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# Effect of Lime and GGBS on Geotechnical Properties of Fly Ash

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***Abstract* - Fly ash, a fine by product from coal combustion in thermal power plants, constitutes about 80% of the total ash produced, with the rest being bottom ash. In recent years, India has significantly improved its fly ash management. As per national trends for 2023-24, approximately 100% of newly generated fly ash and a large portion of legacy stock have been successfully utilized in construction, reclamation, and soil stabilization activities up from ~61% in 2014-16. This study explores the geotechnical improvement of class-F fly ash, collected from Godawari Power & Ispat Ltd., Raipur, by stabilizing it with lime and ground granulated blast furnace slag (GGBS). Fly ash was blended with lime (0%, 2%, 4%, 8%, 12%) and GGBS (0%, 5%, 10%, 15%, 20%), resulting in 25 combinations. Standard Proctor tests were performed to determine the optimum moisture content (OMC) and maximum dry density (MDD), followed by unconfined compressive strength (UCS) tests after curing for 0, 7, 14, and 28 days at 28 °C. Results indicated that untreated fly ash had high OMC, low MDD, and negligible strength. Lime addition improved compaction and strength with curing. GGBS, when used with lime, enhanced pozzolanic and latent hydraulic reactions, resulting in significantly higher UCS. The best performance was observed at 12% lime and 20% GGBS after 28 days of curing. This confirms that combining lime and GGBS effectively transforms fly ash into a sustainable geotechnical material suitable for sub-base, embankments, and pavement layers.**

***Keywords:*** Fly ash, Lime, GGBS, Stabilization, OMC, MDD, UCS, Sustainable Materials.

## I. INTRODUCTION

Fly ash is a fine powdery by product generated during the combustion of pulverized coal in thermal power plants. It possesses pozzolanic properties similar to volcanic ash and primarily consists of silica, alumina, and iron oxides. During combustion, the furnace temperature may rise up to 2800 °F (≈1538 °C), leading to the formation of two types of ash: bottom ash, which settles at the base of the boiler due to its heavier particles, and fly ash, which remains suspended and is collected through electrostatic precipitators or bag filters along with the flue gases. Traditionally, India has faced challenges in managing the large volumes of fly ash generated annually. For example, in 2015-16, the total production of fly ash was around 176.74 million tonnes (MT), out of which only 107.77 MT (≈60.97%) was utilized, with the remaining portion dumped in landfills or ash ponds contributing to air pollution, groundwater contamination, and land degradation.

However, significant progress has been made in recent years. According to national utilization trends, India produced over 270 MT of fly ash in 2021–22, and as per compliance and government reports for 2023–24, nearly 100% of newly generated fly ash and a substantial share of legacy stock were successfully utilized in cement manufacturing, road construction, mine backfilling, and soil stabilization. These efforts were driven by policy mandates under the Fly Ash Utilization Notification and the Fly Ash Management and Utilization Mission initiated by the Ministry of Power and Ministry of Environment, Forest and Climate Change (MoEFCC).

### 1.1 Properties of Fly Ash

Fly ash is a fine product produced from coal combustion at power plants. It is also known as pulverized fuel ash. Its particle size generally ranges from fine sand to silt size. Silica is the main constituent followed by alumina and ferrous oxide.

The pozzolanic activity of fly ash is described as the reaction of $Ca(OH)_2$ with the main components of fly ash. When SiO2and Al2O3 present in fly ash, coming contact with the $Ca(OH)_2$ then it forms CSH and CAH. The main pozzolanic reaction will take place between $Ca(OH)_2$ and $SiO_2$, but reaction between $Al_2O_3$ and $Ca(OH)_2$ will also be considerable.

### 1.2 Lime an Overview

Lime is an alkaline material which formed by heating of limestone. It is an inorganic material which contains carbonates, hydroxides, and oxides as major constituents. When limestone is heated at a very high temperature than quicklime is formed and when water is added to the quick lime than slaked lime is formed and when this slaked lime reacts

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with carbonates than again lime stone is formed. Cycle for the formation of lime is as shown.

