

# Transforming Expansive Clays FROM Waste TO Value: Dual Ash Stabilization Strategy FOR Augmenting Black Cotton Subgrade Soil Performance

Wajid Khan<sup>1</sup>, Ghassan Sattar Khan<sup>2</sup>, Muhammad Munawar<sup>3</sup>, Qaim Shah<sup>4</sup>, Muhammad Haseeb khan<sup>5</sup>, Kashif Daud<sup>6</sup>, Uzair Ali<sup>7</sup>

<sup>1</sup>CECOS University of IT and Emerging Sciences, Peshawar, Pakistan, wajidk@uetpeshawar.edu.pk

<sup>2</sup>University of Engineering and Technology (UET), Taxila, Pakistan, gsk.engineerz@gmail.com

<sup>3</sup>Local Government, Elections and Rural Development Department, Khyber Pakhtunkhwa, Pakistan, sdomunawartma@gmail.com

<sup>4</sup>University of Engineering and Technology (UET), Peshawar, Pakistan, pakistan18pwciv4996@uetpeshawar.edu.pk

<sup>5</sup>CECOS University of IT and Emerging Sciences, Peshawar, Pakistan, muhammad.haseeb@cecos.edu.pk

<sup>6</sup>National University of Sciences & Technology (NUST), Islamabad, Pakistan, engr.kashifdaud@gmail.com

<sup>7</sup>Local Government and Rural Development Department, Khyber Pakhtunkhwa, Pakistan, engruzair91@gmail.com

---

## Abstract

Due to its tendency to expand and shrink when exposed to moisture, black cotton soil is costly. As a result, its strength and other qualities are compromised. Stabilizers can be used to stabilize the black cotton soil in order to improve its weak characteristics. The behavior of black cotton soil with various stabilizer types is erratic. Soil stabilization is done for this reason in order to enhance the soil's engineering qualities. One method for enhancing the engineering qualities of soil is soil stabilization. The engineering properties, including Atterberg's limits (liquid limit, plastic limit, and plasticity index), specific gravity, maximum dry density, optimal moisture content, unconfined compressive strength, and California bearing ratio, have been investigated in this study using a variety of materials, including fly ash and bagasse ash. The aforementioned stabilizers (bagasse ash and fly ash) were applied in varying proportions.

**Keywords:** Stabilization, black cotton soil, bagasse ash, fly ash

---

## INTRODUCTION

The New Peshawar Housing Society is situated in Pakistan's Nowshera district on GT Road. Nearly 700 homes, parks, mosques, clinics, elementary schools, and a business district are all located there [1]. The main issue is that the water table is quite low in this town area because it was once a lowland area that was saturated with water, swamps, and marshes. Despite this, the town is well-planned and easily accessible because it is on the main road to the main city of Peshawar. Clayey soil, which is found in arid climates, is made cohesive by the still water. Individuals are building homes, but they are encountering various issues with the foundation [2].

Many minerals found in clayey soil, such as bentonite, montmorillonite, smectite, vermiculite, illite, chlorite, nontronite, and beidcillite, have a high capacity to absorb water, which results in swelling and an increase in volume [3-4]. The clayey soil shrinks as the water is removed. Additionally, clay cracks out, resulting in repeated swelling and shrinking [5-6]. Buildings and other things made of clay are harmed by these events. Due to the low water table, buildings and other structures built in clayey soil have experienced several negative effects and damages [7-8]. A few of these include increased earth pressure on the basement walls, basement leaks, less bearing capacity, a higher chance of foundation settlement, more cracking, and a significant danger of sulfate attack on the concrete foundation [9-13]. Additionally, the clay may shrink, which would lower the structure's capacity to sustain dynamic load. Lowering the water table can solve a number of issues related to structures built in weak clayey soils, including increased earth pressure in the basement wall, decreased bearing capacity, increased foundation settlement potential,

increased cracking, and a high risk of sulphate attack on the foundation concrete [14–17]. The clay may shrink, which would lower the structure's capacity to sustain dynamic load. Damage to a clay-built structure develops gradually and is not apparent until an earthquake or explosion occurs [18].

Expansive soils, also known as swell-shrink soils, have a propensity to expand and contract in response to changes in moisture content. This variance causes the soil to become seriously distressed, which is followed by harm to the structures that are on top of it. These soils absorb the water and swell during times of higher precipitation, such as monsoons; as a result, they soften and lose their ability to retain water [19–22]. In contrast, these soils become harder during drier seasons, such as summers, when evaporation causes them to lose the moisture they have stored. These soils, which are typically found in arid and semi-arid areas of the world, are considered potential natural hazards because, if left untreated, they can seriously harm buildings and even result in fatalities. These kinds of characteristics are typically found in soils that include montmorillonite. These soils have severely damaged civil engineering structures, costing billions of dollars per year worldwide [23]. The process of improving the engineering qualities of soil by modifying one or more of its properties in accordance with construction demands is known as soil stabilization. Many engineering disciplines use soil stabilization [24]. The major goal is to use locally accessible raw materials to inexpensively strengthen and stabilize the foundation soil that supports a construction.

