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Effect of Recycled Gypsum on Geo-Environmental behavior of Laterite Soil

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Abstract: Approximately 1.6 million tons of gypsum waste plasterboard are produced annually in India. As such, it is essential to find an alternative way to reduce the quantities of this waste material to avoid environmental problems and the high cost of disposal in landfill. This report describes the use of recycled gypsum, which is derived from gypsum waste plasterboard, to improve the strength of laterite soil with taken in consideration environmental impacts. Four different recycled gypsum contents ranging from 0 to 10% was investigated. For this purpose, a series of unconfined compression tests were conducted to evaluate strength performance of treated soil. While a series of environmental tests were conducted to explore pH, solubility concentration of fluorine, boron, and hexavalent chromium in the untreated and treated soil specimens. The early curing days for soil-gypsum mixture had a significant effect on strength performance compared to the later days. The use of recycled gypsum within the investigated limits had no adverse effect on pH value. As well, the solubility concentrations for fluorine, boron, and hexavalent chromium were found within the permitted standard limits up to adding 10% of gypsum content

Keywords—Gypsum waste plasterboard, Unconfined compression (UCC) test

1. INTRODUCTION

The need for efficient and long-lasting ground reconstruction methods grows as urbanization spreads into regions with less-than-ideal soil conditions. Lateritic soils, which are very common in tropical and subtropical areas, are among these difficult soils. They are frequently distinguished by their high permeability, poor strength, and significant volume instability under different moisture

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conditions. Enhancing these soils' engineering qualities is essential to guaranteeing the longevity and safety of civil infrastructure.

Cement and lime are frequently used in traditional soil stabilization techniques because they improve soil performance. However, the manufacturing of cement and lime accounts for almost 4% of all anthropogenic CO_2 emissions, making the production of these binders a major contributor to global GHG emissions(Abdolvand & Sadeghiamirshahidi, 2024). Researchers are looking at low-carbon and sustainable solutions for soil stabilization as a result of this environmental burden. Gypsum has drawn interest as a potential substitute binder, both in its natural form and as a by-product of many industrial processes, including phosphogypsum, flue gas desulfurization gypsum, and recycled plasterboard(Abdolvand & Sadeghiamirshahidi, 2024). Reusing gypsum waste lowers the carbon footprint of ground improvement projects by reducing the need for conventional binders and lessening the environmental impact of disposing of industrial waste. Recycled gypsum from plasterboard waste is a sustainable option for soil stabilization(Ahmed et al., 2015). According to (Weimann et al., 2021), it retains high purity through proper processing and offers environmental benefits such as reduced global warming potential and land use impact compared to natural gypsum. Its stable chemical composition and recyclability make it suitable for geotechnical applications According to studies, adding gypsum to fine-grained soils can enhance a number of geotechnical characteristics, such as swell potential, California Bearing Ratio (CBR), and unconfined compressive strength (UCS) (Latifi et al., 2018)(Ahmed & Issa, 2014). Mechanisms like cation exchange, particle flocculation, and the production of cementitious hydration products like calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH) are primarily responsible for these improvements (Abdolvand & Sadeghiamirshahidi, 2024)However, issues including moderate water solubility and the potential for expansive minerals like ettringite to form, particularly when gypsum and lime are combined, must be taken into account when designing for durability (Ebailila et al., 2022).

The use of gypsum-based stabilization in lateritic soils is still little understood, despite the fact that it has been thoroughly investigated in expansive clays and soft clays(Kamei et al., 2013). When lateritic soils interact with gypsum, their unique mineralogy and high iron oxide content may result in different stabilization behavior than clays rich in kaolinite or montmorillonite. Only few studies are available in stabilisation of Laterite soil using recycled gypsum powder. Examining this relationship is essential to creating soil stabilization plans that are both regionally and sustainably appropriate (Ezreig et al., 2022).

Studying the leaching properties of recycled gypsum is crucial, as it can release harmful substances like fluorine, boron, and hexavalent chromium when exposed to moisture. Understanding these properties helps ensure safe reuse in construction by guiding the use of stabilizers like cement or lime, which reduce contaminant solubility and meet environmental standards(Ahmed et al., 2015). The purpose of this study is to assess how well gypsum waste stabilizes lateritic soils. Important geotechnical factors will be evaluated, including compaction characteristics, Atterberg limits and UCS. It is anticipated that the results will enhance the engineering behavior of troublesome tropical soils and aid in the creation of sustainable stabilizing techniques that use industrial waste.

