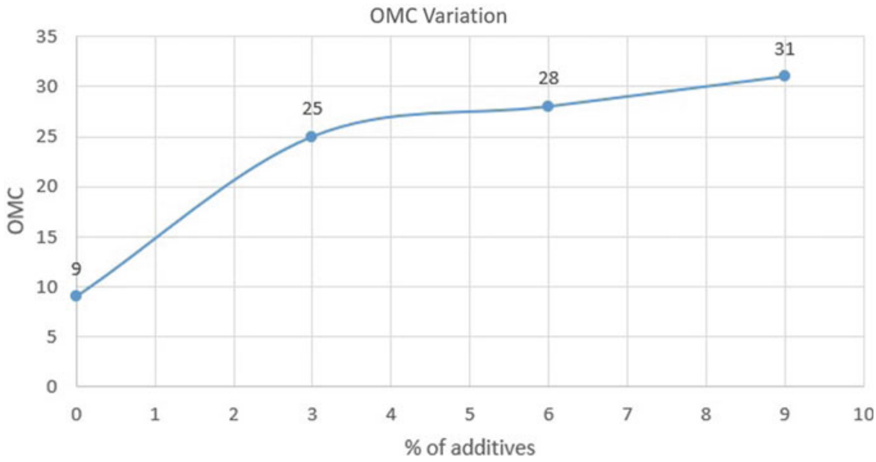


**Fig. 1** OMC variation with various percentage of additives

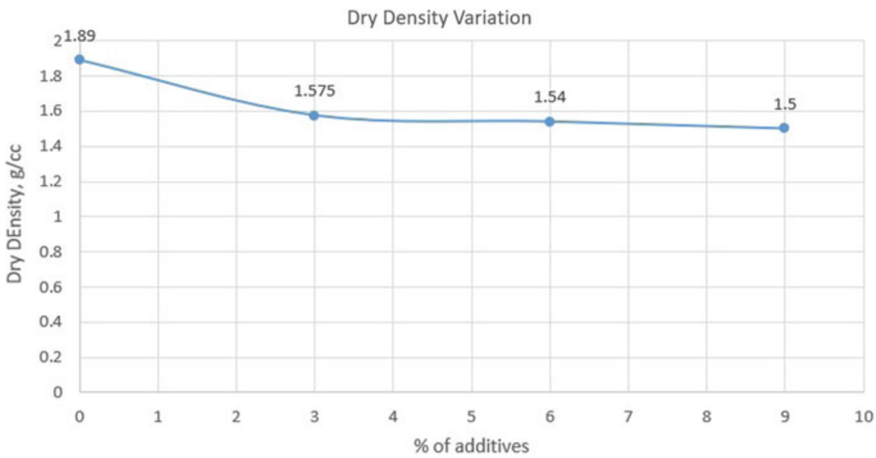


**Fig. 2** Maximum dry density variation

**Table 4** Atterberg limit value with varying percentage of additives

| Percentage composition of additives in soil (%) | Liquid Limit (LL) (%) | Plastic Limit (PL) (%) | Plasticity Index (PI) |
|---|---|---|---|
| 0 | 48.5 | 33.33 | 15.17 |
| 3 | 46.7 | 38.4 | 8.3 |
| 6 | 42.5 | 36.2 | 6.3 |
| 9 | 43.2 | 34.9 | 8.3 |

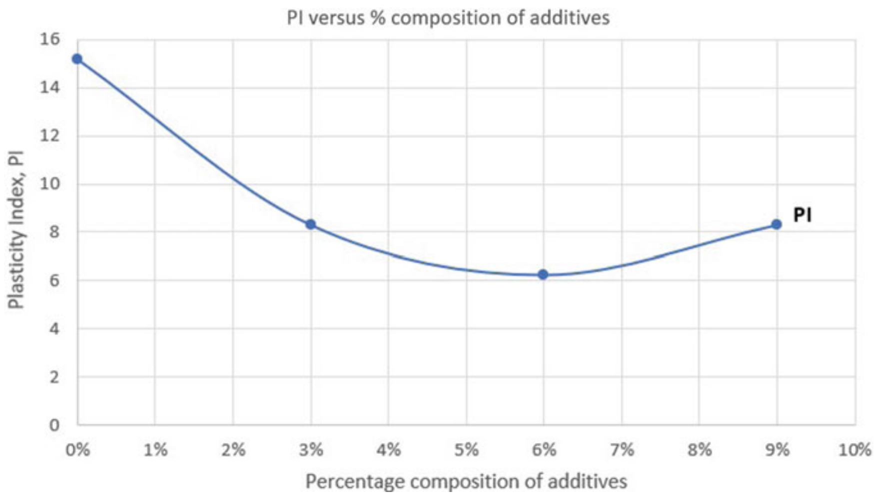


**Fig. 3** Plasticity index value at various percentage of additives

According to Fig. 3, we can infer that up to 6% of the soil's weight, the plasticity index value decreases. Hence, stabilizing it with bagasse ash and eggshell powder which makes up 6% of its weight can provide the soil the needed strength.

