

Experimental Study on the Compaction Behavior of Clayey Soil Stabilized with Fly Ash, GGBS and Eggshell Powder

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Abstract – Soil Stabilization is an important technique used in ground improvement in civil engineering to improve the strength and durability of weak soil. This study investigate the compaction characteristic of clayey soil stabilized with industrial waste such as Fly Ash(FA) & GGBS(Ground Granulated Blast Furnace Slag) and agricultural waste such as Eggshell powder(ESP). The main objective was to determine an optimum combination of these stabilizing material based on maximum dry density (MDD) and Optimum Moisture Content (OMC). SPT Test (standard proctor test) were performed on natural soil and soil treated with different proportion of FA, GGBS & ESP. Based on the experimental results, the mix combination 20%FA + 15%GGBS + 6%ESP was considered the optimum mix among the investigated combination. At this proportion MDD increases from 1.607 gm/cc to 1.76 gm/cc representing an improvement of 9.52% while the OMC changes from 15.80% to 18%. The improvement in dry density indicates better packing of soil particles, void filling and improve compaction behaviour after treatment. The finding indicates that GGBS, FA and ESP can be effectively used as eco-friendly cost effective and sustainable approach to soil stabilization.

Key Words: Clayey Soil, Fly ash, GGBS, Eggshell Powder, standard proctor test

1. INTRODUCTION

In today's era of development [7], the need for infrastructure such as- Road, Building, Bridge & other civil engineering structures is constantly growing. However, there are still many areas where such development is hindered by the lack of adequate soil strength. In such cases, soil stabilization techniques are commonly employed to improve the engineering properties of soil. Clayey soil absorbs water and swells [9] during the rainy season, while it shrinks [5] and forms cracks during dry periods. Therefore, its improvement is essential for safe and durable construction. Generally, stabilizing agents such as cement and lime have been commonly used to improve soil properties [4],[6]. So, the production of these materials is costly and environmental concerns [7]. So, we focused on the use of industrial and agricultural waste [1],[2]. The use of such materials not only improves soil properties but also

helps in effective waste management and promotes sustainable construction practices [3].

2. LITERATURE REVIEW

Geotechnical Characteristics of Fine-Grained Soils Stabilized with Fly Ash (2022): The review reported that fly ash generally tends to decrease MDD and increase OMC, depending on soil type, fly ash content and compaction energy.

Ram and Mohanty (2022): The study reviewed the engineering properties of fly ash and reported that its low specific gravity and particle characteristics significantly affect **OMC and MDD** during compaction.

Bakam et al. (2023) evaluated the strength behavior of soft clay treated with Fly Ash and Egg Shell Powder. The experimental results showed that soil strength increased with curing time and additive content. The study concluded that the combined use of FA and ESP can effectively enhance the performance of weak clay soils.

Alajlan et al. (2026) investigated the stabilization of subgrade soil using Egg Shell Powder and quarry dust. Experimental results showed improvements in strength, compaction and bearing capacity characteristics. The study concluded that waste-derived stabilizers can effectively enhance soil performance while reducing environmental impacts.

Enhancing clay properties with eggshell powder (2026): The study found that adding eggshell powder (ESP) changes the compaction behaviour of clay soil, particularly its OMC and MDD, based on Standard Proctor testing.

Fly ash-GGBS blended geopolymers (2026): The study reported that combining Fly Ash and GGBS can improve expansive soil and significantly influence its compaction characteristics, OMC and MDD.

Eggshell powder and quarry dust (2026): The study showed that ESP and quarry dust modify the OMC and MDD of subgrade soil and can improve its strength properties such as CBR and UCS.

3. MATERIAL USED

Clayey soil

Clayey soil absorbs water and swells during the rainy season, while it shrinks and forms cracks during dry periods. Therefore, its improvement is essential for safe and durable construction. It is generally rich in nutrients [10] such as- Nitrogen, phosphorous, potassium, calcium & sulfur as well as iron, zinc, manganese and copper. Its plasticity and consistency vary depending upon moisture content [2] [8].