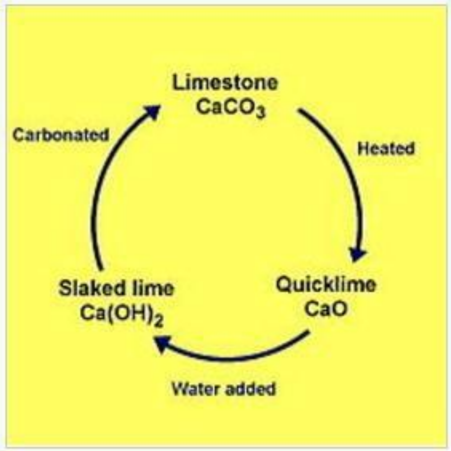


**Figure 1.1: Lime Cycle**

Lime is one of the most important construction materials which has been using since very old time. In many of the Indian ancient infrastructures lime was used as a building material. Lime has also been using in geotechnical engineering work. It is mainly used as a stabilizer for soil. Its necessity as a stabilizer is because it is having pozzolanic properties. When lime is used as a stabilizer than a pozzolanic reaction will take place. And as the time passes the soil gained strength. In the present study, lime was used as the main stabilizer for fly ash but as the lime is an expensive material, so in the study different proportion of lime and slag was used as a stabilizer.

### 1.3 Slag an Overview

GGBS is a by-product produced from the manufacturing process of iron. It is obtained by quenching the molten iron blast furnace slag in water or stream immediately. A glassy granular product formed which then dried and ground into a fine powder. There are mainly three types of slag present on the basis of different production techniques.

- Slag produced from traditional ball mill.
- Slag produced from high-pressure roller press.
- Vertical roller press.

## II. LITERATURE REVIEW

Al-Rawas et al. (2003) stated that Industrial products such as cement, lime, furnace slag and cement by-pass dust (CBPD) can be effectively used for stabilization of Fly ash. Among the following, the stabilization with furnace slag requires any activator such as lime.

Hardjito et al. (2004) investigate the compressive strength of geopolymer concrete using fly ash. The tests conducted are based on curing time, curing temperature, the quantity of superplasticizer. In the test, it is stated that at a higher temperature and longer curing period the compressive strength found to be higher and also it is stated that the workability of fresh geopolymer concrete can be increased by adding naphthalene based superplasticizers. And also it is stated that there is a very little difference in the specimen which is tested immediately and tested after 60 minutes of curing period.

Kim et al. (2005) used the industrial waste like class-F fly ash and bottom ash as a construction material. It will be an economical alternative to the use of traditional material. The materials are collected from Indiana and tested for compaction, permeability, strength, stiffness, and compressibility. The mixtures of fly ash and bottom ash are used in the ratio of 50, 75, and 100 (fly ash to bottom ash by weight). After the test, it is found that specific gravity of fly ash and bottom ash are varied to plant to plant and the maximum dry density was found to be lower than conventional geoengineering material.

Phanikumar et al. (2007) investigate the swelling behavior of expansive soil can be reduced by using fly ash. It will also increase maximum dry density (MDD) and reduce optimum moisture content (OMC).

### 2.1 Objective of the Present Study

As highlighted in the literature, disposing of fly ash demands vast landfill space and poses severe environmental risks. Converting this industrial by product into construction material is therefore the most effective way to maximise its utilisation. The present study aims to replace conventional earth materials with Class F fly ash from Godawari Power & Ispat Ltd., Raipur, by applying an appropriate stabilisation method. Lime is selected as the primary stabiliser; however, to curb lime usage due to its higher cost, ground granulated blast furnace slag (GGBS) is also incorporated. Because GGBS exhibits only latent hydraulic activity, it must be activated by an alkali. In this research, lime provides the necessary alkaline environment, triggering pozzolanic reactions and enhancing the engineering performance of the fly ash mixtures.

The main aspects of the current project work are:

- Effect of addition of lime and curing period on the unconfined compressive strength of fly ash.
- Effect of addition of slag and curing period on the unconfined compressive strength of fly ash.
- Effect of addition of lime and slag in proper proportion and curing period on the unconfined compressive strength of fly ash.