The objective of the study is to;

- To determine the effect of gypsum content on compaction properties
- To determine the effect of recycled gypsum content on the compressive strength of tested samples for different curing periods
- To determine the effect of recycled gypsum content on the pH of tested samples for different curing periods
- To determine the effect of recycled gypsum content on measurement of harmful substances such as fluorine, boron, and hexavalent chromium.

2. METHODS AND METHODOLOGY

2.1. Soil samples

The soil was collected from IES College of Engineering, Chittilappilly; the soil sample was collected from 1m below ground. We air-dried the laterite soil for all the laboratory tests. Fig. 1 shows the laterite soil used for this study.

Figure 1. Laterite soil collected from Chittilappilly, Thrissur

2.2. Recycled Gypsum

The recycled gypsum used in this project was brought from a local construction site in Guruvayoor, Thrissur, and is derived from gypsum waste plasterboard. The scientific name for the produced recycled gypsum is bassanite or hemihydrate calcium sulfate ($CaSO_4$. ½H_2O). Fig. 2 provides the procedures for producing the recycled gypsum from gypsum waste plasterboard. The dried-air gypsum waste plasterboard was crushed by hammer and then screened to remove any solid wastes such as synthetic Fibers, paper, and wood. Subsequently, the crushed gypsum was heated at a temperature of 140°C for a certain time to produce a hemihydrate calcium sulfate, or what is called bassanite. Researchers investigated four different contents of recycled gypsum based on soil weight: 3, 5, 7, and 10%.

2.3. Experimental procedure

The performance of laterite soil stabilized with recycled gypsum was evaluated based on its geotechnical and environmental functions. To evaluate the geotechnical function, a series of unconfined compressive strength tests were conducted on soil samples stabilized with recycled gypsum. Furthermore, the effect of curing time was investigated to study the performance of the soil-gypsum mixture. Tests were done to check the pH levels and the amounts of fluorine (F), boron (B), and hexavalent chromium (Cr^6) to understand how the soil-gypsum mixture affects the environment. In laboratory investigations, soil samples brought from the site were taken 1m below the ground.

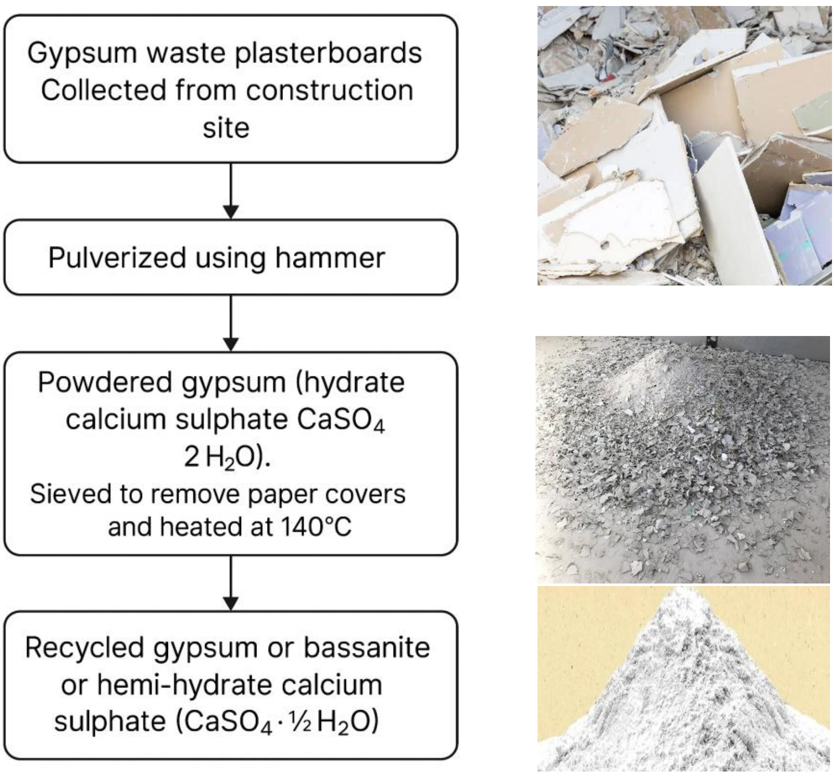

Figure 2. Procedure for the preparation of recycled gypsum

2.4. Sample Preparation

Firstly, the recycled gypsum was mixed dry, and then the mixture was added to the tested soil and mixed for 5 minutes to obtain, as much as possible, homogenous and isotropic properties for the mixture.