Eggshell Powder

Eggshell is a Agricultural waste material generated from poultry farms, households, restaurants, and food processing industries. Most of this eggshell waste is disposed of in landfills or open dumping sites, which creates environmental issues such as foul odour & land pollution. Due to its high calcium carbonate content (around 90–95%), eggshell powder can be effectively used in soil stabilization works. ESP improves compressive strength of soils (optimally at 3–5%) while reducing swelling.

Fly Ash

Fly ash is an industrial by-product generated from coal-based thermal power plants during electricity generation. India is among the largest producers of fly ash due to its heavy dependence on coal-fired power plants for electricity generation. Because of its pozzolanic properties and high silica content, fly ash has been widely used in soil stabilization, road construction, concrete production, and embankment works.

GGBS

Ground Granulated Blast Furnace Slag (GGBS) is a by-product obtained from the iron and steel manufacturing industry during the production of pig iron in blast furnaces. When molten slag from the blast furnace is rapidly cooled and ground into a fine powder, it forms GGBS, which has cementitious properties. It used as a supplementary cementitious material in construction.

4. METHODOLOGY

The methodology adopted in present study consists of soil collection, characterization of the constituent's materials, preparation of stabilizing agent, prepare mix proportion, laboratory testing and analysis of experimental results.

4.1 Collection of Soil Sample- The soil used in this study was clayey soil collected from a Tinpahar area of rajmahal sahibganj jharkhand site. The soil sample was collected from a depth of about 0.5–1.0 m below the ground surface to avoid organic matter and surface impurities. The collected soil was air-dried, pulverized, and passed through a 4.75 mm sieve before laboratory testing.

4.2 Preparation of stabilizing Agent

The Prepared Fly ash & GGBS used in the study was obtained from a nearby ACC Cement plant. It is a fine powder containing silica and alumina and possesses **pozzolanic properties**, which help in improving soil strength.

Waste eggshells were collected from our Hostel Mess and food outlets. Eggshells were washed to remove impurities, dried in sunlight, remove inner membrane and then crushed and ground into fine powder. The powder was passed through a 75 μ & 425 μ sieve to obtain uniform particle size.

4.3 Mix proportioning and sample preparation

Different proportion of Fly ash, GGBS and ESP were added to the natural clayey soil according to the selected mix combination. Such as-

- a. Mix-1 – 84%CS +10% FA +3% GGBS + 3% ESP
- b. Mix-2 – 77%CS +15% FA +5% GGBS + 3% ESP
- c. Mix-3 – 67%CS +20% FA +10% GGBS + 3% ESP
- d. Mix-4 – 59%CS +20% FA +15% GGBS + 6% ESP
- e. Mix-5 – 50%CS +20% FA +20% GGBS + 10% ESP

The required quantity of soil and stabilizing materials was weighed according to the selected mix proportions. The dry materials were mixed thoroughly to ensure homogeneity. Water was then added gradually and the mixture was compacted in moulds as per standard laboratory procedures.

Prepared samples were used for different geotechnical tests to evaluate the improvement in engineering properties of stabilized soil.

4.4 Analysis of results

The experimental results obtained for the stabilized soil mixture were compared with those of the untreated soil. Based on the observed improvement in engineering properties, the most effective mix combination was identified as the optimum stabilizing combination

5. RESULT AND DISCUSSION

We conducted compaction test in our laboratory according to IS:2720 (part-7)-1980[11] When clayey soil mix with different proportion of (FA+GGBS+ESP), it show different behavior which is represented in following tables & graphs-

5.1 NATURAL SOIL

Table-1 SPT Test data of clayey soil

Moisture content (%) after oven drying	Weight of mould + soil + Base plate (kg)	Weight of mould + base plate (kg)	Weight of soil only (gm)	Volume of mould (cc)	Bulk Unit weight (gm/cc)	Dry unit weight (gm/cc)
10.78	5495	3798	1697	1000	1.697	1.531
15.74	5659	3798	1861	1000	1.861	1.607
21.68	5667	3798	1869	1000	1.869	1.535
27.78	5573	3798	1775	1000	1.775	1.389

