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Improvement of Soil Stability and Strength by Integrating Industrial Waste (Fly Ash and Steel Slag)

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Abstract - *In this thesis we explores the potential of improving the soil stability and the strength by the incorporating the industrial waste as the stabilizing agents. The materials like fly ash, steel stag, from the industrial sources, were used to enhance the strength and the properties of the soil. In this study, we have to evaluates the effect of these stabilizers on the various soil which includes the unconfined compressive strength (UCS) moisture content, California Bearing Ratio (CBR), permeability, and the shrinkage limit .We have to do the experimental results demonstrated that the use of industrial It is not only to improve the strength and the stability of soil but it also offers us the environmental and the economic benefits by the reducing the need and stabilizing the traditional stabilizing agents to minimize the waste disposal challenges. The rapid growth of industries residue a large quantity of waste material in form of slag and ashes. These materials can be used for soil stabilization due to containing some useful elements like Silica oxide (SiO_2), Calcium oxide (CaO_2) Iron Oxide (FeO_2) and Steel etc. needed for the soil's gripping. Waste material like Steel slag and Fly ash Class C (produced from burning anthracite or bituminous coal, having high amount of calcium fly ashes with carbon contents more than 10%) can add with Clayey Soil in proportion ratio to improve soil behavior and its strength.*

The mix proportion of industrial waste material ie Steel Slag is taken in the ratio of 13% , 26% & 39 % and Fly Ash are taken in ratio of 7% , 14 % 21% respectively. The examinations conducted to assess geotechnical properties include tests for water content, specific gravity, sieve analysis, liquid limit, and plastic limit. These tests are shown the results of Steel slag and Fly ash that it improves the geotechnical properties of the soil samples with the waste material Steel slag and fly ash of Class C is useful for clayey soil. The optimum values of mixed material for higher California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) value are achieved in mix ratio 66 % Clayey Soil, 21 % Fly Ash and 13 % Steel Slag

Keywords: *California Bearing Ratio (CBR), Free Swell Index, Grain Size Analysis, Modified Proctor Density, Optimum Values, Specific Gravity, Unconfined Compressive Strength (UCS), Waste Material, Steel slag.*

1. INTRODUCTION

Soil is a crucial factor in determining the strength and the stability of the earth's surface and it serves as the foundation for construction, agriculture, and various other human activities. Many soils have poor properties such as the highly expensive in nature, high compressibility, and poor drainage characteristics, which are not good for use in infrastructure projects. We can't avoid these challenges we have to face so to minimize these challenges we have to improve the physical properties of the soil, which enhances their strength, durability, and the load-bearing capacity of the soil.

Among all these various soil stabilizers, the incorporation of industrial has gained attention because of their potential to provide us with a sustainable solution.

Industrial by-products such as steel slag, fly ash are increasingly being demanded as stabilizing agents. They are not only for enhancing the soil's mechanical properties but also offer an environmentally friendly way to recycle the waste materials which they are contributing to environmental pollution.

Industrial waste residues in the soil stabilization are particularly significant in the growing environmental concerns. These waste products are inexpensive and locally available, making them a cost-effective alternative to traditional soil stabilization methods. The contribution of reducing the environmental footprint of both the waste and the soil stabilization process. The challenges of the poor soil conditions in various regions and the exploration of waste-based stabilization methods are critical. The integration of industrial waste into the soil can lead to improved soil properties and we have to promote more and more sustainable construction practices.

This thesis aims to investigate the effects of the stabilizing agents on soil strength and stability, assessing their potential for widespread use in construction and infrastructure projects.

2. LITERATURE REVIEW

Sneha Rathod et.al (2024) : This research examines the effectiveness of fly ash, steel slag, and coconut shell in stabilizing black cotton soil. Testing through the Standard Proctor Test revealed that these additives enhance soil density, with the ideal mix found at 15%. The study highlights a sustainable and economical method to improve soil strength, offering a unique approach to eco-friendly construction.

Sultan Almuaythir et.al (Oct 2024) : The study investigates using industrial by-products—SF, CKD, CCR, RHA, and GGBS—to stabilize expansive clay soil. Tests with 3–9% additives showed improved soil behavior, including reduced plasticity and swell potential, and a notable rise in strength. UCS increased from 114.64 kPa to 1582.91 kPa with 9% GGBS after 30 days. Microstructural analysis confirmed the formation of binding compounds, enhancing soil durability. The results support these materials as sustainable alternatives to conventional stabilizers.

Alemshet, et.al (2023): This study investigates the impact of Fly Ash (FA) and Phosphogypsum Steel Slag (PGSS) on stabilizing expansive soil. The results showed an 80.04% reduction in Free Swell Index (FSI), an increase in Maximum Dry Density (MDD) from 1.46 to 1.93 kg/cm³, and a decrease in Optimum Moisture Content (OMC). California Bearing Ratio (CBR) values improved, with 20% FA and 10% PGSS achieving soaked and unsoaked CBR of 13.8% and 16.21%. Unconfined Compressive Strength (UCS) increased by 97.47% after 14 days of curing. Micro structural analysis revealed enhanced bonding, confirming the effectiveness of FA and PGSS in improving soil properties for construction use.