2.5. Unconfined Compressive Strength Test

Unconfined compressive tests were conducted on pure and stabilized soil samples in accordance with IS 2720-Part X. The use of compressive strength to evaluate the performance of stabilized soil is one of the most important design parameters used in earthwork projects. Cylindrical stabilized soil specimens 3.8 cm in diameter and 7.5cm in height were used in unconfined compressive tests. Specimens for compressive strength were moulded using cylindrical split mould. The samples were placed in the moulds in three layers and then compacted to a height of 7.5cm. Oil was used to lubricate the inner sides of the moulds to ensure no friction occurs during sample extraction. The soil samples were extracted from the mould after 1 hour from placing, and extreme care was taken during the extraction process to avoid any pre-stress for the specimens before testing and wrapping them in the cling film. The soil samples were then cured in air for 1, 3, 7, 14, and 28 days. After each curing time, specimens are subjected to compression tests by applying load and recording the reading on the proving ring dial and compression dial for every 5 mm of compression. Continue loading until failure is complete. Then the stress-strain relationship was plotted for each tested specimen.

2.6. pH Measurement

In general, the pH of the soil refers to its acidity or alkalinity and is a measure of the concentration of free hydrogen ions (H^+) in the soil solution. The pH value is considered one of the most important parameters when evaluating the quality of the groundwater, especially when waste materials are introduced in earthwork projects. In addition, the pH value is essential for the continued pozzolanic activity for cement stabilization and is responsible for promoting chemical activity between the stabilized cement agent and the soil. The pH value of different soil samples treated with recycled gypsum was determined by using Universal Indicator Solution. Click on the dropper in the universal indicator solution bottle and drag it towards the solution in the beaker to pour the universal indicator into it. The solution changes colour. To find the pH value of the solution, select the colour strip from the standard colour pH chart and drag it near to the solution in the beaker to compare it. The colour that matches with the colour of the solution in the beaker indicates the pH value of the solution. The effect of curing times on the pH value of soil samples treated with recycled gypsum was investigated. For that purpose, the solution of stabilized soil sample and distilled water was placed in a plastic container covered tightly and kept curing at room temperature. The pH was measured after curing times of 1, 3, 7, 14, and 28 days.

2.7. Measurement of Harmful Substances Elements

The solubility concentrations of fluorine (F), boron (B), and hexavalent chromium (Cr^{+6}) for untreated and treated soil samples were measured to investigate the effect of using recycled gypsum on the environment. It is well known the plaster contains fluorine, and gypsum waste plasterboard in ground improvement is subjected to groundwater or rainfall. Because the concentration of fluorine is expected to increase over the standard limits. A high fluorine concentration in the water supply is a health hazard for both humans and animals. As per Indian environmental regulations, the standard limit for fluorine dissolution is set at less than 0.80 mg/L. Furthermore, other chemical elements, such as boron (B) and hexavalent chromium (Cr^{+6}), may be released when the gypsum-cement mixture is subjected to water. Soil may be toxic to humans or animals if the concentration of such elements exceeds the standard limits. Therefore, it is essential to explore the effect of using recycled gypsum in ground improvement on the release of such harmful substances to ensure a sound environment. The solubility of fluorine (F), boron (B), and hexavalent chromium (Cr^{+6}) was measured for different percentages of gypsum-soil mixture. The tests were carried out in KERI (Kerala Engineering Research Institute), Peechi, Thrissur, Kerala. The environmental samples tested were taken from the destroyed samples of the unconfined compressive test, and these samples, which were subject to the same curing regime used in the compressive strength tests, were tested after 1, 3, 7, 14, and 28 days of curing.

3. RESULTS

3.1. Basic properties of laterite soil

The basic properties of laterite soil were determined by conducting a series of laboratory experiments. Table 1 clearly shows the basic properties of soil.