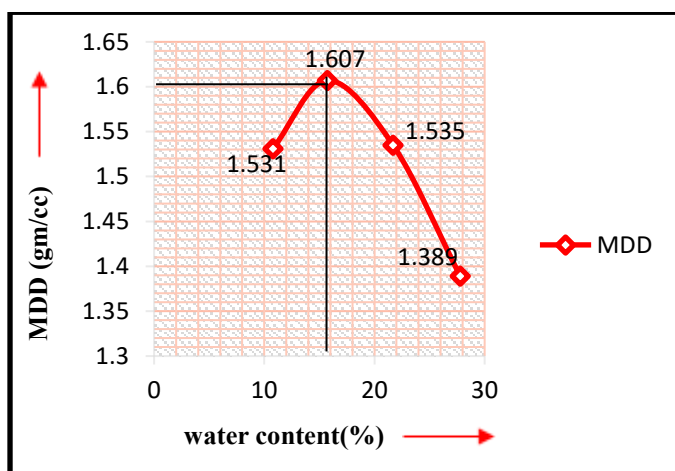


Fig-1 Compaction curve of Clayey soil

From Fig-1 it is observed that The Maximum dry density of naturally available clayey soil is 1.607 gm/cc and its optimum moisture content is 15.80%.

5.2 Mix-1 [84%CS +10% FA +3% GGBS + 3% ESP]

Table-2 SPT Test data of Mix-1 soil

Moisture content (%) after oven drying	Weight of mould + soil + Base plate (kg)	Weight of mould + base plate (kg)	Weight of soil only (gm)	Volume of mould (cc)	Bulk Unit weight (gm/cc)	Dry unit weight (gm/cc)
10.83	5554	3798	1756	1000	1.756	1.584
17.05	5718	3798	1920	1000	1.920	1.640
22.19	5790	3798	1992	1000	1.992	1.630
27.78	5726	3798	1928	1000	1.928	1.514

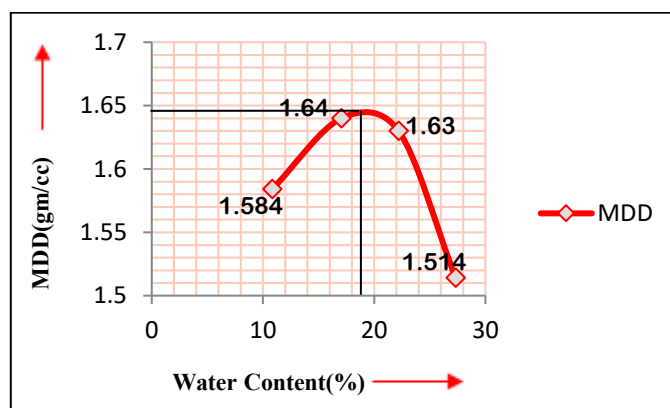


Fig-2 Compaction curve of Mix-1

From Fig-2 it is observed that The Maximum dry density of Mix-1 soil after treatment is found to be 1.643 gm/cc and its optimum moisture content is 19.2%.

5.3 Mix-2 [77%CS +15% FA +5% GGBS + 3% ESP]

Table-3 SPT Test data of Mix-2 soil

Moisture content (%) after oven drying	Weight of mould + soil + Base plate (kg)	Weight of mould + base plate (kg)	Weight of soil only (gm)	Volume of mould (cc)	Bulk Unit weight (gm/cc)	Dry unit weight (gm/cc)
11.785	5560	3798	1762	1000	1.762	1.577
16.83	5735	3798	1937	1000	1.937	1.657
22.015	5799	3798	2001	1000	2.001	1.640
28.535	5701	3798	1903	1000	1.903	1.480