Worku Firomsa Kabeta and Hinsene Lemma (2023) : This study explores the use of steel slag to enhance the properties of highly expansive clay. With 25% steel slag, the liquid limit reduced from 90.8% to 65.2%, the plasticity index decreased from 30.5% to 22.7%, and swelling dropped from 104.6% to 58.2%. Specific gravity increased to 3.05, while MDD improved from 1.504 to 1.69 g/cm³, and OMC declined to 12.01%. Unconfined Compressive Strength (UCS) rose from 94.3 to 170.6 kPa, and California Bearing Ratio (CBR) improved from 3.64% to 6.82%. The findings suggest that steel slag is a sustainable and cost-effective soil stabilizer, though further chemical analysis is recommended.

Eilei Gu et.al.(2023): This study examines the use of steel slag powder as a partial cement replacement to improve fluidic silty sands. A 9:6 cement-to-steel slag ratio optimizes strength (≥100 kPa) and environmental benefits. Steel slag enhances early strength, while high temperatures accelerate CSH/CAH gel formation. Over time, soil structure compacts, confirming pozzolanic reactions. These findings support the use of steel slag in soil stabilization for better engineering performance.

Witold Waciński, **et.al (2023) :** This study investigates the use of waste-based materials for soil stabilization, enhancing strength, sealing, and frost resistance while lowering costs. For sand, the most effective stabilizers included EPW from WPEF with waste H_2SO_4, tire pyrolytic oil emulsion, and NaOH-based mixtures. For clay, the highest strength improvements were achieved using EPW from WPEF with NaOH and waste H_2SO_4. Some materials, such as EPW from WMP and CBPD "by-pass" ash, exceeded the 1.6 MPa requirement for light traffic stabilization, while others met the 1.25 MPa subbase standard. A correlation (R^2 = 0.8904) between frost resistance and capillary rise was observed in control samples, but not in treated soils. Due to variations in waste composition, further large-scale testing is recommended.

Z. Zhang et.al. (2023) :This study examines the use of MSWI fly ash and FFA for stabilizing expansive clays in pavements. MSWI fly ash, with higher CaO content, showed superior stabilization, reducing dry density, increasing compressive strength (up to 2 MPA in 28 days), and improving durability and moisture resistance. Micro-structural analysis confirmed effective bonding, and leachate tests showed safe heavy metal levels. Optimal mixes (15–20% MSWI) performed well in all conditions, while 10% MSWI and FFA were suitable for dry conditions. MSWI fly ash offers a sustainable alternative to traditional stabilizers but requires careful evaluation due to composition variability.

Ismail Zorluer and Suleyman Gucek (2020) : Industrial wastes can effectively stabilize soil, offering cost savings and environmental benefits. This study examines the effects of marble dust (MD), granite dust (GD), waste boron (BR), and fly ash (FA) on granular soils. Strength & UCS: FA enhances strength when combined with MD, with the optimal mix being 10MD-20FA. GD-FA and BR-FA mixtures also improve strength, whereas MD-GD lacks pozzolanic properties, leading to no significant strength gain.CBR Performance: GD-FA mixtures show the highest CBR values, followed by MD-FA. BR-FA has a slight improvement, while MD-GD results in decreased values. Freeze-Thaw Resistance: The 10MD-20FA mix retains the highest strength after cycles. GD-FA specimen's show increased strength at **12 cycles**, while MD-GD has the most weight loss.

Umar farook et.al (2019): A laboratory study assessed the stabilization of Stabilization of expansive soil with steel slag and fly ash. Key findings include OMC increased, MDD decreased, but MDD rose with higher steel slag content due to reduced clay and increased friction.UCC improved at 4% steel slag + 6% fly ash but declined beyond this ratio. Cohesion decreased, internal friction angle increased, enhancing shear strength. Index properties (liquid limit, plasticity, swelling) reduced, improving soil stability. Permeability decreased as steel slag minimized voids, enhancing soil structure. Cost analysis showed significant savings, making these industrial wastes a viable, sustainable alternative for soil stabilization in construction.

Mehran Nasiri et.al (Jan 2016). This study, conducted on forest roads in northern Iran's Caspian region, highlights the importance of forest roads for timber transport and conservation. It evaluates the effectiveness of rice husk ash (RHA) as a soil stabilizer in the sub-base layer of pavements. Experimental results show that adding 9% RHA reduces the liquid limit and plasticity index, while increasing optimum moisture content (21.9%) and CBR strength (37.5% at water moisture, 28% in saturated conditions).UCS tests indicate a strength of 237 kN/m² after 28 days, surpassing natural soil by 23 kN/m². The optimal mix for sub-base improvement consists of 9% lime, 4% soil, and RHA, enhancing road durability and stability.

