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Evaluation of Strength Properties and Performance Characteristics of Lime-Quarry Dust, Cement Stabilized Inorganic Clay for Sub-Base Pavement

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ABSTRACT: This research worked on the improvement of inorganic clay for use as a sub-base material in flexible pavement through stabilization with lime-quarry dust and cement mix. The research focused on evaluation of change in key geotechnical parameters; Optimum Moisture Content, Maximum dry density, Atterberg limit, Compaction characteristics, Unconfined compressive strength, Permeability and Shear Strength of the Inorganic clay.

The soil sample were mixed at varying proportions 2% - 8% lime, 15% - 30% quarry dust and 2% - 8% cement. Standard laboratory tests including particle size analysis, Atterberg limits, Specific gravity, proctor compaction, California bearing ratio, Unconfine compressive strength test and permeability test were conducted in accordance to relevant ASTM standard.

The stabilised mixes show optimal at 6% lime + 20% quarry dust and 6% cement mix. Lime + quarry dust mixes reduced plasticity index from 8.6% to 2.6% while cement mix reduced the plasticity index from 19.4% to 9.5%. The MDD value decreases from 1.74g/cm^3 to 1.65g/cm^3 while the OMC increases which is typical for lime stabilization. For the cement mix, the OMC decreases while the MDD decreased slightly. The UCS increases for both stabilisers with curing time with 866.1kN/m^2 at 28 days for lime + quarry dust mix and 1069.9kN/m^2 for the cement mix and the CBR values increases for both stabilisers showing enhancement in strength which meet up with sub-base pavement requirement.

Based on this work, it is concluded that lime-quarry dust stabilisation enhances the geotechnical performance of inorganic clay offering a cost effective and environmentally sustainable alternative to cement. Therefore, lime-quarry dust blends are recommended for use in road construction projects involving clayey soils.

KEYWORDS: Sub-base pavement, Inorganic clay, Strength characteristics, lime quarry dust, soil stabilization.

INTRODUCTION

Soil improvement is the most practical strategy for geotechnical engineers working on construction sites with problematic soils. By enhancing properties like high resistance, reduced plasticity, decreased permeability, and lower compressibility, soil improvement outperforms other options. A key method highlighted is soil reinforcement using specific materials, as noted by Nnadi (2022). This approach addresses the inherent weaknesses of certain soils, making them viable for building foundations, roads, and other infrastructure without the need for complete removal. Clayey soils belong to the expansive soil category and are often described as fine-grained or soft soils. These soils are notorious for causing severe damage to structures built on them, particularly under increased loads or external impacts. According to Nnadi (2022), buildings and roads on clayey soils experience significant deformation, leading to foundation failures and structural collapses. The issue stems from the soil's poor physical qualities, such as excessive swell-shrink behavior influenced by moisture changes. Continuing construction on untreated clayey soils is deemed extremely dangerous, as it triggers instability in the construction industry. The conventional remedy involves excavating the problematic soil and replacing it with stronger alternatives, like crushed stones or rocks. However, this method incurs high costs, prompting researchers to explore more economical alternatives Rohmatum (2024). Soil replacement not only demands substantial labor and materials but also disrupts sites and generates waste, making it unsustainable for large-scale projects. To render soils suitable for construction, stabilization techniques are employed to boost strength and durability Khalid et al., (2012). Modern research focuses on improving clay soil's geotechnical properties to prevent road deterioration, control foundation settlement, avoid structural collapses, and mitigate related risks. Various stabilization procedures for expansive clays include chemical stabilization, soil replacement, reinforcement moisture and compaction control, surcharge loading, and thermal methods Yong and Ouhade (2007). Reusing or recycling waste resources offers cost-effective alternatives to traditional chemical additives. Materials like lime, cement, and quarry dust are prime examples used to enhance soil functionality. Edil and Craig (2007) note that while these methods aim to eliminate environmental issues, they come with benefits and drawbacks, such as potential inefficiencies or exposure risks. Ongoing research seeks innovative techniques to reduce swell potential and amplify strength in expansive soils. Lime and cement have dominated soil stabilization for decades, but the 1970s energy crisis dramatically increased their costs Nevile, (2000). Road construction on stabilized soils remains expensive due to reliance on these synthetic chemicals. To counter this, industrial byproducts like quarry dust, sawdust ash, rice husk ash, and sugarcane straw ash are recommended for substantial cost reductions Asiagwu et al., (2012). Lime stabilization imparts improved strength and moisture resistance, with the most pronounced effects in moderately to highly plastic clays. Upon addition to reactive soils, lime initiates a pozzolanic reaction, yielding long-term strength gains. The calcium ions from lime react with silicates and aluminates dissolved from the clay, forming stable compounds like calcium silicate hydrate and calcium aluminate hydrate. Quarry dust serves as a pozzolanic material that partially ameliorates clayey soil's geotechnical properties. Alone, it falls short for demanding applications like foundation design or road construction. However, combining quarry dust with lime—or even lime and cement—proves highly effective as a stabilizing agent, significantly enhancing soil properties. Cement-stabilized clayey soils provide additional environmental perks by reducing the demand for natural aggregates, curbing soil erosion, and minimizing dust during construction Indraratna et al., (2015). This approach fosters sustainable building practices and conserves natural resources.