Table 1. Basic properties of laterite soil

SOIL PROPERTIES	VALUES
Uniformity coefficient, $\mathbf{c_u}$	6.67
Coefficient of curvature, $\mathbf{c_c}$	1.204
Specific gravity	2.77
Liquid limit (%)	42
Plastic limit (%)	18
Plasticity index (%)	16.06
Optimum moisture content (%)	16.23%
Maximum dry density(g/cc)	1.836
Unconfined compressive strength (kN/m²)	36

The basic geotechnical properties of the soil used in the present study are shown in Table 1. The soil is well-graded, as evidenced by its uniformity coefficient (Cu) of 6.67 and coefficient of curvature (Cc) of 1.204. As is common for mineral soils, the specific gravity is 2.77. The soil has a plasticity index of 16.06% and liquid limit of 42%, indicating organic clay of high plasticity (MH or OH). The maximum dry density is 16.23 g/cc, while the optimum moisture content is found to be 16.26%. suggesting good compaction characteristics. Moderate shear strength is indicated by the unconfined compressive strength (UCS), which is measured at 36 kN/m².

3.2. Effect of gypsum content on compaction properties

The dry density and moisture content relationship for different percentages of gypsum was analyzed and represented as shown in Figure 4.

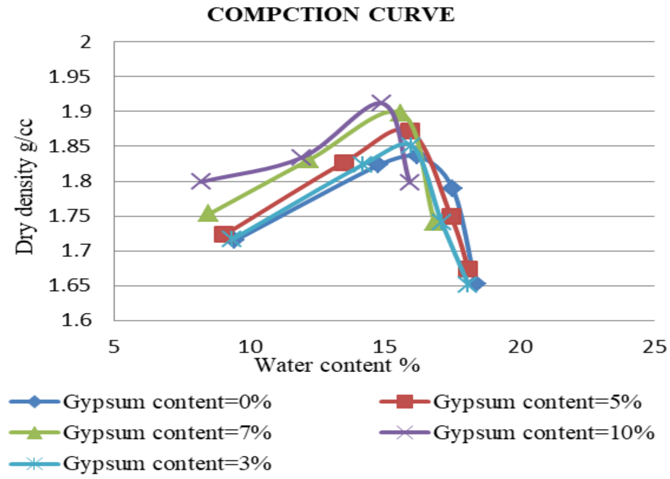

Figure 4. Moisture content -dry density relationship of various gypsum percentage

The result obtained from the investigation, as shown in Figure 5, reveals that the dry density increases as gypsum content increases. This observation agrees with the fact that chemicals such as cement, lime, and ash have the potential to increase densification of the soil particles. In other words, the addition of a chemical stabilizer most often results in the expulsion of voids; hence, the increase in density after adequate compaction has been applied. At low gypsum concentrations (up to 15-30% by weight), gypsum can act as a filler, helping to pack the soil particles together and slightly increasing the maximum dry density (MDD)(Kuttah & Sato, 2015).

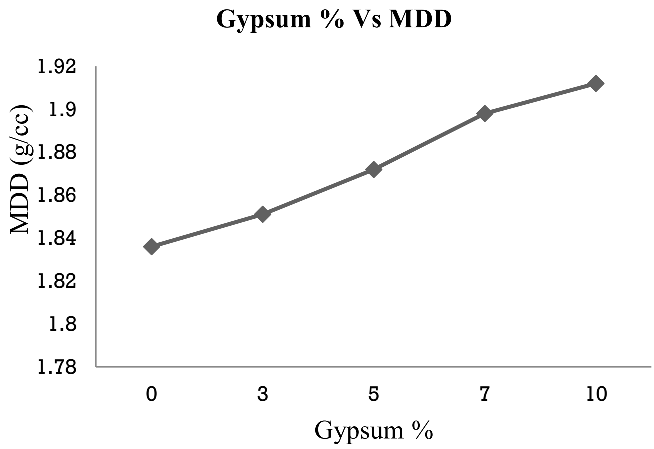

Figure 5. Maximum dry density variation with increasing gypsum content.

Furthermore, from the series of tests carried out, it can be observed that optimum moisture content (OMC) reduces as the gypsum content increases, as illustrated in Figure 6. OMC reduction was assumed to be due to the less water required in hydrating and lubricating the laterite-gypsum mixture or due to gypsum's ability to absorb water, effectively increasing the water content required to reach the maximum dry density(Kuttah & Sato, 2015).