Kayal Rajakumar (2015): This study examines the stabilization of expansive soil using steel slag and fly ash. The findings show a reduction in liquid limit, shrinkage limit, plastic limit, and swelling index. Permeability decreases as steel slag content increases, minimizing air voids. The best unconfined compressive strength is achieved with 4% steel slag and 6% fly ash. The results confirm that steel slag and fly ash effectively improve soft soil stability. Further research is recommended on CBR performance in soaked and unsoaked conditions and the impact of temperature on stabilization.

Kiran B. Biradar, **et.al**. **(2014):** The study concludes that adding steel slag and fly ash improves soil properties. Steel slag reduces the liquid limit by 22.96% and plasticity index by 65.76%, while fly ash decreases them by 17.19% and 25.67%, respectively. Maximum dry density increases by 9.20% with 40% steel slag but decreases by 19.62% with 50% fly ash. Optimum moisture content drops by 39.24% for steel slag but rises by 35.44% for fly ash. CBR (soaked) increases by 180% with 40% steel slag and 65% with 30% fly ash, while CBR (unsoaked) improves by 122% and 45%, respectively. Steel slag provides higher CBR enhancement than fly ash.

Irem Zeynep Yildirim et.al (2013) : This research focuses on using a steel slag-fly ash blend as a cost-effective solution for subgrade stabilization. Laboratory tests identified 7% steel slag and 3% fly ash as the most effective combination. This mixture was implemented in the I-65 subgrade project in Indiana, with field assessments using DCP and nuclear gauge tests confirming proper compaction.

RESEARCH GAP

Identifying research gaps is an essential component of any dissertation or research study. In the context of clayey soil stabilization using steel slag and fly ash, several key areas require further investigation:

1. **Limited Understanding of Combined Effects:** While the individual use of steel slag and fly ash as soil stabilizers has been explored, there is limited research on their combined application. Investigating their synergistic or antagonistic interactions could provide valuable insights into their effectiveness in clayey soil stabilization.

2. **Variability in Material Properties:** The properties of stee slag and fly ash can vary significantly depending on their source and production process. However, research is lacking on how these variations influence their stabilization performance. A comprehensive study could help establish guidelines for material selection.

3. **Long-Term Performance and Durability**: Most studies focus on the short-term effects of stabilization, while the long-term behavior of clayey soil treated with steel slag and fly ash remains underexplored. Understanding its durability and performance over extended periods is crucial for infrastructure development.

4. **Environmental Impact Assessment:** Although the environmental benefits of utilizing industrial by-products are recognized, limited research exists on the potential leaching of harmful substances from steel slag and fly ash in stabilized soils. A thorough environmental impact analysis is required to assess their sustainability and safety.

5. **Standardization and Engineering Guidelines**: There is currently no standardized methodology for using steel slag and fly ash in clayey soil stabilization. Research is needed to establish uniform procedures, mix design guidelines, and performance criteria to ensure consistency in engineering applications.

6. **Economic Feasibility and Cost-Benefit Analysis**: While these materials present a potentially cost-effective alternative to traditional stabilizers, there is a lack of detailed economic feasibility studies. Analyzing the cost-effectiveness and long-term financial benefits of using steel slag and fly ash could help encourage their wider adoption.

3. MATERIALS AND METHODOLOGY USED

3.1.1 SOILS

For research we have to take soil samples which we were collected from the nearby area at some depth of the ground level from locations **Jammu city, Jammu and Kashmir**. The surface clay is considered for the work. The sample is placed open to the environment and exposed to direct sunlight during day time. We have to packed the soil sample and placed it in water resistance bag they will keep the soil remain in dry condition. After that we have taken the sample and shattered into the smaller fragments using hammer in the laboratory, the crushed soil is now sieved passing through the 4.75mm sieve for the subsequent test as the untreated soil sample. Soil sample is obtained from the Jammu city, Jammu and Kashmir, India and tested as per Indian standard IS 2720. For the study, the sample must be clean and inspected to remove lumps and then sieved. We have used various stabilizing agents to enhance the strength and stability of the problematic soil such as fly ash and steel slag.

Fig 3.1 Clayey soil sample

Table 3.1 Engineering Characteristics of Untreated Clayey Soil

Sr.No	Properties	Values
1	Clay Content	87.5 %
2	Silt Content	4.3
3	Fine Sand	5.4
4	Medium Sand	2.8
5	Liquid Limit1	42.85%
6	Plastic Limit	32.45%
7	Plasticity Index	10.40
8	Specific Gravity	2.64

3.1.2 FLY ASH

Fly ash is an industrial by product produced from burning anthracite and bituminous coal. Class C fly ash contains more than 10% lime (CaO), giving it both pozzolanic and cementitious properties. The silica and alumina in fly ash require a binding agent like Portland cement, quicklime, or hydrated lime, along with water, to trigger a reaction and form cement-like compounds.