The selected research topic, "Evaluation of Strength Properties and Performance Characteristics of Lime-Quarry Dust Mix, Cement Stabilized Inorganic Clay for Sub-Base Pavement," investigates how these additives influence clay soils' engineering properties. By examining mixes of lime-quarry dust and cement-stabilized inorganic clay, the study aims to quantify improvements in strength and performance, particularly for pavement sub-bases. This work benefits geotechnical studies and projects by validating cost-effective, eco-friendly stabilization for real-world applications, potentially reducing construction expenses while enhancing durability and safety.

Materials and Method

MATERIALS

1.1 Clay

The study area is located in Ile-Ife expressway, Irewole local government, Osun state, Nigeria. The Engineering properties of clay soil are given in Table 1.

Table 1; Engineering properties of the sample (clay soil).

Properties	Values
Soil Classification	Low to Medium Plasticity (CL)
Liquid Limit (LL)	43%
Plastic Limit (PL)	30%
Plasticity Index (PI)	13%
Specific Gravity	2.67
Unconfined Compressive Strength (UCS)	45.84kN/m^2
Optimum Moisture Content (OMC)	10.4%
Maximum Dry Density (MDD)	1.76g/cm^3
California Bearing ratio (CBR)	At 2.5mm penetration = 2.23%
	At 5.0mm penetration = 2.42%

1.2 Lime

The lime used in this study was obtained from Afrimash Company Limited, Akobo Ibadan. The chemical composition of the untreated lime as supplied by the manufacturer is given in Table 2 below;

Table 2; Chemical composition of Lime

Chemical composition	Values (%)
Calcium oxide CaO	75.0
Magnesium oxide MgO	1.8
Silicon dioxide SiO_2	1.5
Aluminum oxide Al_2O_3	0.3
Iron (ii) oxide Fe_2O_3	0.2

Sulphur oxide SO_3	0.3
Loss of ignition LOI	2.5

1.3 Quarry Dust

The quarry dust used in this study was obtained from where granite aggregates are processed. The geotechnical properties of Quarry dust are given in Table 3 below;

Table 3; Geotechnical properties of Quarry dust.

Geotechnical Parameter	Values
Gravel Content	12.3%
Sand Content	79.6%
Silts content	6.08%
Clay contents	2.03%
Specific gravity	2.62%
Optimum moisture content OMC	7.5%
Maximum dry density MDD	1.90g/cm^3

1.4 Cement

The Dangote 3X cement employed in this research was sourced from an accredited supplier within the study area and the chemical composition is shown in Table 4.