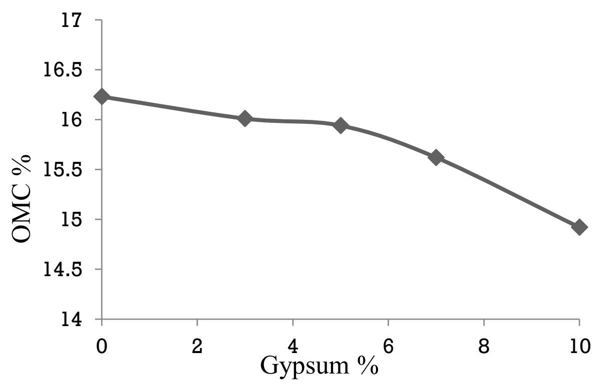

Figure 6. Optimum moisture content variation with increasing gypsum content

3.3. Effect of Recycled Gypsum on Unconfined Compressive Strength Over Time

Unconfined compressive testing for soil-gypsum specimens is performed to determine the suitability of using recycled gypsum as a stabilizing agent for laterite soil. The purposes of using compressive strength data in this study are (1) to determine if the tested soil will achieve a significant strength increase with the addition of recycled gypsum (2) to determine the optimal content of recycled gypsum needed to achieve the design strength and (3) to study the effects of curing time. The ultimate compressive strength against the content of recycled gypsum for different tested samples is plotted and presented in Figure 7.

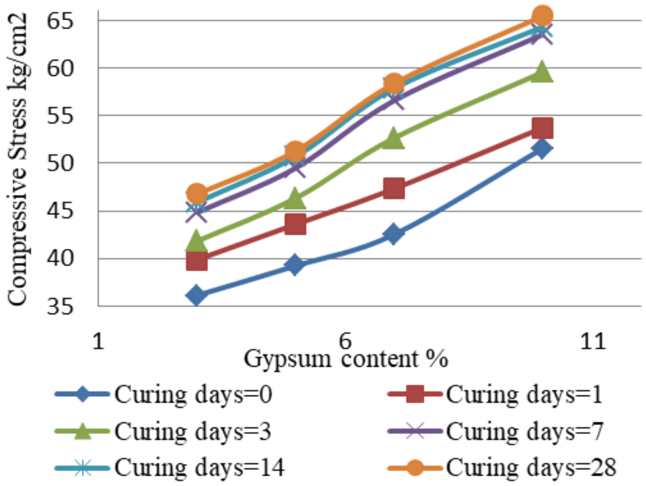

Figure 7. Influence of recycled gypsum and curing time on Unconfined compressive strength

It is clear that the compressive strength increased with the increase in recycled gypsum content for the different samples tested compared to identical, untreated samples. This improvement can be explained by the hardening of the soil particles in the soil after the addition of recycled gypsum, resulting in an increase in the strength between the soil particles, and also gypsum, when added to soil, can react with cement to form ettringite, a cementitious product that contributes to strength gain. Ettringite can also act as a pore infill, leading to a more homogeneous and stronger soil matrix(Wu et al., 2022). Figure 7 also shows the effect of curing time. It is clear from this figure that the strength of stabilized soil-gypsum increased with the curing time. It can be stated that the curing time has a significant effect on the strength of stabilized soil gypsum up to the first 7 days of curing, and beyond that time, the effect of curing on strength is less significant. This is because the setting time for gypsum is short, and most of the reactions between gypsum and the soil particles take place rapidly, so the soil-gypsum mixtures strengthen quickly.

3.4. Effect of Gypsum Content and Curing Time on Sample pH

Figure 8 shows the pH values for various combinations of recycled gypsum and laterite soil used in the laboratory tests. It appears that the additive of pure recycled gypsum soil has an insignificant effect on the value of pH.