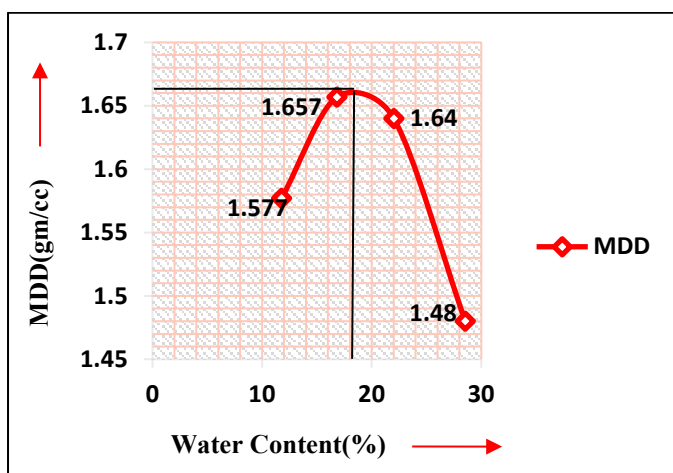


Fig-3 Compaction curve of Mix-2

From Fig-3 it is observed that The Maximum dry density of Mix-2 soil after treatment is found to be 1.665 gm/cc and its optimum moisture content is 19%.

5.4 Mix-3 [67%CS+20% FA+10% GGBS + 3% ESP]

Table-4 SPT Test data of Mix-3 soil

Moisture content (%) after oven drying	Weight of mould + soil + Base plate (kg)	Weight of mould + base plate (kg)	Weight of soil only (gm)	Volume of mould (cc)	Bulk Unit weight (gm/cc)	Dry unit weight (gm/cc)
10.35	5575	3798	1775	1000	1.775	1.61
15.24	5765	3798	1967	1000	1.967	1.706
21.57	5802	3798	2004	1000	2.004	1.648
26.61	5717	3798	1919	1000	1.919	1.515

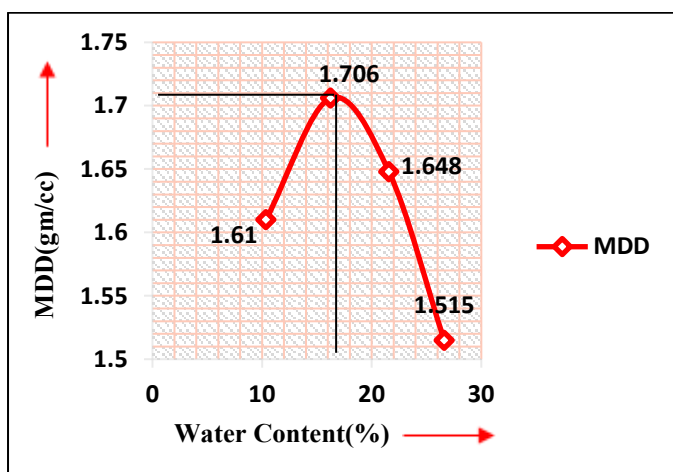


Fig-4 Compaction curve of Mix-3

From Fig-4 it is observed that The Maximum dry density of Mix-3 soil after treatment is found to be 1.709 gm/cc and its optimum moisture content is 17%.

5.5 Mix-5 [67%CS+20% FA+20% GGBS+10% ESP]

5.4 Mix-4 [59%CS+20% FA+15% GGBS + 6% ESP]

Table-5 SPT Test data of Mix-4 soil

Moisture content (%) after oven drying	Weight of mould + soil + Base plate (kg)	Weight of mould + base plate (kg)	Weight of soil only (gm)	Volume of mould (cc)	Bulk Unit weight (gm/cc)	Dry unit weight (gm/cc)
11.67	5546.5	3798	1748.5	1000	1.748	1.565
17.38	5876	3798	2078	1000	2.078	1.764
23.14	5768	3798	1970	1000	1.970	1.659
29.56	5684	3798	1886	1000	1.886	1.455

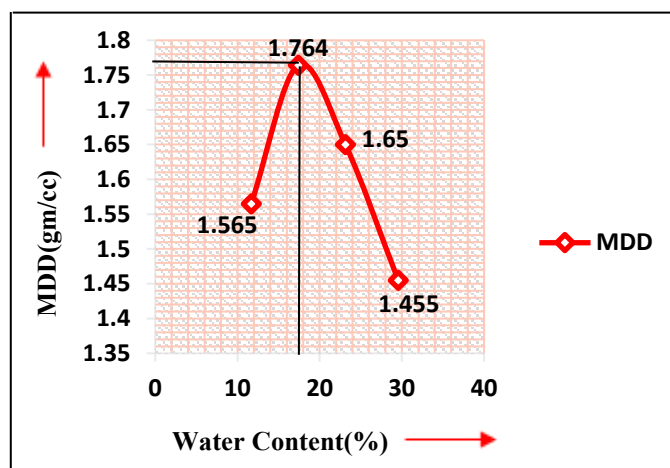


Fig-5 Compaction curve of Mix-4

From Fig-5 it is observed that The Maximum dry density of Mix-4 soil after treatment is found to be 1.76 gm/cc and its optimum moisture content is 18%.