Fly ash is a waste product that is removed from the gases that come from coal-fired furnaces, usually found in thermal power plants. These ashes were thought to be among the best pozzolans, or binding agents, available in the world. In the past, one of the main uses for volcanic ashes was to make hydraulic cements; fly ash is quite similar to these volcanic ashes. Fly ash is the mineral waste that remains when coal is burned [25–27]. These days, the growing urbanization and industrialization phenomena have caused an exponential increase in the need for power supplies. As a result of this expansion, there are now more power plants that provide thermal power plants that generate energy by burning coal. These fly ashes are collected by the power plants' Electro Static Precipitator (ESP). Fly ash production raises two main issues: managing fly ash and safely disposing of it. Because of the hazardous nature of wastes produced by industries and their complex characteristics, it is imperative that they be disposed of safely and effectively to avoid upsetting the ecological system and endangering both human life and the environment. If these industrial wastes are not pre-treated before being disposed of or stored, environmental contamination will soon occur. Fly ashes are essentially micro-sized particles made of iron, silica, and alumina. Because fly ash particles are typically spherical in shape, they may easily mix and flow to create the right mixture. Fly ash is composed of minerals that are both crystalline and amorphous [28–29]. It is essentially non-plastic silt, though its composition varies according to the type of coal used for burning. Fly ash is a possible material that can be utilized for waste liners. It can also be used as a barrier material when combined with specific minerals, such as bentonite and lime. In the existing situation, fly ash the waste material seen in the picture is generated significantly more frequently than it is currently used. Stated differently, we are creating more fly ash than we can use.

Following are the objectives of the research investigation.

- To address the issues with the soil
- To improve a soil's engineering qualities, such as its unconfined compressive strength, plastic limit, and liquid limit
- To raise a soil's bearing capacity

## MATERIALS AND METHOD

Following are the material used in this research.

### Black Cotton Soil (BCS)

The black cotton soil is the residual soil it is expensive in nature, its expensive nature is due to the presence of clay mineral called montmorillonite which cause a quick swell and shrink phenomena in the soil, this type of soil is a great source of damage to infrastructure and buildings. It's very difficult to construct a foundation on such type of soil. Special care in the form of soil stabilization can be made to enable this soil to become stable and load bearing. For such a purpose this task in the form of research

work have been performed by using bagasse ash and fly ash as a stabilizer to improve different geotechnical properties of black cotton soil [30].

#### Bagasse Ash (BA)

Bagasse ash is the raw material of sugar cane which is produced from burning of bagasse and sugar factory, each ton of sugar cane produces almost 250kg of bagasse ash. Bagasse ash can also be used in production of paper, pulp and also in various building material. This bagasse ash is the problem for sugar industry to dispose, its utilization is a challenging task for the researcher to protect the environment from its impact the bagasse ash is cementing in nature because of ingredient named amorphous silica therefore it can be used as a stabilizer with soil in order to improve the expensive nature of the soil [31-32].

#### Fly Ash (FA)

Fly ash can be obtained from combustion of coal in thermal power plants. Disposal is a big issue because it has adverse effects on environment as well as on human in Pakistan about 105 million tons of fly ash is produced every year although in various research fly ash has been used in concrete in order to improve its workability and durability but in this research work the fly ash have been used as a stabilizer with black cotton soil in order to Improve Its geotechnical property.

### METHODOLOGY

The research investigation's methodology points are listed below.

- To observe how the soil varies over space, representative sites of black cotton soil (BCS) were selected, and disturbed bulk samples were taken from the top 0-1 m at three-five locations. We removed 10 to 15 kg of soil from each location using a hand auger or borrowed spade. To prevent moisture loss during transportation to the laboratory, we placed the samples in airtight plastic bags, maintained at its natural moisture content until testing.
- Bagasse ash (BA): This is produced nearby in a sugar mill. After gathering a brand-new production batch, we let it to air dry before baking it at  $105\pm 5^{\circ}\text{C}$  until its weight remained constant. Filter to a size of less than  $75\ \mu\text{m}$ .
- Fly ash (FA): Purchased from a local supplier. After drying, sieve to less than  $75\ \mu\text{m}$ .
- We conducted baseline and index geotechnical tests on BCS combined with stabilizers as part of the treatment. These tests included the California bearing ratio (CBR), the optimum moisture content (OMC), the modified proctor test (MDD), the Atterberg limits, the unconfined compression test (UCS), and the specific gravity.
- Determined the appropriate dosage of each stabilizer based on the dry weight of the soil. Common sequences are 0% (control), 3%, 6%, and 9% for BA and FA, respectively, with the possibility to mix.
- Creating tables and graphs that show the results of every experiment that was conducted.

### RESULTS AND DISCUSSION

Following are the results of the experiments performed in the laboratory.