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## III. EXPERIMENTAL PROGRAM

### 3.1 Introduction

When fly ash gone through the compaction than it gain some strength but when it became saturated than it will lose its strength immediately. So a proper stabilization technique is must to use for using fly ash as a construction material. In the current project, fly ash is stabilizing with lime as the main constituent. But as the lime is an expensive material GGBS is using as a stabilizer. But to activate GGBS, the addition of lime was required. So in the study, an attempt has been made to stabilize the fly ash and enhance its physical and chemical properties to use it as a geoengineering material by adding lime and GGBS in proper proportion. The different mixes of fly ash, lime, and slag were gone through light compaction test to check the OMC and MDD and UCS has been done to check the strength of different mixes at different curing period. In this chapter, a detail on the material used, sample preparation and testing procedure has been given.

### 3.2 Experimental Arrangements

### 3.2.1 Materials Used

*3.2.1.1 Fly ash*

In the study, class-F fly ash was used. The fly ash has been brought from Godawari Power & Ispat Ltd., Raipur. Before using, the sample was passed through 2mm sieve for the separation of foreign and vegetative matters. The sample was collected and mixed thoroughly and kept it in the oven for 24hr at a temperature of 105º-110ºC. Then the sample was kept in an airtight container for further use.

**Figure 3.1: Fly Ash**

*3.2.1.2 Lime*

The lime used in the present study was commercial lime, which has been brought from Raipur market and passed through 150µ sieve and kept in an airtight container for further use.

**Figure 3.2: Lime**

*3.2.1.3 Slag*

The ground granulated blast furnace slag was brought from Shiva Cement Raipur. And it was crushed, oven dried, passed through 300µ sieve and kept in an airtight container for further use.


**Figure 3.3: Powdered Slag**

### 3.2.2 Physical Properties of Fly Ash

Physical properties of class-F fly ash, passing through 2mm sieve are determined and shown in the table:

**Table 3.1: Physical Properties of Fly ash**

| Physical Parameters | Values | Physical Parameters | Values |
|---|---|---|---|
| Colour | Grey | Shape | Rounded/Sub-rounded |
| Fine Sand (%) | 14 | Coefficient of Curvature, $C_C$ | 1.26 |
| Silt and Clay (%) | 86 | Coefficient of Uniformity, $C_C$ | 5.66 |
| Coarse Sand (%) | 0 | Specific Gravity, G | 2.40 |
| Medium Sand (%) | 0 | Plasticity Index | Non-plastic |

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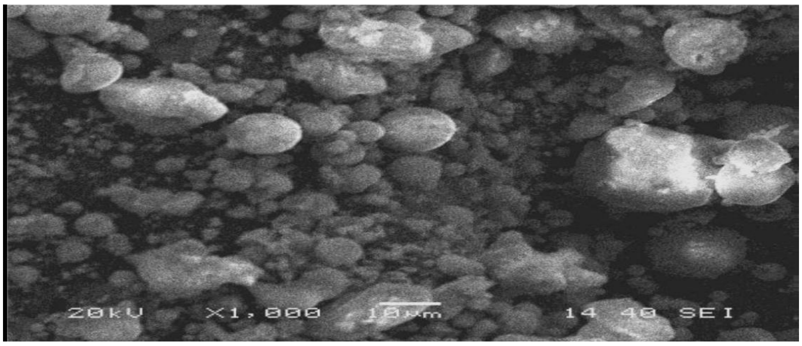


**Figure 3.4: Scanning Electron Micrograph (SEM) of Fly ash**

The fig shows the surface morphology of fly ash taken by using scanning electron micrograph (SEM). The picture shows the particles are mainly angular size particles and having a uniform gradation. For the best possible resolution morphology were done at an accelerating voltage of 20kV.

### 3.2.3 Chemical Composition of Fly ash

The chemical composition of class-F fly ash was determined and is shown in Table 3.2. The main chemical component was found to be $SiO_2$and $Al_2O_3$. Apart from these minerals, it also contains (MgO), potassium ($K_2O$), calcium oxide (CaO).

**Table 3.2: Chemical Composition of Fly ash**

| Elements | $M_gO$ | $Al_2O_3$ | $S_iO_3$ | $K_2O$ | $P_2O_3$ | $C_aO$ | $Fe_2O_3$ | $Na_2O_3$ | MnO | $TiO_2$ | Loss on Ignition |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Composition (%) | 1.6 | 28.2 | 53.11 | 1.98 | 1.71 | 2.66 | 1.79 | 0.6 | 0.4 | 0.75 | 6.4 |

### 3.3 Determination of Index Properties

### 3.3.1 Determination of Specific Gravity

The specific gravity of class-F fly ash was determined according to IS:2720 (part III, section-1) 1980. By density bottle test using kerosene as the solvent and it was found to be 2.40.