Table-6 SPT Test data of Mix-5 soil

Moisture content (%) after oven drying	Weight of mould + soil + Base plate (kg)	Weight of mould + base plate (kg)	Weight of soil only (gm)	Volume of mould (cc)	Bulk Unit weight (gm/cc)	Dry unit weight (gm/cc)
10.64	5598	3798	1800	1000	1.8	1.626
18.45	5785	3798	1987	1000	1.987	1.677
21.99	5796	3798	1998	1000	1.998	1.637
28.21	5736	3798	1938	1000	1.938	1.511

From Fig-6 it is observed that The Maximum dry density of Mix-5 soil after treatment is found to be 1.677 gm/cc and its optimum moisture content is 18.40%.

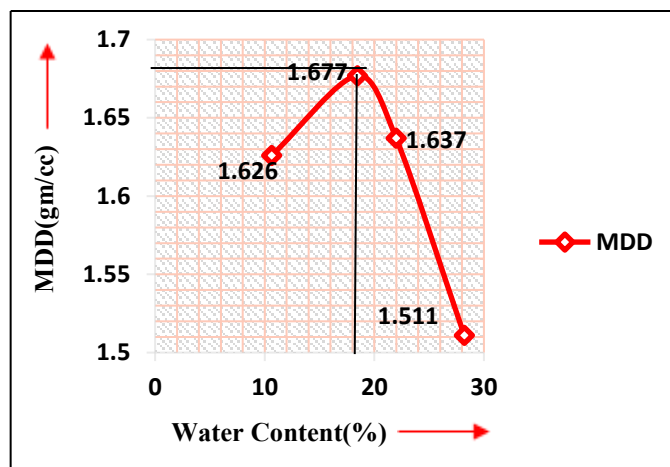


Fig-6 Compaction curve of Mix-5

5.6 COMBINE OMC V/s MDD CURVE

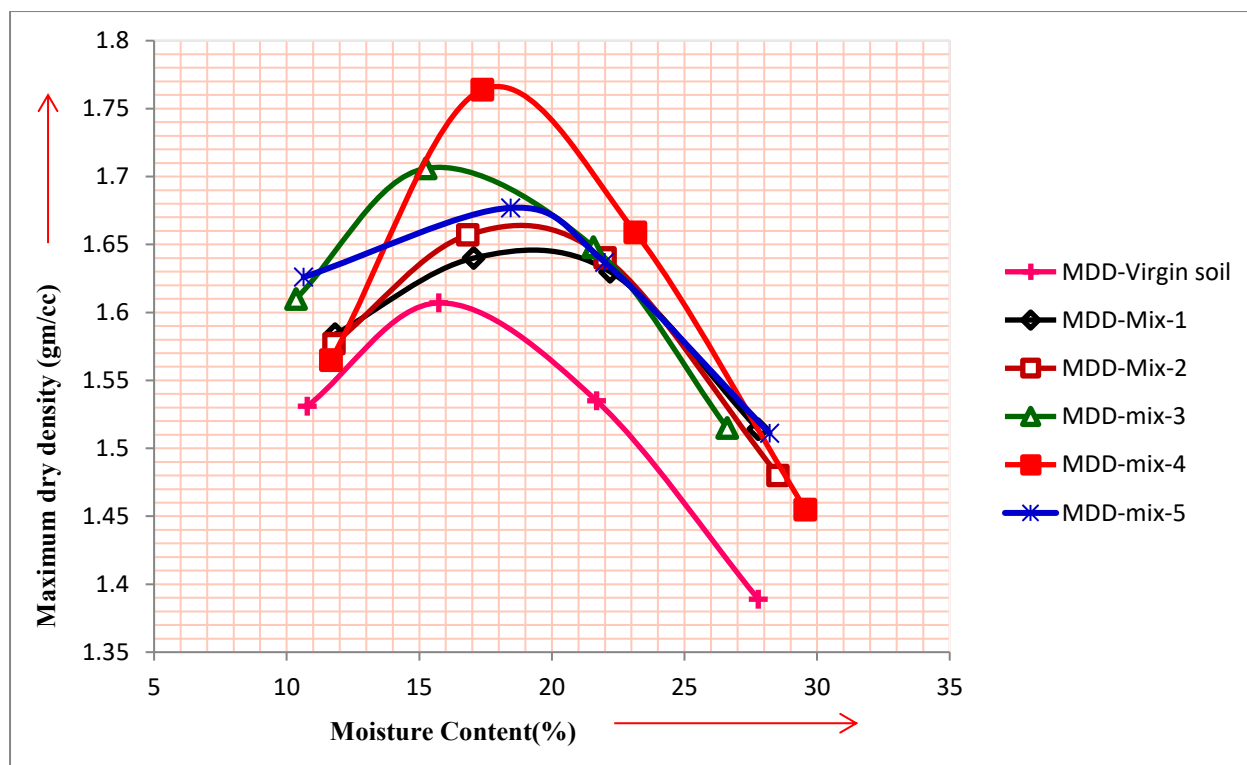


Fig-7 combined compaction curve of clayey soil

The different curve in fig-7 show the relation between moisture content & maximum dry density of clayey soil. The dose of (FA+GGBS+ESP) was varied from 16% to 50 % and it show optimum at 41%.

Table-7 Compaction test reading for different proportion

S.No	Soil : FA: GGBS: ESP	MDD(gm/cc)	OMC
1	100: 0 : 0: 0	1.607	15.80
2	84 : 10 : 3: 3	1.643	19.2
3	77 : 15 : 5: 3	1.665	19

4	67 : 20 :10:3	1.709	17
5	59 : 20 :15:6	1.76	18
6	50 : 20 :20:10	1.677	18.4

It was observed that from fig-7 with increase in percentage of (FA+GGBS+ESP) in clayey soil, the MDD increases from 1.607 gm/cc to 1.76 gm/cc by improving particle interlocking, thereby increasing the load bearing capacity of treated soil [2]. However, the OMC changes from 15.8% & to 19% with the change of content mix (FA+GGBS+ESP) and then decreases up to 17% for further increases. MDD increases up to 1.76 gm/cc due to pozzolanic reaction takes place due to presence of calcium, aluminum, silica etc. in fly ash,