Fig 3.2 Fly ash sample

Table 3.2 Engineering characteristics of Fly Ash (Class C)

Sr.No	Properties	Values
1	Calcium Oxide (Cao)	20.45%
2	Classification of Fly ash	Type C
3	Silica (SiO_2)	23.08 %
4	Al (as AlO)	40.94%
5	Silt Content	26.84
6	Fine Sand	79.02
7	Liquid Limit (%)	43.2
8	Specific Gravity	2.02

3.1.3 STEEL SLAG:

Steel slag, a by-product of the steel manufacturing process, has gained significant attention as an effective material for soil stabilization. It is produced during the separation of molten steel from impurities in a blast furnace or electric arc furnace. Steel slag consists of sand-sized particles with high density, a high internal friction angle, and excellent drainage properties. These characteristics make it well-suited for embankment and sub grade applications. Steel slag meets the required density and plasticity standards, making it a suitable material for such construction purposes.

Fig 3.3 Steel Slag Sample

Table 3.3 Engineering Characteristics of Steel Slag

Sr.No	Properties	Values
1	Calcium oxide (Cao)	50%
2	Silicon dioxide (SiO_2)	20%
3	Aluminium Oxides (Al_2O_3)	1.21 %
4	Gravel (%)	44.35 %
5	Sand (%)	55.02%
6	Fines (%)	1.63%
7	Maximum Dry Density (MDD) , gm/cc	2.0 gm/cc

3.2 METHODOLOGY ADOPTED

1. To assess the various characteristics indicated in the objectives, the following experiments will be performed on virgin soil as well as soil having proportions of steel slag and fly ash**:**

 2. Calculation of soil Index characteristics (IS 2720 Part-V)

 a. Liquid Limit Test

 b. Plastic Limit Test

3. Mass Density Test
4. Free Swell Test
5. Grain Size Distribution Test
6. Compaction Factor Test
7. CBR Test
8. UCS Test

4. RESULT ANALYSIS

The **Result Analysis** section is a crucial part of this study, providing insights gained through meticulous experimentation and data interpretation. It presents a detailed breakdown of the collected empirical evidence, offering a comprehensive understanding of the significance of our findings.

After the soil was oven dried, following basic tests were performed on it:

- Specific Gravity Test (Pycnometer test) (IS: 2720 Part III Section I/II-1980)
- Free swell index test
- Grain size test
- Consistency Limit test
- Standard proctor test (IS: 2720 Part VII-1980)
- California bearing ratio test (IS: 2720 Part XVI-1987)
- Unconfined compressive strength test (IS: 2720 Part X-1991)

4.1 SPECIFIC GRAVITY TEST

Table 4.1 Value of Specific gravity test

Container Number	**Unit**
Mass of the empty pycnometer (M1), (M_1)	37.16
Mass of pycnometer plus mass of dry soil (M_2)	63.50
Mass of pycnometer plus soil plus distilled water (M_3)	154.59
Mass of pycnometer plus fill with water only (M_4)	138.21
Specific gravity G	2.64

4.2 FREE SWELL INDEX OF CLAYEY SOIL

Table 4.2 Value of Free Swell Index of soil

Sr.No	**Sample Level in Water (Vd) ml**	**Sample Level in Kerosen (Vk) ml**	**FSI in water (Vd-Vk)**	**FSI % =** $\left(\frac{V_d - V_k}{V_k}\right) \times 100$
1	23	16	7	43.75
2	20	14	6	42.85
3	21	15	6	40

4.3 GRAIN SIZE ANALYSIS RESULT OF CLAYEY SOIL

Table 4.3 Value of Grain size analysis

S. No	Sieve (mm)	Weight of sample retained on sieve	Cumulative weight retaining on sieve	Percentage of soil retained on sieve	Percentage of soil passed on sieve
1	2.36	0	0	0	100
2	1.18	0	0	0	100
3	0.6	0	0	0	100
4	0.42	11.4	11.4	1.14	98.86
5	0.3	23	34.3	3.43	96.57