### 3.3.2 Determination of Grain Size Distribution

For the determination of grain size distribution, fly ash were passed through a 75μ sieve. For the distribution of coarser particles sieve analysis was conducted as per IS:2720 part (IV), 1975 and similarly for finer particles hydrometer analysis was conducted as per IS:2720 part (IV). The fly ash passing through the 75μ sieve was found to be 87%. So the fly ash can be classified as fine sand to silt size. The coefficient of uniformity (Cu) was found to be 5.66 whereas the coefficient of curvature (Cc) was found to be 1.26. That indicates the uniform gradation of fly ash.

### 3.4 Determination of Engineering Properties

### 3.4.1 Moisture Content Dry Density Relationship

The moisture content dry density relationship was found by using standard Proctor test as per IS:2720 (part VII) 1980. Fly ash was mixed with lime at 0%, 2%, 4%, 8% and 12% and with slag at 0%, 5% 10% 15% and 20% by its dry weight and different combinations have been made. For this test, an adequate amount of water was added to the mixtures and thoroughly mixed and compacted in Proctor mould in three layers using standard Proctor hammer weighing 2.6 kg as per IS: 2720 (part 2) 1973 and the optimum moisture content (OMC) and dry density (MDD) were determined. Similarly, the different combinations were tested to the same procedure and corresponding OMC and MDD was determined. The compactive energy used in the test program was 595 $kJ/m^3$.

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**Table 3.3: Details of Fly Ash-GGBS-Lime Mixes Used in the Test Program**

| % Lime | Fly Ash-Slag Mixing Proportion | | | | |
|---|---|---|---|---|---|
| 0 | (100-0) | (95-5) | (90-10) | (85-15) | (80-20) |
| 2 | (100-0) | (95-5) | (90-10) | (85-15) | (80-20) |
| 4 | (100-0) | (95-5) | (90-10) | (85-15) | (80-20) |
| 8 | (100-0) | (95-5) | (90-10) | (85-15) | (80-20) |
| 12 | (100-0) | (95-5) | (90-10) | (85-15) | (80-20) |

**Table 3.5: Variation of MDD with Different Combinations of Lime and Slag**

| % Lime | Maximum Dry Density ($kN/m^3$) | | | | |
|---|---|---|---|---|---|
| | % Slag | 5% Slag | 10% Slag | 15% Slag | 20% Slag |
| 0 | 10.93 | 11.18 | 11.24 | 11.41 | 11.68 |
| 2 | 11.13 | 11.25 | 11.34 | 11.52 | 11.75 |
| 4 | 11.33 | 11.41 | 11.47 | 11.63 | 11.83 |
| 8 | 11.42 | 11.55 | 11.63 | 11.79 | 12.01 |
| 12 | 11.66 | 11.72 | 11.76 | 11.87 | 12.12 |

**Table 3.6: Variation of OMC with Different Combinations of Lime and Slag**

| % Lime | Optimum Moisture Content ($kN/m^3$) | | | | |
|---|---|---|---|---|---|
| | % Slag | 5% Slag | 10% Slag | 15% Slag | 20% Slag |
| 0 | 42.12 | 38.58 | 38.28 | 38.12 | 37.96 |
| 2 | 40.32 | 38.28 | 38.17 | 37.93 | 37.83 |
| 4 | 38.32 | 37.86 | 37.52 | 36.83 | 36.11 |
| 8 | 36.85 | 36.21 | 35.83 | 35.24 | 34.95 |
| 12 | 34.16 | 33.86 | 33.24 | 32.97 | 32.23 |

### 3.4.2 Determination of Unconfined Compressive Strength

The unconfined compression strength test was used to determine the compressive strength of fly ash and fly ash stabilized with lime and slag. For the preparation of specimen MDD at OMC determined by the standard Proctor test at an energy of 595 $kJ/m^3$ was used as per IS:2720 Part (X). The size of the cylindrical specimen was 76 mm in height and 38 mm in diameter and the specimen were gone through an axial strain of 1.25mm/min till the failure occurs. The samples prepared were wax coated to retain the moisture so that proper reaction can take place between fly ash, lime and GGBS. To measure the effect of curing the samples were kept for 0, 7, 14 and 28 days of curing period. For each different combinations of fly ash, lime and GGBS with different curing period three identical test specimen were tested and the average value has been reported.