#### Overall outcomes of the tests performed

**Table 1: Result of the properties of black cotton soil modified with fly ash and bagasse ash**

% Replacement	Liquid limit (LL) (%)	Plastic limit (PL) (%)	Specific gravity	OMC (%)	MDD (g/cc)	CBR	UCS (KN/m <sup>2</sup> )
0	74.22	32.78	2.63	30.50	1.305	12.88	138.58
3	72.31	34.91	2.41	30.51	1.265	12.86	159.78
6	33.48	26.63	2.55	31.71	1.509	14.78	637.95
9	65.57	22.81	2.55	30.81	1.369	12.99	238.27

#### Atterberg Limits

Following figure is to show the effect of additives on the atterberg limits utilized in the soil collected for the research purpose

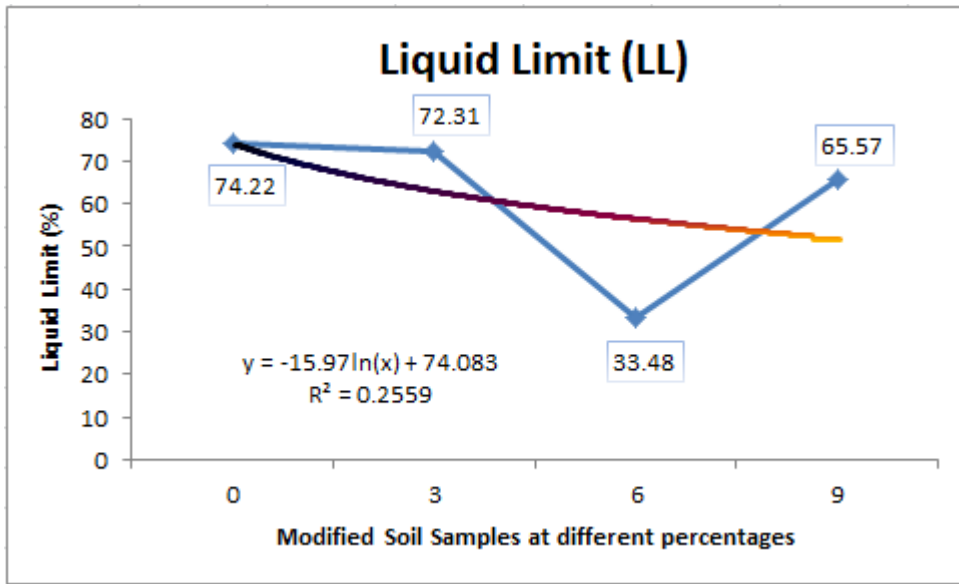


Figure 1: Liquid limit of modified soil samples

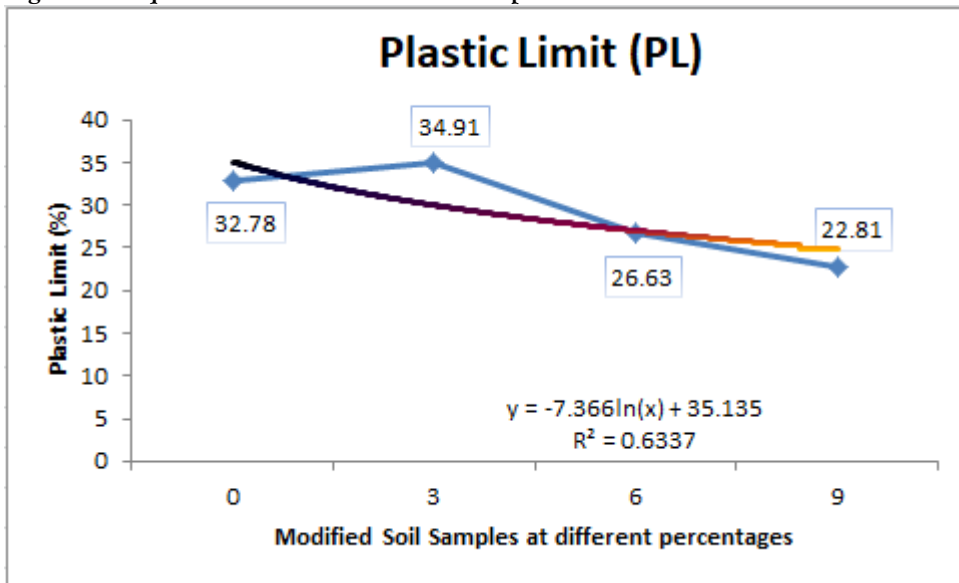


Figure 2: Plastic limit of modified soil samples

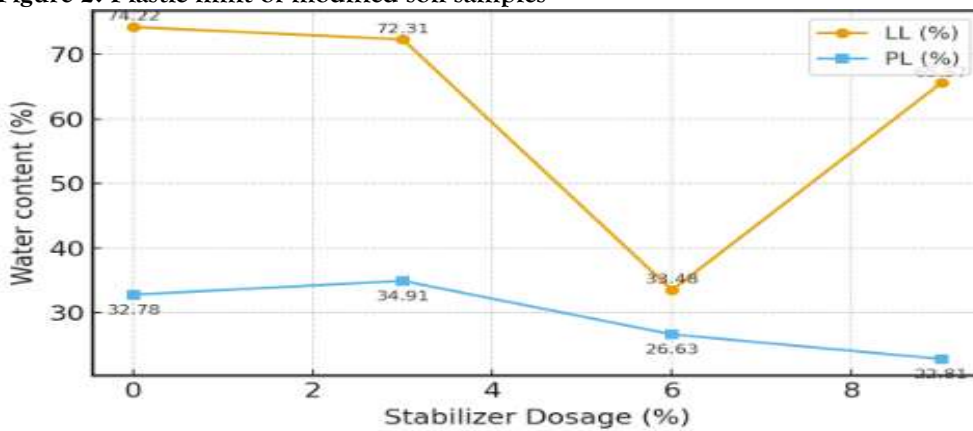


Figure 3: Liquid limit and plastic limit vs. stabilizer dosage graph

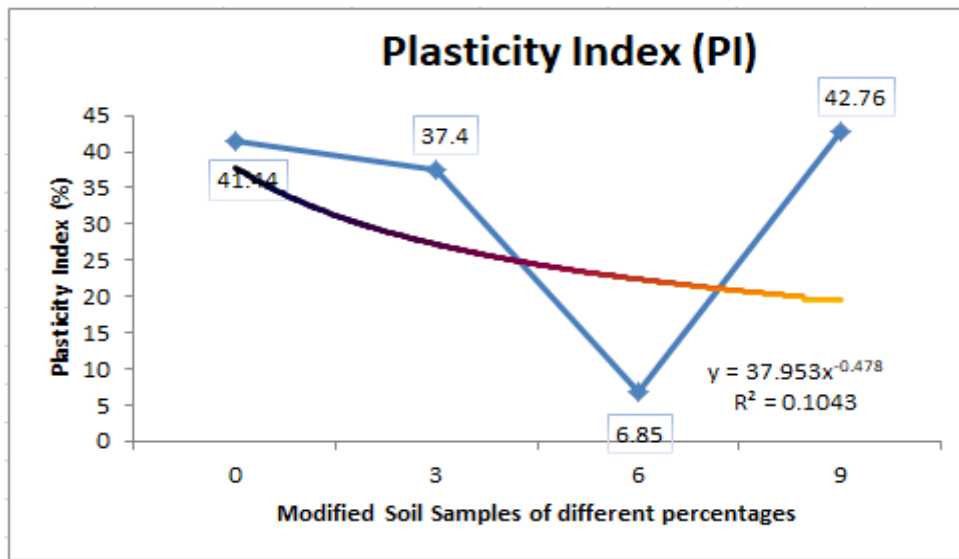


Figure 4: Plasticity index (PI) of modified soil samples

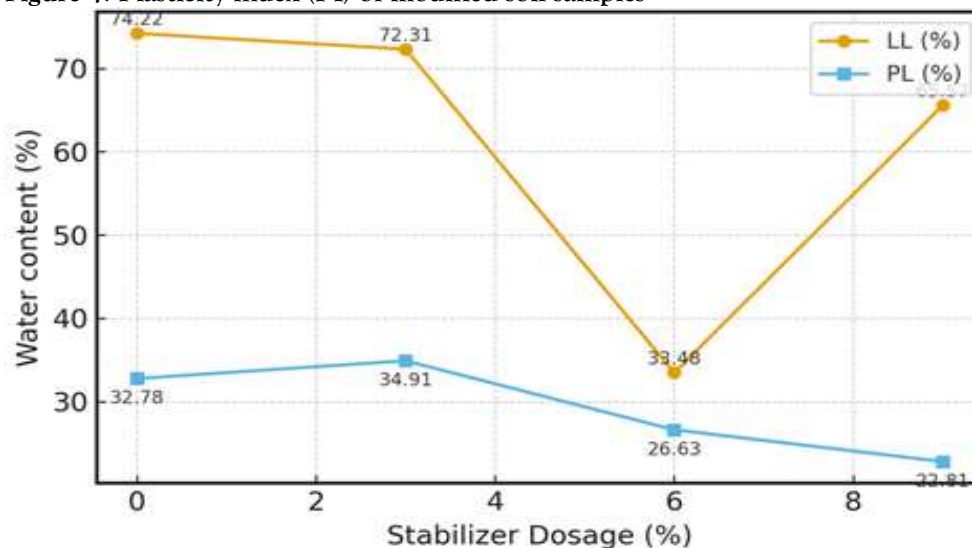


Figure 5: Plasticity index vs. stabilizer dosage graph

**Discussion**

According to the Atterberg limits, adding different amounts of fly ash and bagasse ash causes a noticeable shift in both the liquid limit (LL) and the plastic limit (PL). The relatively high liquid limit of the untreated soil indicated its size. When stabilizers are added, the LL decreases (for instance, from 74.22 to 33.48), allowing the soil to store less water and swell less. The use of stabilizers also causes a gradual increase in the plastic limit. This indicates that in order for the soil to reach the plastic condition, more moisture is required. Together, they result in a lower plasticity index ( $PI = LL - PL$ ), making the material easier to work with and less prone to expansion. The pozzolanic reaction of fly ash and bagasse ash, which are rich in silica and alumina, with soil minerals explains this behavior. Cementitious chemicals are produced by this process, which bind soil particles together and reduce their propensity to absorb water. Overall, the best results are obtained when 6-9% stabilizers are added, indicating that these waste materials are beneficial for enhancing the engineering characteristics of black cotton soil.