## *3.4 California Bearing Ratio*

It is a penetration test that is primarily used to assess the subgrade strength of roads, pavements, and foundations. The soil's subgrade strength and bearing capacity are evaluated using the CBR value. According to Fig. 4, soil CBR value increases when additives are added up to the optimal level (6%) and then starts to decline at 9%.

Table 5 demonstrates how the addition of bagasse ash and eggshell in varying ratios has raised the CBR value. The value rises up to 6% before falling at 9%. Thus, 6% is the optimum value.

## *3.5 Permeability*

The permeability test evaluates how easily a liquid pass through a sample of soil.

According to Fig. 5, the coefficient of permeability value declines at 3%, increases somewhat at 6%, and then drops again at 9%. As a result, the permeability reduces with increasing sugarcane bagasse and eggshell powder contents.

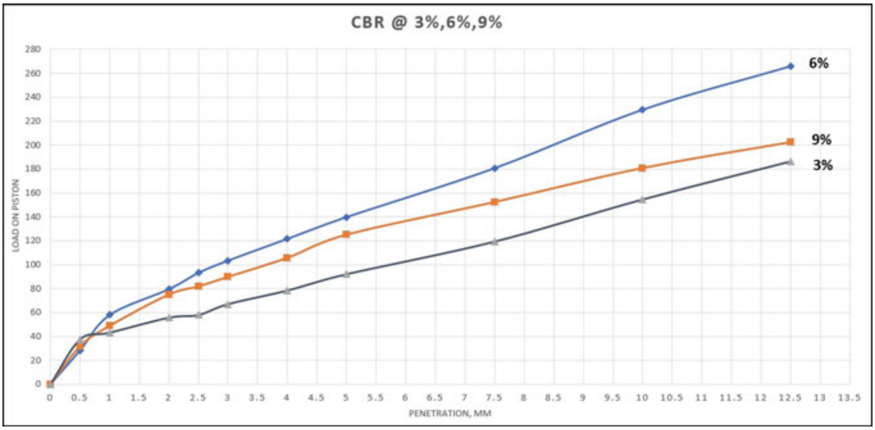


**Fig. 4** CBR value at 3%, 6%, 9% of additives

**Table 5** CBR value of soil with different percentage of additives

| Percentage of additives added (%) | CBR value |
|---|---|
| 0 | 1.74 |
| 3 | 4.6 |
| 6 | 6.8 |
| 9 | 6.08 |

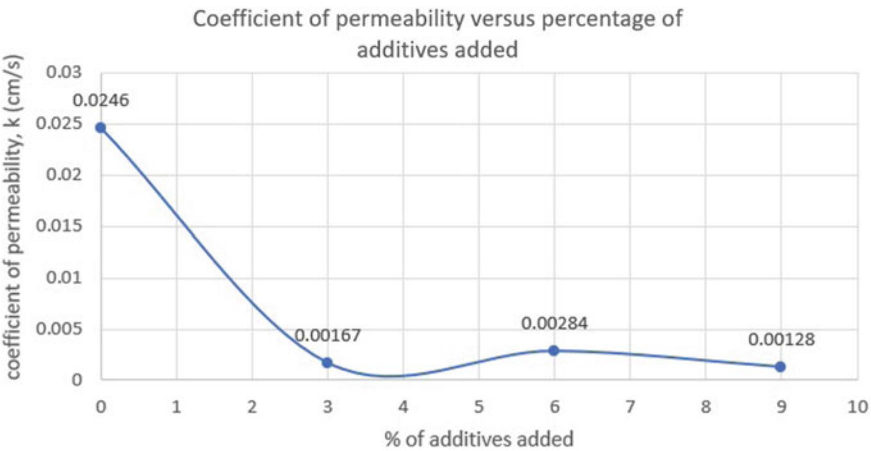


**Fig. 5** Coefficient of permeability value at various percentage of additives

**Table 6** Unconfined compressive strength at different percentages of additives

| % composition of additives | Unconfined compressive strength kN/m$^2$ |
|---|---|
| 0 | 1.765 |
| 3 | 24.5 |
| 6 | 36 |
| 9 | 34 |

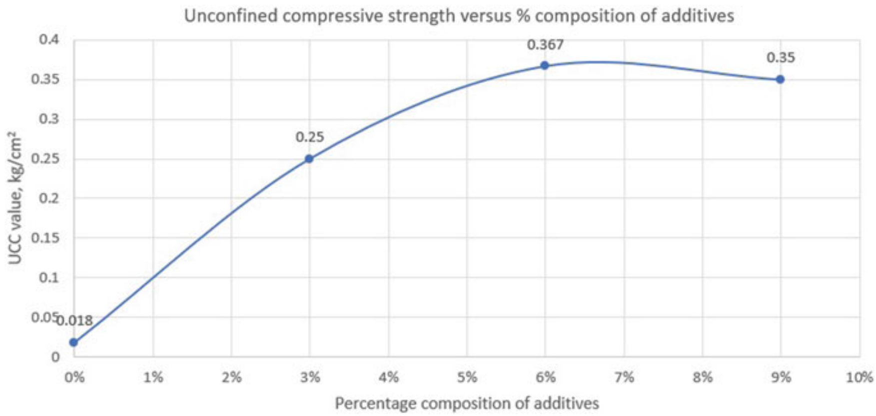


**Fig. 6** Unconfined strength value at various percentages of additives

## *3.6 Unconfined Compressive Strength*

The unconfined compression test (UCT) is a simple laboratory testing procedure to evaluate the mechanical characteristics of rocks and fine-grained soils.