**Figure 3.5: UCS Arrangement**

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**Figure 3.6: UCS Samples Coated With Wax**

**Table 3.8: Unconfined Compressive Strength (UCS) MPa at 0% Slag**

| % Lime | Unconfined Compressive Strength in Mpa | | | |
|---|---|---|---|---|
| | Immediate | 7-Days | 14-Days | 28-Days |
| 0 | 0.24 | 0.24 | 0.24 | 0.24 |
| 2 | 0.61 | 0.62 | 0.68 | 0.78 |
| 4 | 1.02 | 2.02 | 2.87 | 3.05 |
| 8 | 1.03 | 3.01 | 3.05 | 4.52 |
| 12 | 1.22 | 3.16 | 3.55 | 5.75 |

## IV. RESULTS AND DISCUSSION

### 4.1 General

Coal ash is a fine particulate by-product generated during the combustion of coal in thermal power plants. These wastes, when not properly managed, are often disposed of by dumping into the ground, leading to serious environmental and health concerns such as soil contamination, groundwater pollution, and air quality degradation. Therefore, it is essential to utilize coal ash in large quantities to minimize its negative impacts. One of the most effective ways to achieve this is by using it as a construction material.

In the present study, Class-F fly ash has been selected for investigation. Due to its low calcium content and limited self-cementing properties, it has been stabilized using lime and Ground Granulated Blast Furnace Slag (GGBS) to enhance its engineering properties. The prepared mixtures were subjected to standard geotechnical tests, including the Standard Proctor Test to determine compaction characteristics and the Unconfined Compressive Strength (UCS) Test to evaluate strength development.

### 4.2 Grain Size Distribution

In the test, it was found that the particles present in the class-F fly ash were uniformly graded. And the particle size varies mostly from fine sand to silt size. In the test 86% of fly ash passed through the 75μ sieve, and the coefficient of curvature (Cc) was found to be 1.26, whereas the coefficient of uniformity (Cu) was 5.66. The grain size distribution mainly depends on the degree of pulverization, temperature present in boiler unit and also on the presence of foreign particles in the fly ash.

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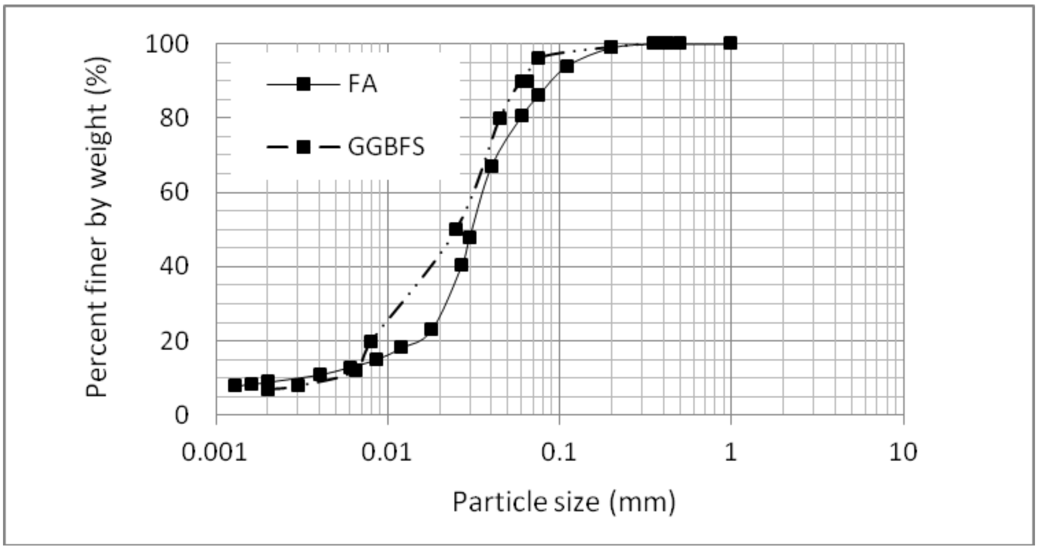


