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Original Article

Effects of Top Seal White on Performance of Road Wearing Course Materials; A Case Study of Lateritic Gravel

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Abstract *- It has proven possible to improve some soil qualities by stabilizing natural materials. Soils can be blended or mixed with commercial additives to alter the gradation, texture, or plasticity to attain the desired gradation. Additionally, the additives serve as binders to tie the soil together. Soils have been treated with bitumen, fly ash, Portland cement, and lime to improve their mechanical properties, including strength, texture, workability, and plasticity. This study evaluates how the top seal white additive affects lateritic gravel's performance as a material for road wearing courses. Most of the unpaved roads in the rural areas of Kenya have undergone much deterioration, characterized by many ruts, potholes and loose stones. Ruts and potholes have resulted in rough and uncomfortable driving surfaces, leading to high vehicle maintenance costs and low speeds and delays. The dust coming from the road surfaces reduces drivers' visibility at times, leading to loss of control and accidents. There is a need to develop innovative materials that can be used to improve the properties of the road wearing course either by full or partial replacement of the wearing course materials. These materials will enable the wearing course to be adequate and overcome the shortcomings it is currently experiencing. Through the road agencies, the Kenyan government has implemented several programs to aid in developing and maintaining rural roads. The Rural Access Roads Program (1974-1986), Minor Roads Program (1986-1996) and Roads 2000 and 10000 strategies (1996 onwards) have been implemented. However, the approaches have been capital intensive, and the government does not have the resources to match the demand. This has made it necessary for engineers to continuously look for alternative materials that can be used to develop new and maintain the existing Kenyan roads. The laterite gravel and the top seal white used in this study were subjected to physical and chemical tests to determine their properties. The top seal white was added to the laterite gravel, and tests were conducted to determine the influence of the top seal white on the laterite gravel's properties. Top seal white achieves optimum results with applications in soils containing at least 15% fines passing a 200 sieve, or in soils suitable for road wearing course construction. This study used 15, 20, 25 and 30 percent of fines passing a 200 sieve to determine the optimum acceptable content at which the compressive strength, atterberg limits and California bearing ratio are at their maximum. The concentration of the top seal white additive varied at ratios of 1:3, 1:5, 1:7, and 1:9. The assessment done in this research indicates that the higher the fines content, the better the performance of the lateritic gravel. This is attributed to the maximum dry density achieved with a higher percentage of fines involving a particle arrangement where smaller particles are packed between larger particles, thus reducing the void space between particles. This creates more particle to particle contact, increasing stability and reducing water infiltration. With the application of the top seal white, the properties of the soil sample were immensely improved. The plasticity index of the soil is reduced with the application of the additive, reducing the soil's susceptibility to water content changes. The plasticity index upon treatment dropped from 24.99% for the untreated sample to 15.91%, 10.3%, 10.81% and 12.73% at top seal white concentrations of 1:3, 1:5, 1:7 and 1:9, respectively. The permeability of the soil was reduced, an indicator that the addition would increase strength. The maximum reduction in permeability was 93.38% at 1:7 top seal white concentration. Increasing the top seal white additive to the laterite soil improved the compressive strength and the California Bearing Ratio. The highest compressive strength improvement recorded was 136% at 25% fines passing the 200 sieve with 1:3 concentration of top seal white, while the lowest strength increase was at 54% with 1:9 concentration. The highest California Bearing Ratio of 32.66 was recorded, with 25% fines passing the 200 sieve at 1:3 top seal white concentration. This was a 25% increase in the California Bearing Ratio of the neat laterite gravel. Therefore, applying this additive will improve the properties of the pavement-wearing course and give it a long life. This is based on the improvement in the properties of the laterite gravel attained by the top seal white addition. Its application is therefore recommended whenever it is economically feasible. Top seal white should be tried in other soil types, too, as it will allow its use in soils that cannot support engineering structures.*

Keywords *- California Bearing Ratio (CBR), Compressive strength, Laterite gravel, Stabilization, Top seal white.*

1. Introduction

In addition to offering several social and economic benefits, well maintained roads are key for economic growth and development. They are essential to the expansion and development of a nation. Roads provide access to social amenities, health care, education, and economic possibilities; a road network is essential to ending poverty [1]. Roads promote social and economic development by opening up new areas. Road infrastructure is the most significant public asset as a result of these causes [2]. Because physical infrastructure affects manufacturing prices, job creation, market access, and investment, it is essential for rapid economic growth and poverty reduction [3].

The Kenyan government has adopted numerous labour-based approaches to assist in developing and maintaining unpaved rural roads. The Rural Access Roads Program (RARP) was implemented between 1974 and 1986, and approximately 8,000 km of farm-to-market-place roads were constructed. This was then followed by the Minor Roads Program (MRP) between 1986 and 1996, in which approximately 4,500 km of the classified Secondary (Class D), Minor (Class E) and particular purpose roads were improved. However, it was realized in the 1990s that the road maintenance programs that had been implemented were capital intensive, and the government could not meet the demands to maintain the high number of roads that had been improved in good condition. In a bid to counter this, the government initiated the low volume seal roads 2000 strategy (labour based approach that targeted 2,000 km of roads) and roads 10000 strategies (machine based approach that targeted 10,000 km of roads), which was a technique of road development and management that would ensure optimum utilization of locally available resources where technically and economically feasible and have a final thin coat of bitumen. The strategy was unsuccessful due to its high financial demand on road agencies [4]. The bitumen used as the wearing surface also leads to soil pollution, air pollution through carbon emissions, habitat disruption, environmental degradation and health risks to workers during its extraction. It is, therefore, necessary for engineers to innovate alternative materials that are technically, economically feasible and also environmentally friendly.