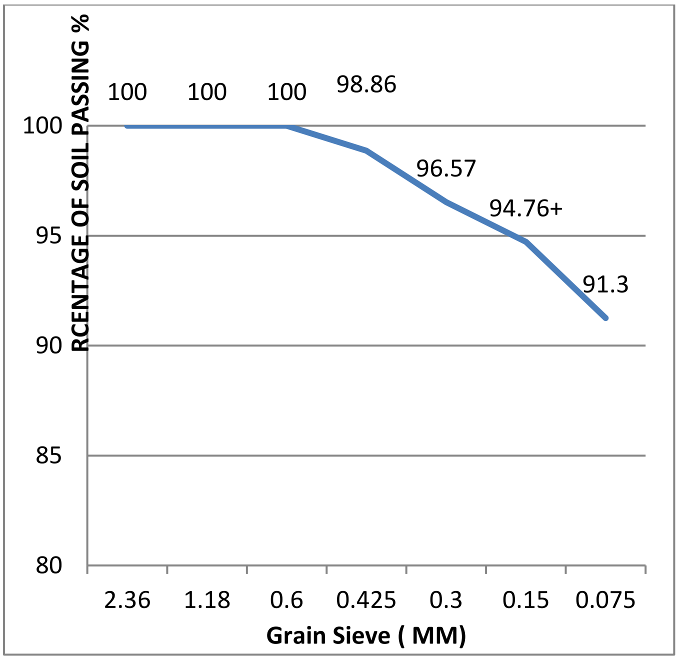

Fig 4.1 Graph of Grain Size

4.4 CONSISTENCY LIMIT (IS: 2720, PART 5 – 1980

4.4.1 LIQUID LIMIT

Table 4.4.1 Values of Liquid Limit of various mixture

S. No	Mix No	Sample Details	Liquid Limit
1	M1	100% Clayey Soil	42.80
2	M2	93 % Clayey Soil + 7 % Fly Ash	43.50
3	M3	86% Clayey Soil + 14 % Fly Ash	44.10
4	M4	79% Clayey Soil + 21 % Fly Ash	45.05

4.4.2 PLASTIC LIMIT

Table 4.4.2 Values of Plastic Limit of various Mixture

S. No	Mix No	Sample Details	Plastic Limit
1	M1	100% Clayey Soil	32.46
2	M2	93 % Clayey Soil + 7 % Fly Ash	30.96
3	M3	86% Clayey Soil + 14 % Fly Ash	29.64
4	M4	79% Clayey Soil + 21 % Fly Ash	27.35
5	M5	87 % Clayey Soil + 13 % Steel Slag	29.16

4.4.3 PLASTICITY INDEX

Table 4.4.3 Values of Plasticity Index of various Mixture

S. No	Mix No	Sample Details	Plasticity Index
1	M1	100% Clayey Soil	10.3
2	M2	93 % Clayey Soil + 7 % Fly Ash	9.5
3	M3	86% Clayey Soil + 14 % Fly Ash	9.50
4	M4	79% Clayey Soil + 21 % Fly Ash	8.7
5	M5	87 % Clayey Soil + 13 % Steel Slag	10.8