**Figure 4.1: Grain Size Distribution Curve of Class-F Fly Ash**

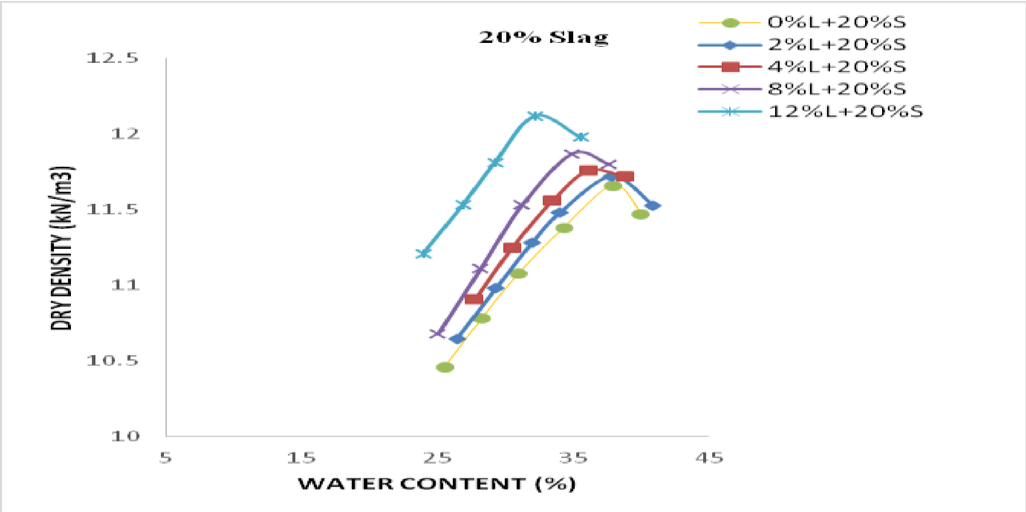


**Figure 4.2: Compaction Characteristic of Fly Ash at 20% Slag and 0%, 2%, 4%, 8% and 12% Lime Content**

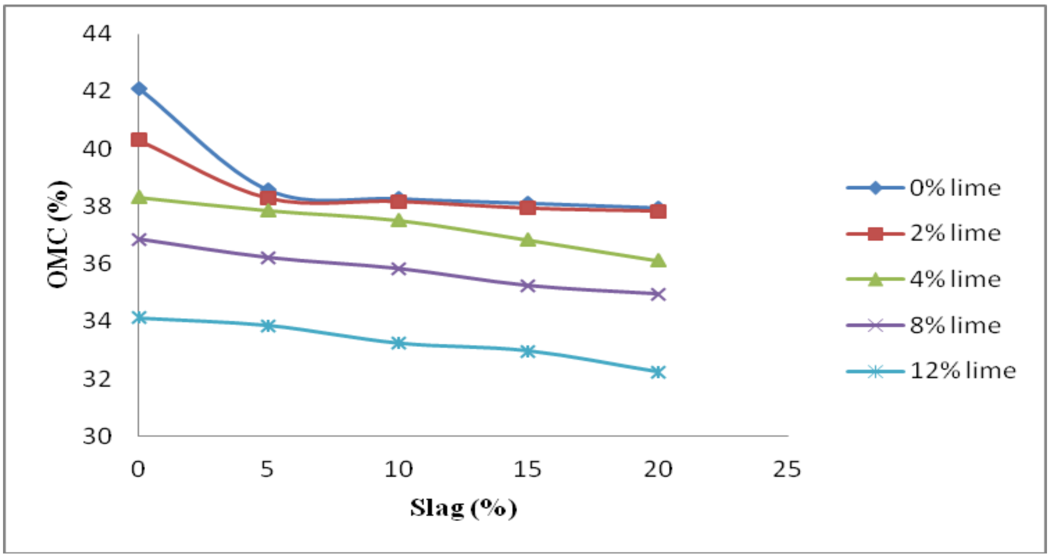


**Figure 4.3: Variation of OMC with Varying Percentage of Slag**

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### 4.3 Determination of Unconfined Compressive Strength

The unconfined compressive strength or UCS values were determined by UCS test. The sample size taken was 76mm in height and 38mm in diameter. Three samples have been made for each different combination of fly ash, lime and GGBS using OMC and MDD determined by SPT test, and an average of the three has been taken the stress-strain relationship for the treated fly ash has been compared with 0, 7, 14 and 28 days of curing period. Variation of UCS values with varying curing period i.e. 0, 7, 14, and 28 and variation of UCS values with varying percentage of lime was presented through bar charts. Variation of UCS values with different lime content at different slag with varying curing period has also been presented.