Table 4; Chemical composition of Dangote 3X cement.

Chemical composition	Value (%)
Silicon dioxide SiO_2	20.26
Aluminum oxide Al_2O_3	4.96
Iron (ii) oxide Fe_2O_3	3.08
Calcium oxide CaO	53.69
Magnesium oxide MgO	1.06
Potassium oxide K_2O	0.52
Sulphur oxide SO_3	1.53
Sodium (ii) oxide Na_2O	0.27

3. METHOD

This study experimental program investigates the Atterberg Limit, Standard compaction test, California bearing ratio (CBR), Unconfined compressive strength test, Shear strength characteristics and the Permeability test. The soil sample is prepared with various mix proportions of Lime + Quarry dust and Cement mix. The percent of stabilizers varies with 2% lime + 30% quarry dust, 4% lime + 25% quarry dust, 6% lime + 20% quarry dust and 8% lime + 15% quarry dust. Also, cement mix proportions include; 2% cement, 4% cement, 6% cement and 8% cement.

The experiments were conducted with the following standards;

- ❖ ASTM D4318 - Atterberg limit test which includes liquid limit, plastic limit and plasticity index.
- ❖ ASTM D1557 – Compaction test
- ❖ Unsoaked test – California bearing ratio test (CBR)
- ❖ ASTM D2166 – Unconfined compressive strength test (UCS)
- ❖ ASTM D3080 – Shear strength test
- ❖ ASTM D2434 – Permeability test

4. RESULTS AND DISCUSSION

4.1 Atterberg Limit Test

Table 5 and 6 shows the variation of LL and PI of stabilized clay soil. For the Lime + quarry dust mix, liquid limit decreased from 26% to 24%, plastic limit rose from 17.4% to 21.5%, and plasticity index fell from 8.2% to 2.6% up to 6% lime, excess lime at 8% increased plasticity index to 8.8%. Cement reduced liquid limit from 45.5% to 38% and plastic limit from 19.3% to 9.5% at 6%; plasticity index rose at 8%. Both stabilizing agents cut plasticity optimally at 6% cement or 6% lime + 20% quarry dust.

Table 5; Atterberg limit test on Cement mix

Sample ID	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)
2% cement	45.57	26.2	19.4
4% cement	41.8	23.6	18.2
6% cement	38.22	28.7	9.5
8% cement	40.99	26.0	14.99

Table 6; Atterberg limit test on Lime + Quarry dust mix

Sample ID	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)
2% lime + 30% quarry dust	26.0	17.4	8.6
4% lime + 25% quarry dust	25.5	21.2	4.3
6% lime + 20% quarry dust	24.0	21.5	2.6
8% lime + 15% quarry dust	25.0	16.2	8.8

4.2 Compaction Test.

Figure 1 and 2 presents the compaction curve for the stabilized clay soil. The curve shows that for lime + quarry dust mixtures, OMC rose from 11.2% to 14.2% (2-8% lime, 30-15% dust) while MDD fell from 1.74 to 1.65 g/cm³. Cement stabilization reduced OMC from 14.9% to 11.5% (2-8% cement); MDD dipped to 1.63 then rose to 1.73 g/cm³. Cement excels in densification; lime-dust aids workability.