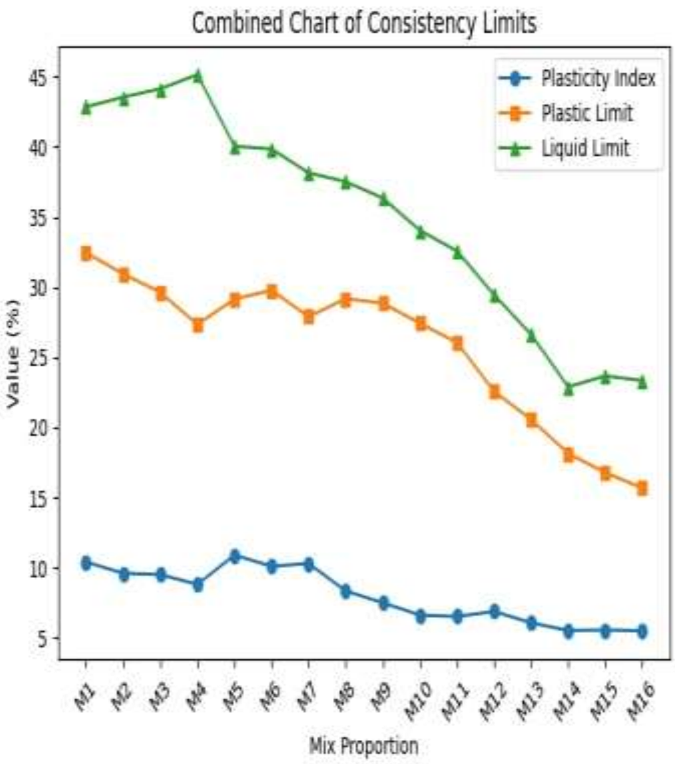

Fig 4.2 Consistency Limit of different value

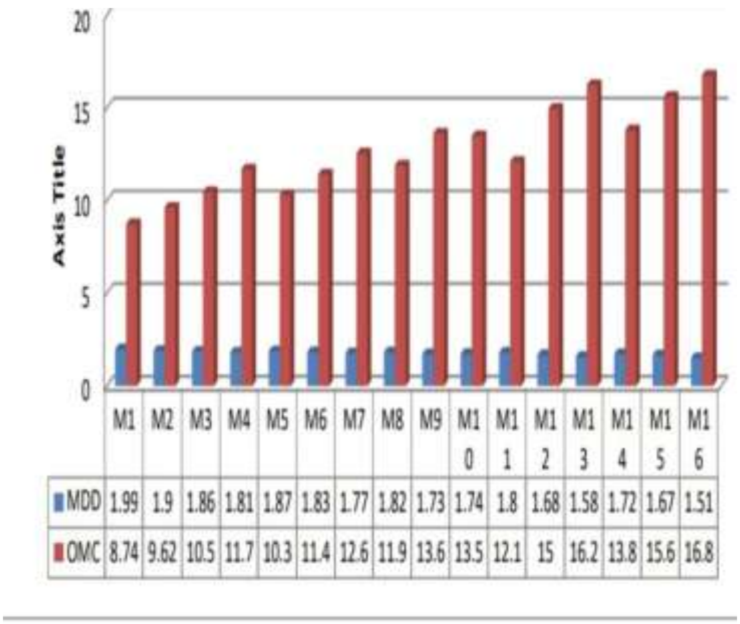

Fig 4.3 Graph of Compaction Proctor Test

4.5 COMPACTION PROCTOR TEST

Table 4.5 Values of Compaction Proctor of various Mixture

S. No	Mix No	Sample Details	MDD	OMC
1	M1	100% Clayey Soil	1.989	8.74
2	M2	93 % Clayey Soil + 7 % Fly Ash	1.902	9.62
3	M3	86% Clayey Soil + 14 % Fly Ash	1.862	10.46
4	M4	79% Clayey Soil + 21 % Fly Ash	1.811	11.68
5	M5	87 % Clayey Soil + 13 % Steel Slag	1.874	10.3

4.6 CBR TEST

Table 4.6 Values of CBR (Unsoaked & Soaked) of Various Mixture

S. No	Mix No	Sample Details	CBR	
			Unsoaked	Soaked
1	M1	100% Clayey Soil	1.29	3.20
2	M2	93 % Clayey Soil + 7 % Fly Ash	3.19	4.9
3	M3	86% Clayey Soil + 14 % Fly Ash	4.0	6.2
4	M4	79% Clayey Soil + 21 % Fly Ash	6.8	8.2
5	M5	87 % Clayey Soil + 13 % Steel Slag	4.6	7.2

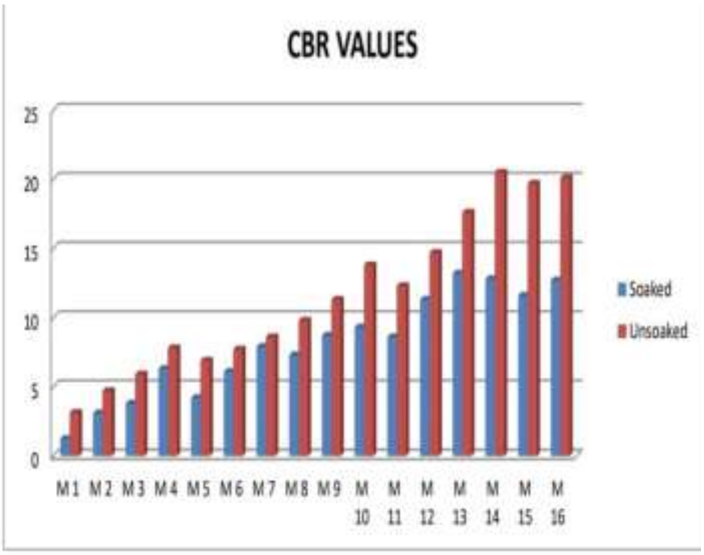

Fig 4.4 Graph of CBR (Unsoaked & Soaked) of Various Mixture

4.7 UCS TEST

Table 4.7 Values of UCS of various mixture after 7 day & 28 days

S. No	Mix No	Sample Details	UCS	
			7 Days	**28 Days**
1	M1	100% Clayey Soil	141.42	188.32
2	M2	93 % Clayey Soil + 7 % Fly Ash	151.40	215.60
3	M3	86% Clayey Soil + 14 % Fly Ash	171.25	238.35
4	M4	79% Clayey Soil + 21 % Fly Ash	181.25	263.45
5	M5	87 % Clayey Soil + 13 % Steel Slag	160.45	235.51

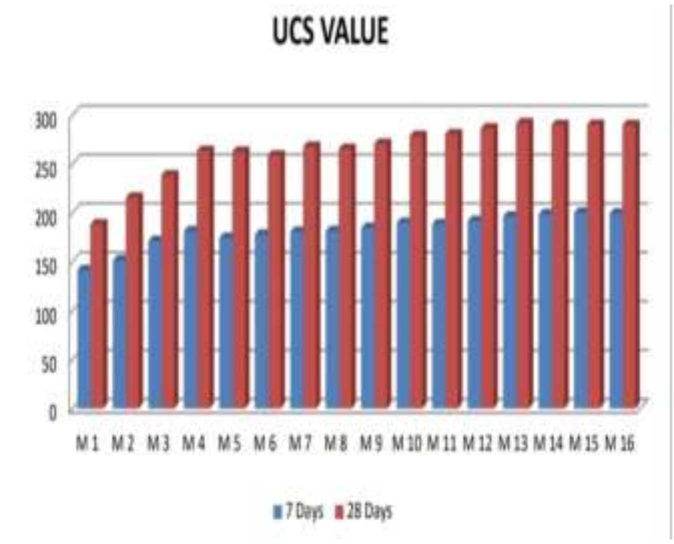

Fig 4.5 Graph of UCS of Various Mix after 7 & 28 days

5. DISCUSSION

5.1 Compaction Characteristics (MDD and OMC)

The compaction characteristics of soil stabilized with industrial waste materials such as fly ash and steel slag were evaluated in terms of Maximum Dry Density (MDD) and Optimum Moisture Content (OMC).