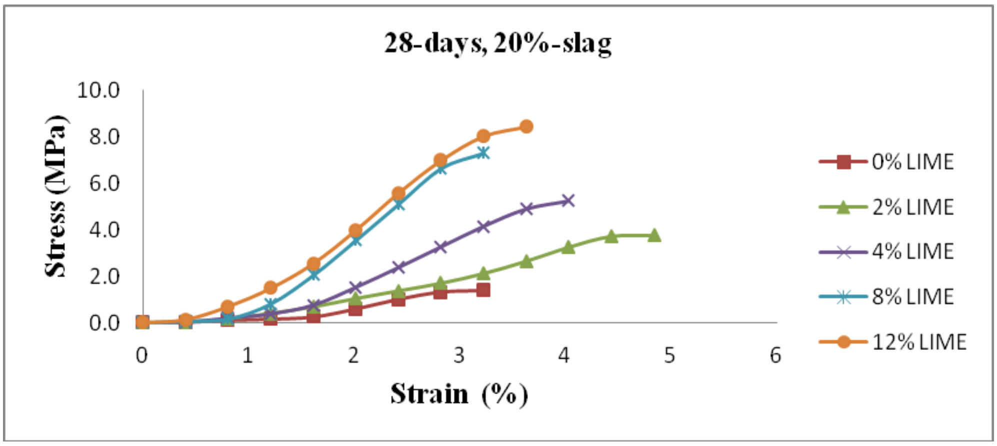


**Figure 4.4: Stress-Strain Relationship of Fly Ash with 20% Slag at 28-Days of Curing Period**

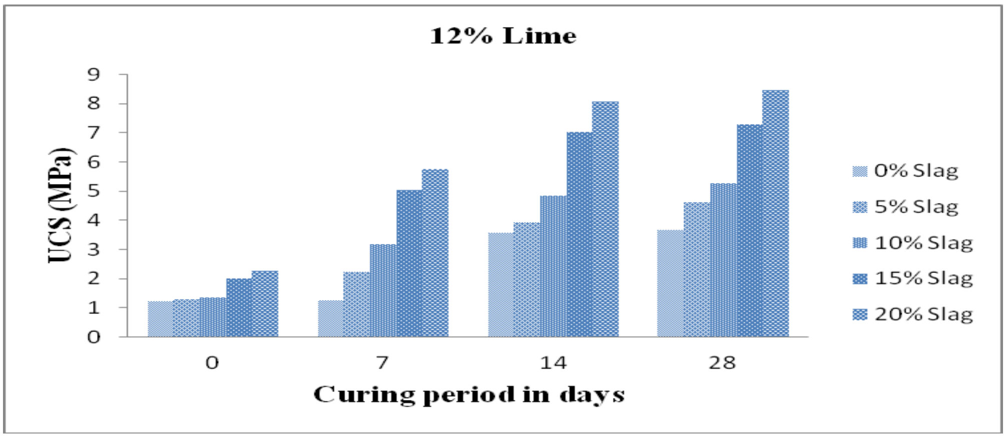


**Figure 4.5: Variation of UCS Values of Fly Ash at 0, 7, 14 and 28 Days of Curing Period with 12% lime**

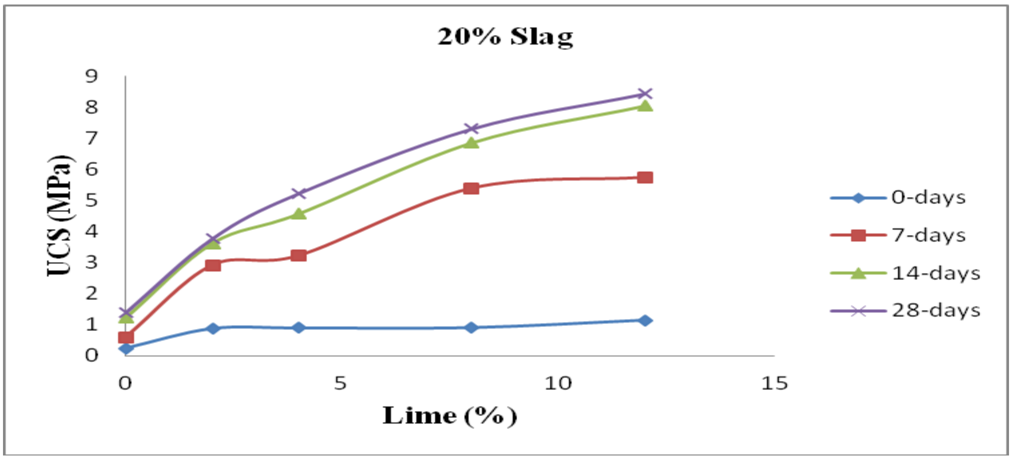


**Figure 4.6: Variation of UCS Values of Fly Ash at 20% Slag and 0%, 2%, 4%, 8%, and 12% Lime**

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## V. CONCLUSION AND FUTURE WORK

### 5.1 Conclusion

This study explored the potential of utilizing waste fly ash as a geoengineering material by stabilizing it with lime and Ground Granulated Blast Furnace Slag (GGBS). A series of experiments, including the Standard Proctor Test and Unconfined Compressive Strength (UCS) Test, were conducted to evaluate the compaction and strength characteristics of the stabilized mixtures.

Key findings from the investigation are summarized as follows:

a) **Particle Size Distribution:** Sieve analysis revealed that 86% of the fly ash particles passed through the 75µ sieve, with particle sizes predominantly ranging from fine sand to silt. The calculated coefficient of uniformity (Cu = 5.66) and coefficient of curvature (Cc = 1.26) indicate that the fly ash is well-graded within its size range.

b) **Compaction Characteristics:** Using the Standard Proctor Test with a compaction energy of 595 kJ/m³, the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) for untreated fly ash were found to be 42.12% and 10.93 kN/m³, respectively, indicating low dry density at high moisture content.

c) **Effect of Lime:** Fly ash was blended with lime in varying proportions (0%, 2%, 4%, 8%, and 12%). The highest MDD of 11.68 kN/m³ was recorded at 12% lime content, with a corresponding OMC of 34.12%. The results showed that increasing lime content leads to higher MDD and reduced OMC.