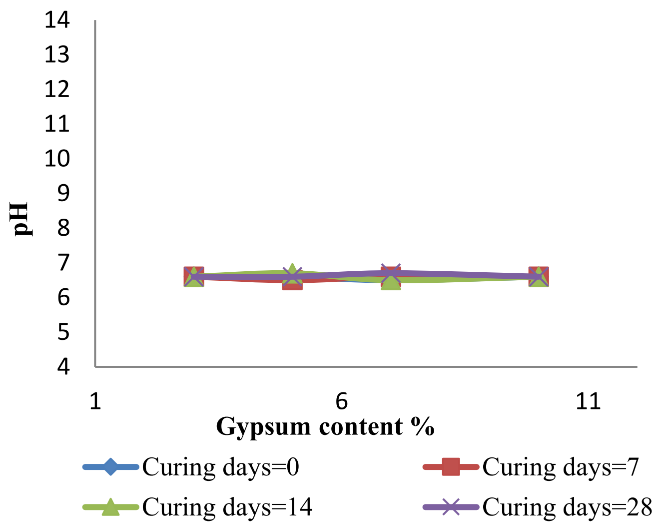

Figure 8. Effect of recycled gypsum content on PH of tested samples for different curing time

Since the measured pH values were found to be between 6 and 7, which are the neutral values acceptable in environmental regulations, the use of recycled gypsum in ground improvement does not have any negative effect on the pH of soil.

3.5. Effect of recycled gypsum content on measurement of harmful substances

The effect of curing time on the solubility of F, B, and Cr^{+6} obtained from leaching soil-gypsum mixtures is examined. For this purpose, the two different curing times of 7 and 28 days were used. The table below presents the results. The concentrations of F, B, and Cr^{6+} in the normal laterite soil were below the detection limit and are therefore not included in the graph and tables.

Table 2. Harmful Substances by Gypsum Percentage (7 Days)

% of gypsum	Fluorine F(mg/l)	Boron B (mg/l)	Hexavalent Chromium (mg/l)
3	0.1	0.1	0.01
5	0.4	0.5	0.03
7	0.8	1.1	0.06
10	1.1	1.4	0.08

Results indicated that increasing the gypsum content from 3% to 10% and increasing the curing period both increased the level of these compounds in the leachate. At 10% gypsum, fluorine concentrations increased to 0.7 mg/L after 28 days; however, this value is still less than the 1.5 mg/L WHO drinking water standard (WHO, 2017). Under the same conditions, boron concentrations were 0.8 mg/L, which was within the WHO's more general recommendation of roughly 1.0 mg/L but somewhat above the more cautious California Environmental Protection Agency (CalEPA) limit of 0.75 mg/L (WHO, 2017)(California Environmental Protection Agency (CalEPA), 2022). The greatest increase was seen in hexavalent chromium, a more hazardous and carcinogenic form of chromium, which after 28 days reached 0.05 mg/L at 10% gypsum, which is in line with the WHO and Indian Bureau of Standards (BIS) allowable levels for drinking water (WHO, 2017)(B u r e a u o f I n d i a n S t a n d a r d s, 2012). Notably, this quantity is higher than the more severe CalEPA Public Health Goal of 0.01 mg/L for Cr^{6+} (California Environmental Protection Agency (CalEPA), 2022), suggesting that larger gypsum dosages and longer curing durations may pose an environmental danger. According to these findings, hexavalent chromium leaching requires careful monitoring and control of gypsum content preferably below 7–10% to mitigate risks of groundwater contamination when recycled gypsum is used for laterite soil stabilization, even though fluorine and boron leaching may fall within acceptable limits under standard guidelines.

Table 3. Harmful Substances by Gypsum Percentage (28 Days)

% of gypsum	Fluorine F(mg/l)	Boron B (mg/l)	Hexavalent Chromium (mg/l)
3	0.3	0.4	0.04
5	0.7	0.8	0.05
7	1	1.5	0.08
10	1.3	1.8	0.11

4. CONCLUSION

The main contribution of this work was to show the potential application of recycled gypsum (Bassanite), which is derived from gypsum waste plasterboard The leachate of recycled gypsum does not have any adverse effect on the pH; the average for the measured value was found to be neutral. The effect of recycled gypsum on the strength of clay soil, taking into consideration the environmental impact, was evaluated based on experimental investigations. The use of recycled gypsum significantly improved its stability and did not show any adverse effect on the environment within the investigated ranges. Based on the results obtained from experimental and site investigations, the following conclusions can be drawn:

- With respect to the influence of gypsum on dry density and moisture content, increase in gypsum content resulted in an increase in density while the inverse was recorded for moisture content.
- The treatment of clay soil with recycled gypsum significantly improves its strength performance.
- The compressive strength of soil-gypsum mixture increased with the increase of recycled gypsum content.
- The addition of recycled gypsum rapidly increases the unconfined compressive strength; it is a vital property and reducing both the time and cost of construction.
- The amount of curing time has a significant effect on the strength of soil-gypsum mixture in the early stage up to 7 days; however, beyond that, the effect of curing time is insignificant.
- Recycled gypsum content above 7–10% increases the leaching of hexavalent chromium beyond safe limits, highlighting the need to control gypsum dosage to prevent potential groundwater contamination during laterite soil stabilization.

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5. REFERENCE

[1] Abdolvand, Y., & Sadeghiamirshahidi, M. (2024). Soil stabilization with gypsum: A review. *Journal of Rock Mechanics and Geotechnical Engineering*, *16*(12), 5278–5296. https://doi.org/10.1016/J.JRMGE.2024.02.007

[2] Ahmed, A., & Issa, U. H. (2014). Stability of soft clay soil stabilised with recycled gypsum in a wet environment. *Soils and Foundations*, *54*(3), 405–416. https://doi.org/10.1016/J.SANDF.2014.04.009

[3] Ahmed, A., Soliman, A. M., Hesham El Naggar, M., & Kamei, T. (2015). An assessment of geo-environmental properties for utilization of recycled gypsum in earthwork

projects. *Soils and Foundations*, *55*(5), 1139–1147. https://doi.org/10.1016/J.SANDF.2015.09.014

[4] B u r e a u o f I n d i a n S t a n d a r d s. (2012). *IS 10500 (2012)*. https://cpcb.nic.in/wqm/BIS_Drinking_Water_Specification.pdf

[5] California Environmental Protection Agency (CalEPA). (2022). *Public Health Goals for Chemicals in Drinking Water: Hexavalent Chromium*. https://oehha.ca.gov/water/public-health-goals

[6] Ebailila, M., Kinuthia, J., & Oti, J. (2022). Role of Gypsum Content on the Long-Term Performance of Lime-Stabilised Soil. *Materials*, *15*(15), 1–14. https://doi.org/10.3390/ma15155099

[7] Ezreig, A. M. A., Ismail, M. A. M., & Ehwailat, K. I. A. (2022). A state of review: challenges and techniques of laterite soil stabilisation using chemical, economical, and eco-friendly materials. In *Innovative Infrastructure Solutions* (Vol. 7, Issue 3). Springer International Publishing. https://doi.org/10.1007/s41062-022-00821-z

[8] Kamei, T., Ahmed, A., & Ugai, K. (2013). Durability of soft clay soil stabilized with recycled Bassanite and furnace cement mixtures. *Soils and Foundations*, *53*(1), 155–165. https://doi.org/10.1016/J.SANDF.2012.12.011

[9] Kuttah, D., & Sato, K. (2015). Review on the effect of gypsum content on soil behavior. *Transportation Geotechnics*, *4*, 28–37. https://doi.org/10.1016/J.TRGEO.2015.06.003

[10] Latifi, N., Vahedifard, F., Siddiqua, S., & Horpibulsuk, S. (2018). Solidification–Stabilization of Heavy Metal–Contaminated Clays Using Gypsum: Multiscale Assessment. *International Journal of Geomechanics*, *18*(11), 1–13. https://doi.org/10.1061/(asce)gm.1943-5622.0001283

[11] Weimann, K., Adam, C., Buchert, M., & Sutter, J. (2021). Environmental evaluation of gypsum plasterboard recycling. *Minerals*, *11*(2), 1–13. https://doi.org/10.3390/min11020101

[12] WHO. (2017). *Guidelines for drinking-water quality, 4th edition, incorporating the 1st addendum*.

[13] Wu, J., Liu, L., Deng, Y., Zhang, G., Zhou, A., & Xiao, H. (2022). Use of recycled gypsum in the cement-based stabilization of very soft clays and its micro-mechanism. *Journal of Rock Mechanics and Geotechnical Engineering*, *14*(3), 909–921. https://doi.org/10.1016/J.JRMGE.2021.10.002