The results indicate that the Maximum Dry Density initially increased with the addition of fly ash and steel slag up to an optimum percentage, after which a slight reduction was observed. The initial increase in MDD can be attributed to the filler effect of fine fly ash particles and the angular nature of steel slag, which improves particle interlocking and soil densification. However, at higher replacement levels, the lower specific gravity of fly ash compared to natural soil leads to a reduction in dry density.

The Optimum Moisture Content showed an increasing trend with increasing fly ash and steel slag content. This increase is mainly due to the higher surface area and water absorption capacity of fly ash, as well as the hydration requirement of steel slag, which demands additional moisture for proper compaction and pozzolanic reactions.

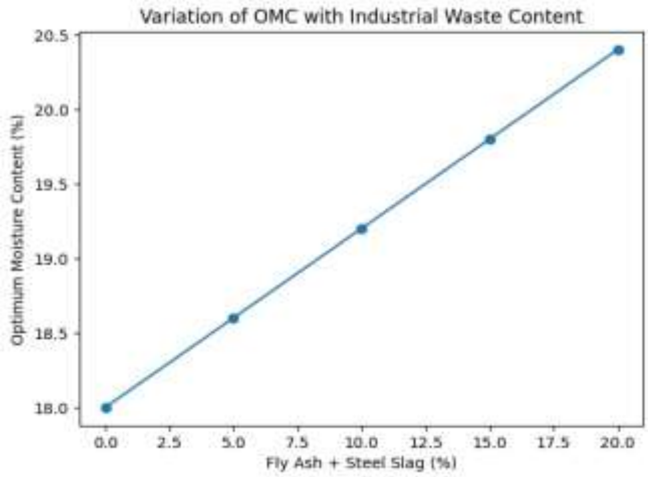

Fig 5.1 Graph represent the variation in OMC

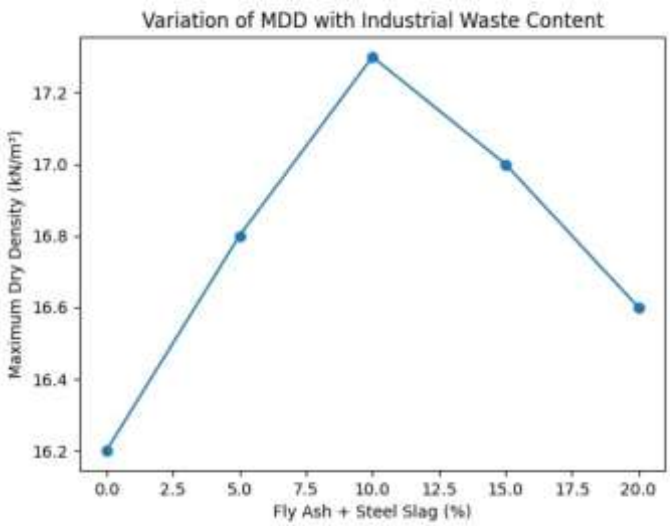

Fig 5.2 Graph represents the variations of MDD

5.2 California Bearing Ratio (CBR) Characteristics

The California Bearing Ratio (CBR) values of the stabilized soil samples showed a significant improvement compared to untreated soil, under both soaked and unsoaked conditions.

The enhancement in CBR values is attributed to:

- ➢ Formation of cementitious compounds due to pozzolanic reactions between calcium-rich steel slag and silica/alumina present in fly ash
- ➢ Improved soil particle bonding
- ➢ Reduction in soil plasticity,
- ➢ Although soaked CBR values were lower than unsoaked values due to moisture penetration, the stabilized soil still exhibited considerably higher bearing capacity than untreated soil. This improvement indicates that the use of fly ash and steel slag makes the soil suitable for subgrade and pavement construction applications.

5.3 Unconfined Compressive Strength (UCS) Characteristics

The Unconfined Compressive Strength (UCS) of soil samples increased substantially with the addition of fly ash and steel slag. The strength gain became more pronounced with an increase in curing period, indicating the time-dependent nature of stabilization.The increase in UCS can be attributed to Pozzolanic reactions between calcium oxide (CaO) from steel slag and silica (SiO_2) and alumina (Al_2O_3) from fly ash Formation of calcium silicate hydrate (C–S–H) and calcium aluminate hydrate (C–A–H) gels Development of a dense and well-bonded soil matrix Longer curing periods allowed sufficient time for hydration and pozzolanic activity, resulting in higher UCS values. This confirms the effectiveness of fly ash and steel slag in enhancing the strength characteristics of soil.