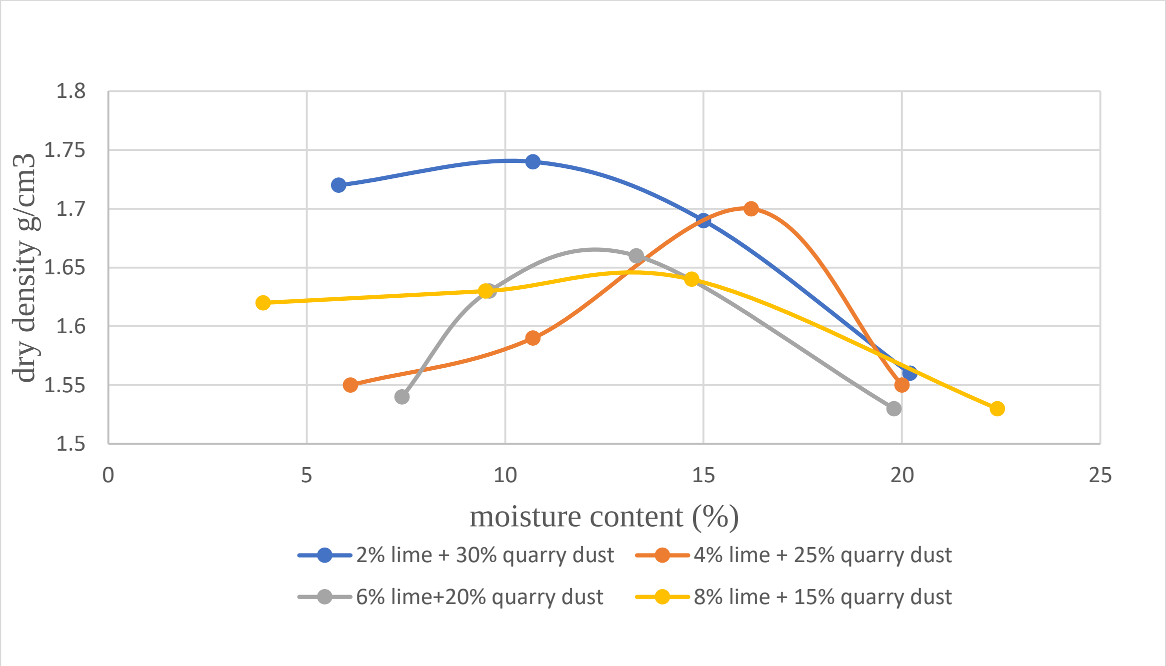

Figure 1; compaction curve for lime + quarry dust mix.

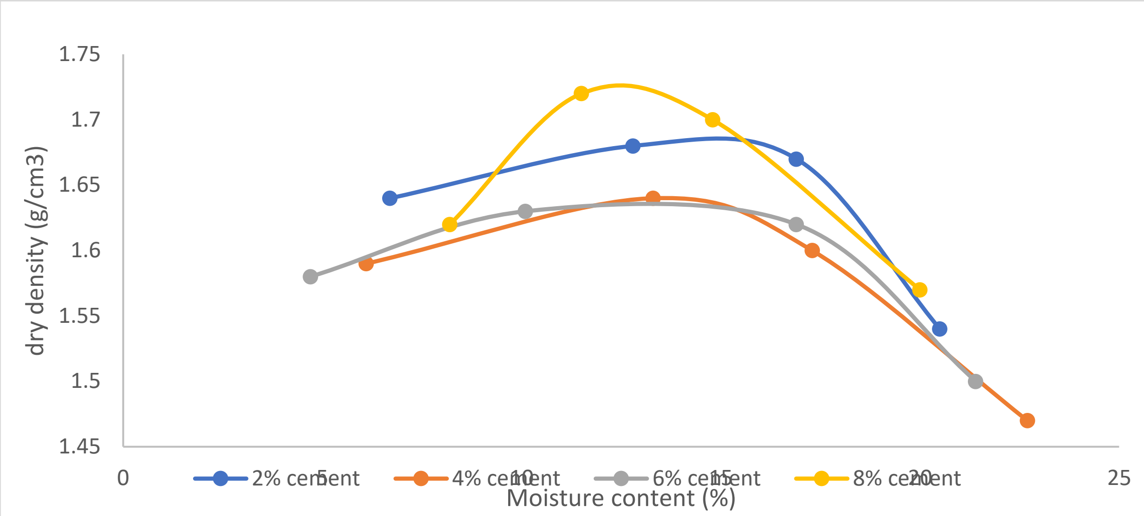

Figure 2; compaction curve for cement mix.