Table 6 and Fig. 6 indicate the change in unconfined compressive strength at various additive percentages. Unconfined compressive strength is found to rise as additives are added, with a slight decrease occurring after a certain percentage.

## *3.7 Sieve Analysis*

Sieve analysis identifies the particle size distribution of a specific soil sample, making it simple to identify the mechanical characteristics of the soil.

Based on the gradation curve shown in Fig. 7 and results from Table 7. It can be inferred that as the percentage of additives is increased, the $C_u$ and $C_c$ values are improving shifting the property of soil towards well gradation.

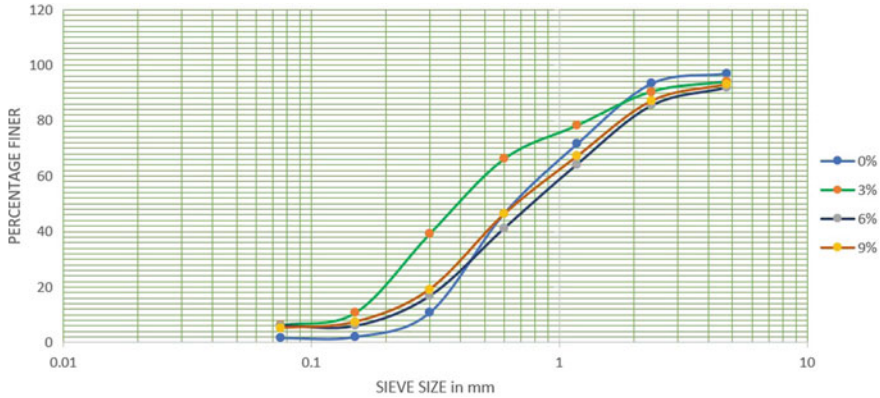


**Fig. 7** Gradation curve of soil

**Table 7** Values of $C_c$ and $C_u$ obtained after sieve analysis

| Percentage of additives (%) | $C_u$ | $C_c$ |
|---|---|---|
| 0 | 3.185 | 0.8156 |
| 3 | 3.904 | 0.872 |
| 6 | 5.269 | 0.969 |
| 9 | 5.349 | 0.979 |

# 4 Conclusion

The objectives of the study were to enhance the geotechnical characteristics of soil and look into the strength of the soil sample when combined with agro-industrial waste. After performing fundamental soil tests and various strength tests such as Atterberg Limit Test, CBR Test, and Unconfined Compression Test etc. to ascertain the strength and stability properties of the soil sample, it can be concluded that the inclusion of additives increases the soil's quality and strength.

1. Based on the specific gravity test, the value for raw soil was 2.15 and with the addition of additives, the value rises to 2.43 up to 9%.
2. The soil's optimum moisture content rises as the proportion of additives is increased, and maximum dry density decreases with additives. This can be due to the presence of organic material or fibres which leads to the reduction of contact between the particles.
3. The pozzolanic action of bagasse ash can lead to improved particle bonding and reduced soil plasticity. Atterberg limit tests led to the conclusion that the plasticity index value decreases up to 6% before increasing at 9%.

4. Eggshell powder and bagasse ash can possibly raise soil's CBR value, indicating better soil strength and load-bearing capabilities. CBR value rises up to 6.8 at 6% of additives and slight fall was observed at 9% of additives. Therefore, optimum value was observed at 6% of additives.
5. A more compacted soil matrix may develop as the additive content rises, which might hinder water movement and based on the permeability test conducted, coefficient of permeability value had decreased by adding additives but a slight increase was observed at 6% and at 9%, the value again decreases.
6. Based on UCC test, the strength increased from 1.765 kN/m$^2$ to 36 kN/m$^2$ up to 6% of additives and at 9% the strength falls. This may be due to the pozzolanic and cementitious property of bagasse ash and the particle interlocking property of eggshell powder.
7. Based on sieve analysis and gradation curve obtained, the soil group classification at 0% of additives was poorly graded sand, and as additive percentage increases, the soil gradation improves towards well graded nature.
8. Maximum dry density of the soil was found to be decreasing with increasing percentage of additives still, the CBR and Unconfined compressive strength was found to be increasing up to 6% of additives.

Based on the analysis of results, 6% of additives was determined to be the ideal amount to be added in order to improve the strength and characteristics of soil.

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