**Specific Gravity**

Following figure is to show the effect of additives on the specific gravity utilized in the soil collected for the research purpose.

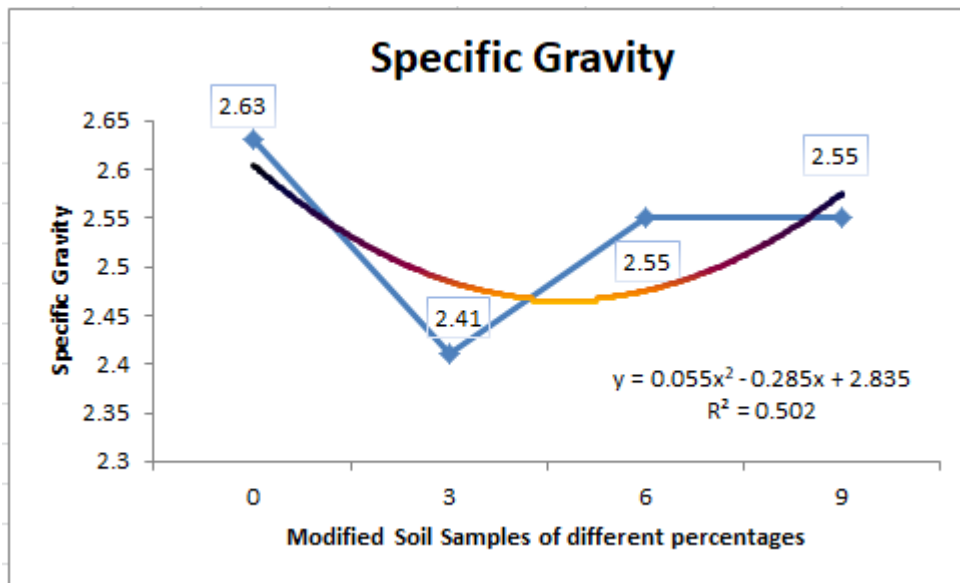


Figure 6: Specific gravity of modified soil samples

**Discussion**

The results show a negative trend in specific gravity when fly ash and bagasse ash are added to black cotton soil. The original soil has a specific gravity of 2.63. It decreased to 2.55, 2.55, and 2.41 when 3%, 6%, and 9% of it were substituted. The reason for this decline is that the specific gravity of fly ash and bagasse ash is lower than that of the minerals found in natural soil. The change indicates that the density of the soil-ash mixture decreases with the number of stabilizers. By generating chemical reactions and particle interlocking, the addition of these pozzolanic materials strengthens and increases the durability of the soil, even while the specific gravity decreases. Therefore, the replacement effect of lighter stabilizer components is what caused the gains we observed, and it didn't negatively impact the soil's performance.

**Optimum Moisture Content (OMC)**

Following figure is to show the effect of additives on the optimum moisture content utilized in the soil collected for the research purpose.

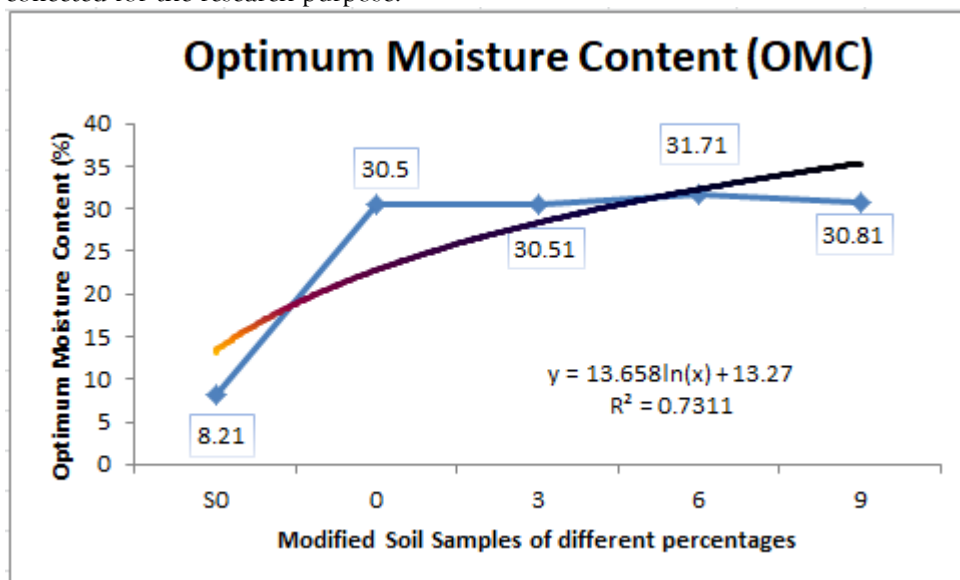


Figure 7: Optimum moisture content of modified soil samples

**Discussion**

30.5%, 30.51%, 31.71%, and 30.81% were the optimal moisture content (OMC) values; these equated to the addition of 0%, 3%, 6%, and 9% stabilizer, respectively. OMC somewhat increased with the addition of fly ash and bagasse ash, particularly at a dosage of 6%, when the maximum OMC (31.71%)