4.3 California bearing ratio (CBR)

Figure 3 and 4 presents the CBR curve, lime + quarry dust CBR rose from 4.8% (at 2% lime, 30% dust) to 10.6% (at 6% lime, 20% dust), then fell to 8.2% (8% lime, 15% dust). Due to flocculation, pozzolanic reactions, and dust gradation. Cement-stabilized CBR steadily rose from 2.7% (2% cement) to 14.7% (8% cement) via hydration bonds.

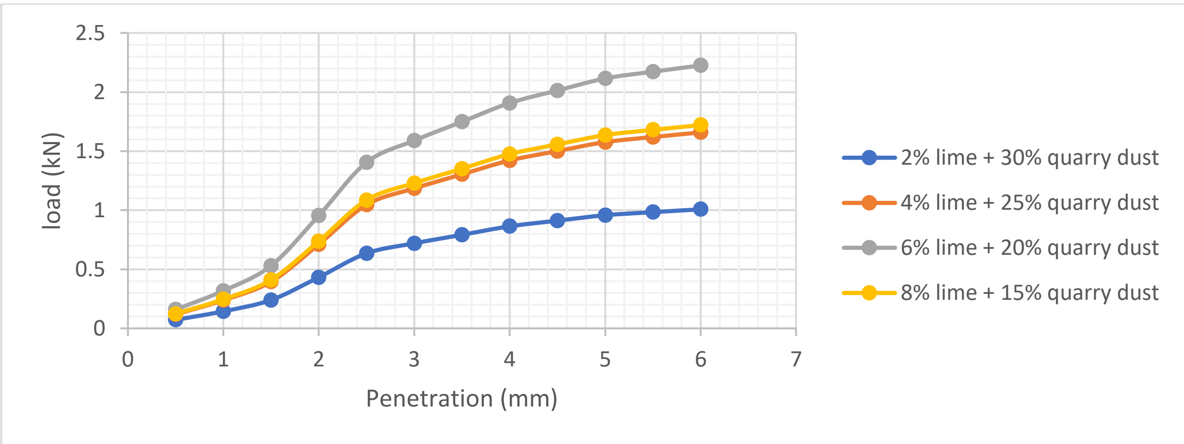

Figure 3; Load penetration curve for Lime + Quarry dust mix.