d) **Effect of Slag:** Fly ash mixed with 0% to 20% slag showed that the maximum MDD (11.66 kN/m³) and minimum OMC (34.16%) were achieved at 20% slag. This confirms that slag also enhances density while reducing the moisture requirement.

e) **Combined Lime and Slag:** A combination of 12% lime and 20% slag yielded the highest MDD of 12.12 kN/m³ with the lowest OMC of 32.23%, highlighting a synergistic effect in improving compaction properties.

**f) UCS Test Results:**

- Virgin fly ash had a UCS of 0.24 MPa.
- With increasing lime content, the UCS improved significantly, reaching 1.22 MPa at 12% lime (immediate testing), and further increasing to 5.75 MPa after 28 days of curing.
- Slag-treated samples showed maximum UCS of 0.25 MPa (immediate) and 1.39 MPa (28-day cured) at 20% slag content.
- The combined mixture (12% lime + 20% slag) displayed the highest UCS of 8.44 MPa after 28 days of curing.

g) **Suitability for Pavement:** According to IRC: 37-2012, the UCS requirement is 1.5-3 MPa for sub-base and 4.5-7 MPa for base courses in flexible pavements. The results of this study exceed these benchmarks, indicating that the stabilized fly ash mix is suitable for use as a sub-base or base course material in pavement construction.

### 5.2 Scope for Future Work

Some of the investigation that is necessary for effective utilization of lime activated fly ash with GGBS are:

- The performance of the above material under repeated loading condition to be evaluated.
- Variation in curing temperature to investigate the effect of curing temperature on UCS.
- CBR test to check the CBR values of mixtures.
- Permeability test to check the permeability of mixtures.
- Durability test to check the durability aspects.
- Oedometer test to the consolidation characteristic of mixtures.
- The effectiveness of lime activated fly ash with GGBS against leachate quality coming out.

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