was recorded. Because the stabilizers are more porous and have a higher surface area, more water is required for optimal compaction and pozzolan reaction. The OMC did, however, somewhat decrease at a higher dose (9%), indicating that stabilizers tend to fill the gaps and reduce the water demand when they are used in excess. The variations in OMC values demonstrate how the amount of stabilizer influences the amount of moisture required by black cotton soil during compaction. This is consistent with what we would anticipate from expansive soils stabilized by ash.

**Modified Proctor Test**

Following figure is to show the effect of additives on the maximum dry density utilized in the soil collected for the research purpose

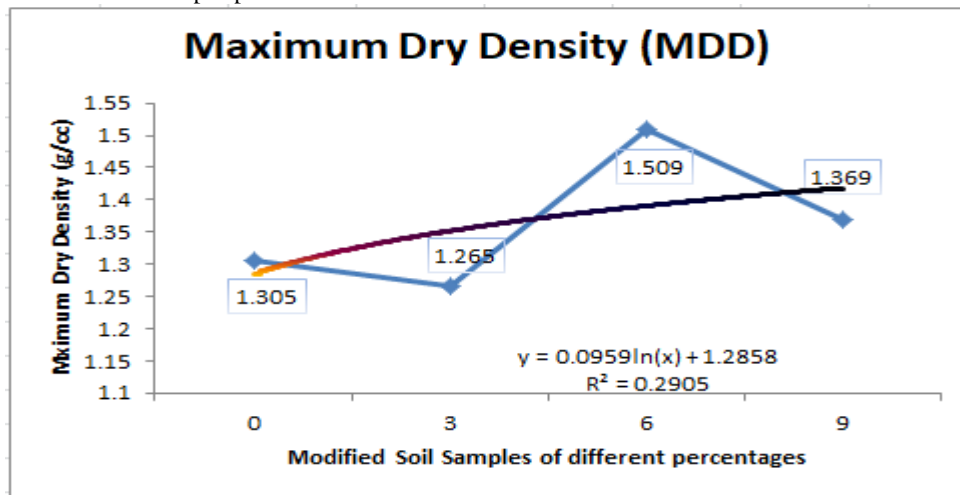


Figure 8: Maximum dry density of modified soil samples

**Discussion**

Adding fly ash and bagasse ash altered the black cotton soil's maximum dry density (MDD). When 3% stabilizer was added, the MDD of 1.305 g/cm<sup>3</sup> in the native soil (0% stabilizer) slightly decreased to 1.265 g/cm<sup>3</sup>. This occurred because the stabilizers are lighter than dirt particles and have a lower specific gravity. However, the MDD increased significantly to 1.509 g/cm<sup>3</sup> with 6% addition. This implies that at this level, the stabilizers filled in the spaces within the soil and compacted. The value decreased somewhat to 1.369 g/cm<sup>3</sup> at 9%, most likely as a result of the excessive ash decreasing the density of the soil and raising the void ratios. Overall, the findings indicate that the greatest results for MDD are obtained with a stabilizer concentration of 6%, which strengthens and increases the soil's capacity to support weight.