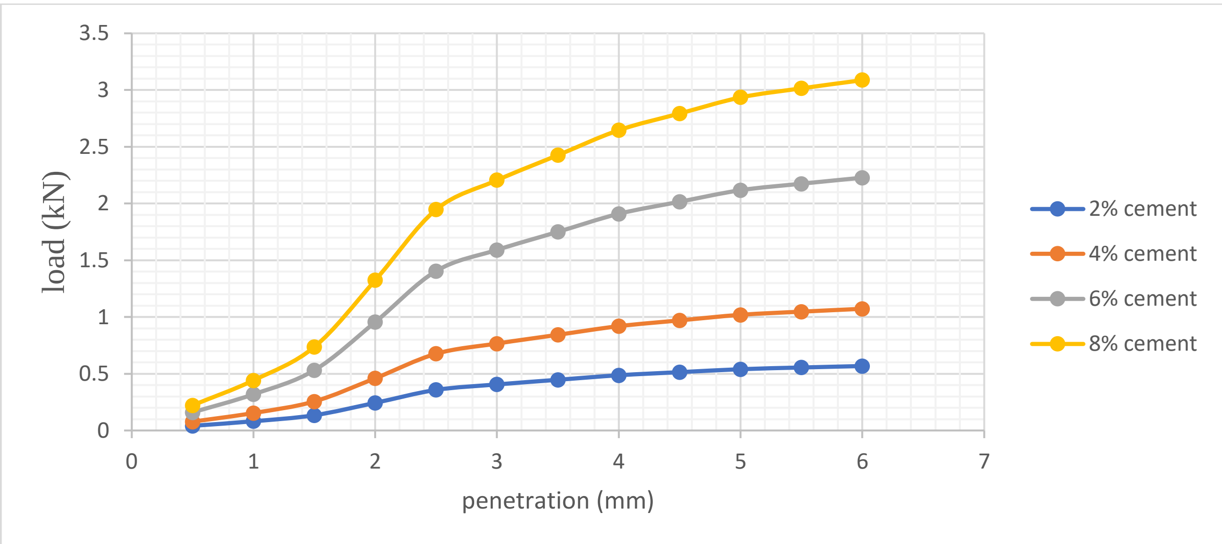

Figure 4; Load penetration curve for cement mix.

4.4 Shear strength test

Figure 5 and 6 presents the curve for the shear strength test of stabilized clay soil, lime + quarry dust, the cohesion peaked at 8.5 kPa (2% lime, 30% dust, 12° friction), then dropped to 0 kPa (8% lime, 15% dust, 38.1° friction). Cement stabilization: 2% cement yielded high cohesion (78.2 kPa, 2.5° friction); higher doses (4-8%) stabilized cohesion (11.5-25.4 kPa) while boosting friction angles to 32.8°.

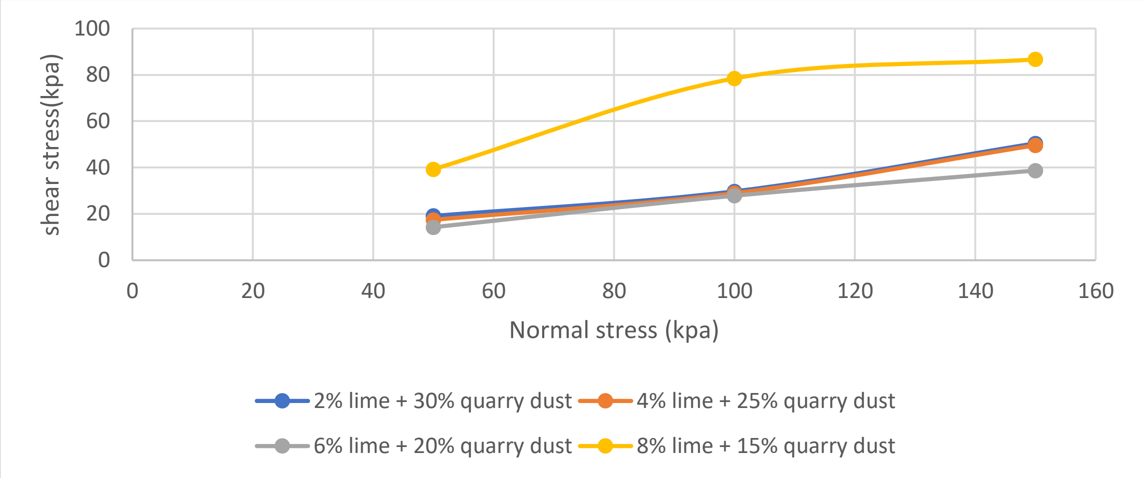

Figure 5; Graph of direct shear strength on Lime + Quarry dust mix.