GGBS & ESP [10]. The moisture content decreases from 19% to 17% due to increases in fly ash & GGBS, because fly ash & GGBS absorbed water more than water requirement [25],[29]. The decreases in MDD from 1.76 gm/cc to 1.677 gm/cc with the increase in quantity of eggshell powder may be contributed to the light weight fly ash particle [25]. The specific gravity of clayey soil is higher than that of eggshell powder, hence the content of eggshell powder increases the maximum dry density of soil mix decreases [25],[23].

6. CONCLUSIONS

The present study was carried out to investigate the compaction behaviour of clayey soil through standard proctor test. The compaction characteristics of the soil were evaluated using the standard proctor test. The result showed an improvement in the MDD from 1.607 gm/cc to 1.76gm/cc at **41%** mixing material comprising (**20%FA+15%GGBS+6%ESP**) while the OMC change from 15.80% to 18%. The increase in dry density indicates better packing of soil particles and improves compaction behaviour after treatment

The experimental result indicate that the optimum mix proportion is **41%** comprising 59% clayey soil, 20% fly ash, 15% GGBS & 6% ESP. This combination provides the maximum improvement in strength parameter. Hence, the utilisation of industrial & agricultural waste material such as- Fly ash, GGBS & Eggshell powder promotes an eco-friendly, cost-effective and sustainable approach to soil stabilization..

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BIOGRAPHIES



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