**California Bearing Ratio (CBR)**

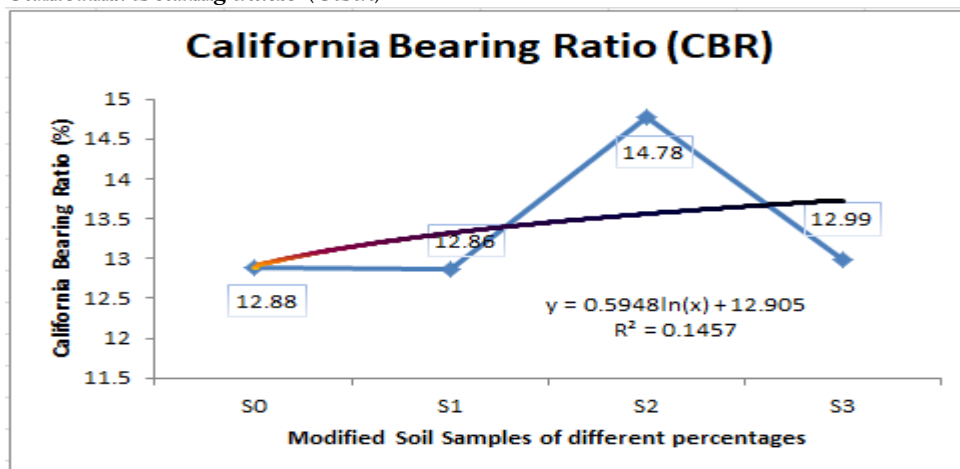


Figure 9: California bearing ratio of modified soil samples

**Discussion**

The measured California Bearing Ratio (CBR) values for stabilizer contents of 0%, 3%, 6%, and 9% were 12.88%, 12.86%, 14.78%, and 12.99%, respectively. The results show that adding fly ash and bagasse ash had an impact on the black cotton soil's capacity to support loads. At a stabilizer dosage of 6%, the CBR value increased significantly to 14.78%. This demonstrates that efficient pozzolanic reactions and particle bonding were the main causes of the soil strength improvement. But at this dosage (9%), the CBR somewhat dropped to 12.99%, indicating that adding too much stabilizers could result in unreacted ash particles and less densification, which would diminish the strength gain. Overall, the findings indicate that while moderate levels of fly ash and bagasse ash increase the bearing capacity of expansive soils, extremely high levels might not be any more beneficial.

## CONCLUSION

Fly ash's and bagasse ash impact on multiple properties of expansive soil was examined. The test results show the following conclusions.

- The index and engineering properties of black cotton soil were significantly impacted by the addition of fly ash and bagasse ash.
- The addition of a stabilizer reduced the liquid limit, making the soil less expansive and easier to work with.
- The varying amounts of change in the plastic limit values indicate that the stabilizers altered the soil's plasticity behavior.
- The specific gravity increased by greater percentages but decreased by 3%. This demonstrates that the admixtures contributed varying densities.
- The maximum dry density (MDD) improved significantly with 6% replacement, indicating enhanced compaction qualities, but the optimum moisture content (OMC) barely changed.
- The load-bearing capability was at its peak when the California Bearing Ratio (CBR) values were at 6% replacement.
- Unconfined Compressive Strength (UCS) significantly increased at 6% replacement (637.95 KN/m<sup>2</sup>), indicating that this is the ideal dosage for strength gain.
- A slight decrease in strength parameters was observed after 6% replacement, indicating that 6% is the ideal quantity of fly ash and bagasse ash to employ for stabilizing expansive soil.

## Acknowledgement

We would like to thank our senior Assistant Prof. Engr. Muhammad Siyab Khan for all his help, support and guidance. We would like to thank our all teachers for their continuous support, for always pushing us forward and for providing us with the calm environment to work in. Last but not least, Thanks to our families specially parents for their endless support, and always being there for us and encouraging us through the tough times.

## REFERENCES

1. Zulfiqar, M., Mian, I. A., Khan, N., Hanan, N. G. D. F., Qazi, M. A., Fahad, S., ... & Naushad, M. (2019). District Nowshera-Pakistan. USA: IISTE (International Institute for Science, Technology, and Education).
2. Khan, W., Fufeng, G., & Khan, M. S. (2022). THE ROLE OF NGOS IN THE EDUCATION AND DEVELOPMENT SECTOR: A CASE STUDY IN THE MERGED DISTRICTS OF KHYBER PAKHTUNKHWA, PAKISTAN. THE SPARK, 7(1), 84-94.
3. Kumari, N., & Mohan, C. (2021). Basics of clay minerals and their characteristic properties. Clay Clay Miner, 24(1), 1-29.
4. Belghazdis, M., & Hachem, E. K. (2022). Clay and clay minerals: a detailed review. International Journal of Recent Technology and Applied Science (IJORTAS), 4(2), 54-75.
5. Jones, L., Banks, V., & Jefferson, I. (2020). Swelling and shrinking soils.
6. El-Zein, A., Airey, D., Yu, B., Esgandani, G. A., Proust, G., Dias-da-Costa, D., ... & Chen, S. (2021). Self-repair of cracks and defects in clay: a review of evidence, mechanisms, theories and nomenclature. Acta Geotechnica, 16(12), 3741-3760.
7. Zumrawi, M. M., Abdelmarouf, A. O., & Gameil, A. E. (2017). Damages of buildings on expansive soils: diagnosis and avoidance. International Journal of Multidisciplinary and Scientific Emerging Research, 6(2), 108-116.
8. Khan, M. S., Tufail, M., & Mateeullah, M. (2018). Effects of waste glass powder on the geotechnical properties of loose subsoils. Civil Engineering Journal, 4(9), 2044-2051.
9. Toll, D. G., Abedin, Z., Buma, J., Cui, Y., Osman, A. S., & Phoon, K. K. (2012). The impact of changes in the water table and soil moisture on structural stability of buildings and foundation systems: systematic review CEE10-005 (SR90).