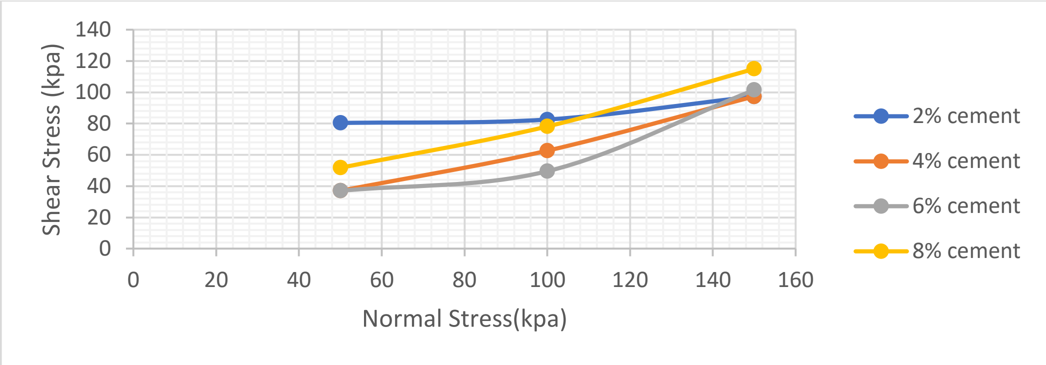

Figure 6; Graph of direct shear strength on cement mix.

4.5 Unconfined compressive strength (UCS)

The Unconfined compressive strength of the studied mixture for different curing times are presented in figure 7 and 8. Lime-quarry dust UCS rose progressively: 7 days (153-305.6 kN/m²), 14 days (305.6-560.2), 28 days (407.5-866.1 kN/m² at 8% lime, 15% dust), due to pozzolanic reactions. Cement UCS trended upward: 7 days (101.9-280.1 kN/m²), 14 days (254.6-611.2), 28 days (356.6-1069.9 kN/m² at 8% cement) via hydration gels, outperforming lime-quarry dust.

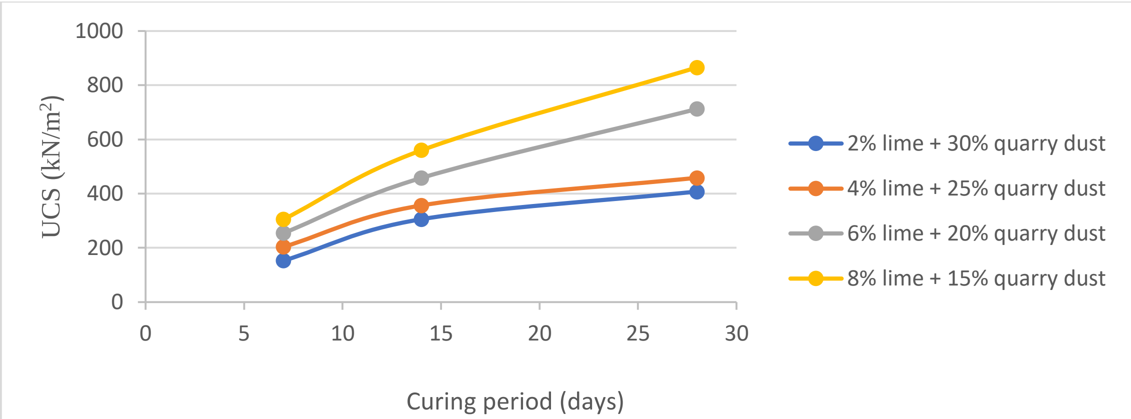

Figure 7; Graph of the Unconfined compressive strength on Lime + Quarry dust mix.