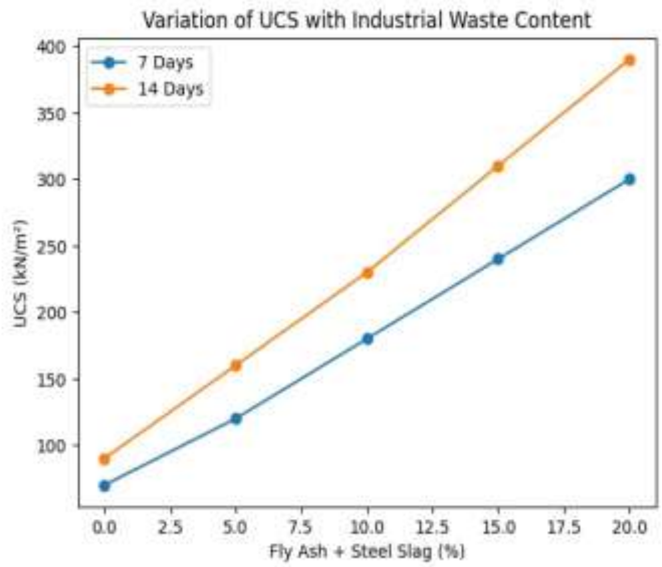

Fig 5.3 Graph represents the UCS in 7 days and 28 days

5.4 Overall Performance of Fly Ash and Steel Slag Stabilization

Based on the experimental results, it is evident that the combined use of fly ash and steel slag significantly improves the engineering properties of soil. The stabilized soil showed:

- ➢ Improved compaction behavior
- ➢ Enhanced bearing capacity
- ➢ Increased compressive strength
- ➢ Reduced permeability
- ➢ Moreover, the utilization of industrial waste materials contributes to sustainable construction practices by reducing environmental pollution and promoting waste reutilization.

5.5 Summary of Discussion

The discussion clearly demonstrates that fly ash and steel slag are effective stabilizing agents for improving soil strength and stability. Their combined application results in enhanced mechanical performance and long-term durability, making them a viable alternative to conventional stabilizers such as cement and lime

CONCLUSION

As discussed, extensive testing was conducted to understand the characteristics and behavior of clayey soil both in its natural state and after the addition of Fly Ash and Waste Steel Slag. The study focused on evaluating the physical and engineering properties of naturally stabilized clayey soil. Tests such as consistency limits, Proctor density, California Bearing Ratio (both soaked and unsoaked conditions), and Unconfined Compressive Strength (over periods ranging from 7 to 28 days) were performed to assess the effects of these additives on the soil.

The following conclusions were drawn from the testing conducted:

1. **Clayey Soil Characteristics**: The clayey soil, with over 90% passing through a 75-micron sieve and an average Free Swell Index of approximately 42.2% so the soil is clay of Intermediate soil (CI) soil,, is unsuitable for use as embankment or reinforcement fill due to its clayey nature and low compressive strength. The engineering characteristics of this soil can be enhanced by incorporating industrial waste such as Steel Slag and Fly Ash of Class C.

2. **Environmental Impact**: To mitigate the environmental effects of Fly Ash and Steel Slag, incorporating these materials into soil stabilization offers an environmentally responsible solution for geotechnical challenges. This approach is cost-effective, sustainable, and helps enhance soil characteristics while promoting eco-friendly construction practices by utilizing solid waste materials in construction.

3. **Consistency Improvements**: The addition of 21% Class C Fly Ash and 13% Steel Slag enhances the consistency of clayey soil.. The liquid limit reduction from 66.80% to 25.74%, while the plasticity index dropped from 34.4 to 8.

4. **To Improved Engineering characteristics**: The main engineering characteristic of clayey soil, such as the Standard Proctor Density (SPT) and California Bearing Ratio (CBR), improve with the addition of Fly Ash and Steel Slag at various proportions. The Modified Dry Density (MDD) of the clayey soil increases from 1.740g/cc to 1.945 g/cc. The optimum CBR value is achieved with a mixture of 66% Clayey Soil, 21% Fly Ash, and 13% Steel Slag.

5. **Unconfined Compressive Strength (UCS)**: UCS increases gradually with different proportion ratios of Fly Ash and Steel Slag, reaching a constant value by Mix No. M16. The highest UCS value is obtained at Mix No. M14, with a proportion of 66% Clayey Soil, 21% Fly Ash, and 13% Steel Slag.

6. **UCS and Soil Strength**: The UCS results for the M14 mix, which contains 66% clayey soil, 21% fly ash, and 13% steel slag, show an optimum value at 28 days. This blend improves soil strength and reduces its permeability and compressibility compared to untreated clayey soil.

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