10. Khan, M. S., Khattak, A., Yaqoob, M. U. Z. A. M. I. L., & Alam, K. A. S. H. I. F. (2021). "Strength and thermal conduction assessment of lightweight aromatic hydrocarbon waste polystyrol glass concrete," *Journal of Engineering Science and Technology*, 16(2), 1082-1097.
11. Pasha, M. S., Aslam, M. F., Hamza, M., Ali, N. M., Jabbar, I., Ahmed, S., & Abbasi, H. K. J. (2025). Sustainable construction: Performance analysis of concrete incorporating E-waste plastic aggregates and silica fume. *Construction and Building Materials*, 474, 141103.
12. Tufail, S. A., Jazaie, F., Bakhshae, A., Ashiq, M. M., & Hamza, M. (2024, December). Assessment of microplastic contamination in biosolids from wastewater treatment plants and its implications for terrestrial environments. In *AGU Fall Meeting Abstracts* (Vol. 2024, No. 1086, pp. H33L-1086).
13. Pasha, M. S., Aslam, M. F., Hamza, M., Bilal, M., Tammar, M., & Khan, F. (2026). Fire-resistant and eco-friendly concrete: investigating HDPE plastic and silica fume as partial replacements. *Journal of Building Pathology and Rehabilitation*, 11(1), 11.
14. Chen, W., Liu, Q., & Wang, E. (2022). The effect of the water table on the bearing capacity of a shallow foundation. *Applied Sciences*, 12(13), 6571.
15. Dixit, M. (2016). Damage mechanism in problematic soils. *International Journal of Civil Engineering and Technology*, 7(5), 232-241.
16. Hamza, M., Ali, S. D., Aslam, M. F., Rashid, M., Abbasi, H. K. J., & Haider, S. (2025). Data-driven insights into urban groundwater contamination: a framework for SDG 6 implementation in developing countries. *Cleaner Waste Systems*, 100351.
17. Shah, M. M., Yaqoob, M., Jibrán, A. A., Rashid, A., Kundi, H., & Khan, M. S. (2020). Integrating heat repulsion and strength evaluation of cost-effective GLP concrete redeeming the cement proportions utilizing thermocouples. *Journal of Technology and Engineering Studies*, 6(2), 6-40003.
18. Abbas, M., Elbaz, K., Shen, S. L., & Chen, J. (2021). Earthquake effects on civil engineering structures and perspective mitigation solutions: a review. *Arabian Journal of Geosciences*, 14(14), 1350.
19. Hashish, S. (2021). Geotechnical Investigation on Soil Properties Influencing the Swelling Characteristics of Expansive Soil (Master's thesis, Eastern Mediterranean University (EMU)-Doğu Akdeniz Üniversitesi (DAÜ)).
20. Osman, K. T. (2018). Expansive soils. In *Management of Soil Problems* (pp. 117-143). Cham: Springer International Publishing.
21. Rashid, M., Haider, S., Rizwan, A., Naseer, M. W., Aslam, M. F., Hamza, M., ... & Tariq, M. A. U. R. (2025). Mitigating Soil Erosion in Arid Landscapes: Integrating RUSLE and Geospatial Analysis for Sustainable Land Management. *Environmental Challenges*, 101210.
22. KHATTAK, M. Y., & ALI, S. (2022). Evaluating the durability of recycled brick aggregates against sulfate attack. *Journal of Engineering Science and Technology*, 17(5), 3410-3423.
23. Kumari, N., & Mohan, C. (2021). Basics of clay minerals and their characteristic properties. *Clay Clay Miner*, 24(1), 1-29.
24. Firoozi, A. A., Guney Olgun, C., Firoozi, A. A., & Baghini, M. S. (2017). Fundamentals of soil stabilization. *International Journal of Geo-Engineering*, 8(1), 26.
25. Joshi, R. C., & Nagaraj, T. S. (2021). Fly ash utilization for soil improvement. In *Environmental Geotechnics* (pp. 15-24). CRC Press.
26. Anjum, N., Ashraf, J., Ahmad, M., Ghani, U., Hamza, M., & Aziz, A. (2025). Numerical Investigation of Flow Dynamics in a Sharp-Crested Weir with Variable Geometry. *Construction Technologies and Architecture*, 17, 191-201.
27. Ozdemir, M. A. (2016). Improvement in bearing capacity of a soft soil by addition of fly ash. *Procedia Engineering*, 143, 498-505.
28. Kehinde, O., Ramonu, O. J., Babaremu, K. O., & Justin, L. D. (2020). Plastic wastes: environmental hazard and instrument for wealth creation in Nigeria. *Heliyon*, 6(10).
29. Hussain, Z., Khan, M. S., Kundi, K., Alaf, K., & Ullah, Y. (2021). Assessment of integrated indoor environmental air quality parameters in selected church buildings of Faisalabad city: A statistical based comparative study. *Scientific Review Engineering and Environmental Sciences (SREES)*, 30(1), 134-147.
30. Dzaklo, C. K. (2023). Application of natural and/or stabilized black soils as Sub-Structural fills for railway foundations. *University of Technology Sydney (Australia)*.
31. Adnan, M., Kumar, S., Garg, N., Gupta, K. K., & Das, S. K. (2023). Soil stabilization using waste "Bagasse ash and lime": A review. *Materials Today: Proceedings*.
32. Khan, Wafa & Fufeng, Gao & Anwar, Faizan & Javed, Asjad & Zaheer, Saad & Sajjad, Muhammad. (2024). China Pakistan Economic Corridor (CPEC), Challenges, Opportunities and Boost to Socioeconomic Development of Pakistan. *REMITTANCES REVIEW*. Volume: 9. pp.502-517.