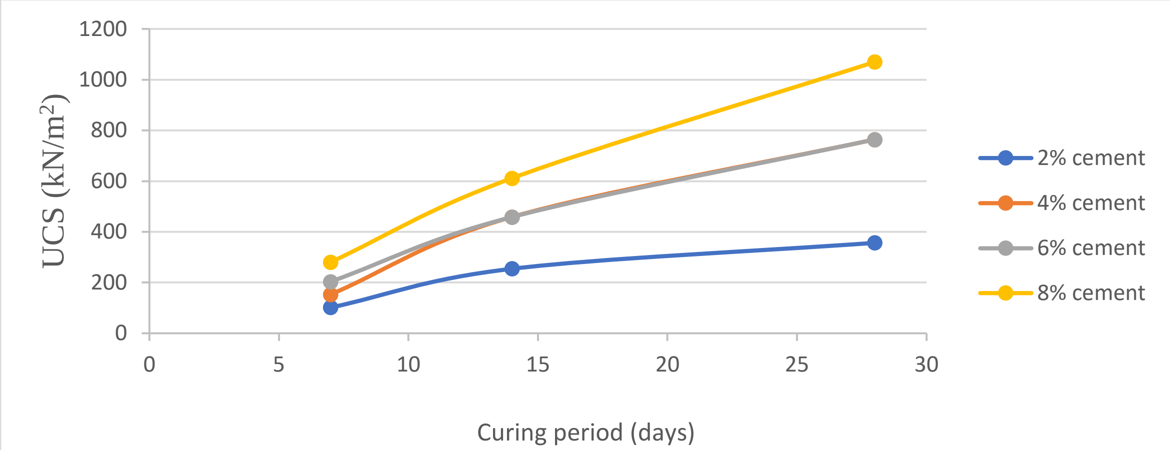

Figure 8; Graph of the Unconfined compressive strength on cement mix.

4.6 Permeability test

Table 7 and 8 shows the permeability test on the clay soil. Permeability of lime + quarry dust mix decreases from 4.20 x 10^{-5}m/s (2% lime + 30% quarry dust) to 1.52 x 10^{-5}m/s (8% lime + 15% quarry dust) due to pozzolanic reactions forming cementitious compounds and quarry dust filling voids. Cement-stabilized permeability drops from 0.0000484m/s (2% cement) to 0.0000242m/s (8% cement) via hydration bonding particles, but higher than lime-quarry dust mixes. 8% lime + 15% quarry dust (0.0000152m/s) is most effective for low-infiltration geotechnical uses.

Table 7; Permeability of Lime-Quarry dust stabilized inorganic clay

Mix proportions	Permeability (m/s)
0	0.0000690
2% lime + 30% quarry dust	0.0000420
4% lime + 25% quarry dust	0.0000319
6% lime + 20% quarry dust	0.0000247
8% lime + 15% quarry dust	0.0000152

Table 8; Permeability of cement stabilized inorganic clay

Mix proportions (%)	Permeability (m/s)
0	0.0000690
2	0.0000484
4	0.0000384
6	0.0000361
8	0.0000242

5 **CONCLUSIONS**

Natural inorganic clay is highly plastic, weak, and compressible, unfit for pavements untreated. Lime-quarry dust or cement stabilization optimizes geotechnical properties—strength, stability, durability—reducing settlement, deformation, and infiltration risks via tuned mixes.

- Liquid limit dropped, lowering the plasticity index to low-plasticity levels via cation exchange and pozzolanic reactions. Notably, 6% lime + 20% quarry dust outperformed equivalent cement.
- Lime-quarry dust addition lowered the clay's MDD while raising OMC through flocculation. Cement increased MDD and decreased OMC. The 6% lime + 20% quarry dust mix achieved sufficient density for sub-base standards.
- Natural clay's CBR was low (5%), unfit for sub-base. Stabilization with lime-quarry dust or cement boosted CBR significantly; lime-quarry dust matched cement at lower cost.
- UCS increased with stabilizers with curing days. Lime-quarry dust gained strength gradually, cement rapidly; optimal 6% lime + 20% quarry dust matched 6% cement. Shear parameters improved: cohesion dipped slightly, friction angle rose markedly, favoring lime-quarry dust via aggregation.
- Lime-quarry dust and cement stabilization increase low clay permeability through

structural changes. The values obtained are suitable for sub-base, enhancing drainage without losing durability.

- Lime-quarry dust offers a cost effective and sustainable alternative to cement
- Lime-quarry dust stabilization offers a reliable solution for improving the performance of inorganic clay soil in various engineering applications.
- Future research should refine lime-quarry dust and cement stabilization for various soils, assess environmental impacts, integrate new technologies, and foster interdisciplinary collaboration.

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