The government has significantly invested in road construction and upkeep during the past ten years. With 4500 km of Low Volume Seal Roads (LVSR) already built and another 3800 km in construction, the investment in LVSR has significantly expanded access to rural areas. The 48,418 km of roads that are the focus of the yearly investment in routine maintenance make up around 30% of the nation's total road network [5]. Through the rapid rural areas infrastructural expansion, Kenya is on track to realize significant gross domestic product growth in rural areas as access to resources and services has tremendously improved in areas where Kenya Rural Roads Authority has completed road projects under the R10000 low volume seal road projects [1]. The construction of the low volume roads has made the demand for road-building materials extremely strong, especially gravel. The acquisition and delivery of road building materials to the work site account for up to 50–60% of the anticipated cost of the completed road. Finding a method to balance road performance, constrained budgets, and tightening environmental laws is becoming a big challenge for road engineers. The cost effectiveness of treatments to enhance the long-term performance of conventional pavements is declining. Compared to the work at hand, road budgets, especially maintenance, appear to be declining [6]. There is, therefore, a need to improve the properties of the gravel used for this road construction to enhance the design life of the roads and to lower the routine maintenance costs.

Soil stabilization has been used to enhance soil gradation, lower the soil's flexibility index or swelling potential, and boost the strength and durability of materials used in road construction. Stabilization has given construction operations a working platform in damp weather. By stabilization, one can increase the strength and stiffness of a soil layer and reduce the design thickness of the stabilized material when compared to an unstabilized or unbound material. The design thickness strength, stability, and durability requirements of a wearing or sub-base course can be reduced if further analysis indicates suitability [7].

The type of soil to be stabilized, the stabilized layer's intended use, the desired types of soil improvement, the stabilized layer's necessary strength and durability, the cost implications, and the environmental factors all need to be taken into account when choosing the additives needed for a given soil. Multiple stabilizers may be appropriate for a given type of soil. Nonetheless, broad principles render particular stabilizers more preferable in relation to soil granularity, flexibility, or texture. Portland cement is used with various soil types. However, the soil must be mixed intimately with the fines fraction (<0.074mm).

The more plastic materials should be avoided. For Portland cement stabilization, well-graded granular materials with enough fines to create a floating aggregate matrix work best. When lime is added to soils with medium to high plasticity, the result is less plasticity, more workability, less swelling, and more strength. It is employed with marginal granular base materials, such as clay-gravels, to build a strong, high-quality base course, and it stabilizes a wide range of materials, including poor subgrade soils, turning them into a sub base. Fly ash is always utilized in conjunction with lime in soils that contain little to no plastic particles because of its pozzolanic (reacts with lime) character. It is usually preferable to utilize a tiny amount of Portland cement, fly ash, and lime for extra strength. This combination of lime-cement-fly ash has been used successfully in base course stabilization [7].

Kenyan companies, in their quest to lower road construction costs, have developed engineered products for road stabilization. Bamburi cement has developed RoadCem, which is designed to stabilize and improve soil's physical and mechanical properties in road construction. Unlike the standard lime or cement stabilization solutions, RoadCem allows using normally untreatable soils, including organic and sulphate-bearing soils. In 2014, Savannah Cement manufactured hydraulic road binders to stabilise road surfaces. This product is used globally for road stabilization. However, embracing the products has been challenging due to the cost implications on the roads [8]. The high costs associated with these stabilizers have forced Kenyan road agencies to look for alternative stabilizers that are efficient and economical in use.

Top seal white liquid soil sealant and stabilizer have also been used to perform several functions, especially in the United States. It has been used for dust control, soil erosion control, and stabilising road/parking lot/airfield bases. It is, therefore, important to test the suitability of the product in other parts of the world, such as different types of soils where it is not in use. In this study, the specific objectives that have been focused on are;

- To characterize laterite soil and top seal white additive for use in unpaved roads
- Assess the effect of Top Seal White on the properties of laterite gravel used for unpaved roads.

This study is limited to laterite gravel and laboratory and short-term performance of the laterite gravel wearing course.

2. Literature Review

Soils are naturally occurring materials used in construction and are tested to provide a general concept of their engineering properties. The soils, at times, do not meet the required engineering characteristics and are treated with additives, which, when added to the soil in the required quantities, improve some engineering characteristics such as strength, texture, workability, and plasticity [7]. Stabilization is the process in which suitable materials are mixed with soil to improve certain engineering properties of the soil. The process involves mixing soils to achieve a desired particle gradation or mixing commercially available additives that may alter the gradation, texture or plasticity or act as a binder for soil cementation [7]. The stabilization can be mechanical stabilization, additive stabilization, or modification.

2.1. Mechanical Stabilization

This is achieved by mixing or blending soils of two or more gradations to obtain a material that achieves the required gradation.

2.2. Additive Stabilization

Adding adequate proportions of cement, fly ash, bitumen, or a combination of these materials to the soil does this. The type and required proportion of additive depends on the soil type and the desired degree of improvement. Small proportions improve soil properties such as gradation, workability, and plasticity. More significant portions are used when strength and durability properties are to be improved.

2.3. Modification

This is stabilization done to improve certain soil properties but does not improve strength and durability significantly.

Many studies have investigated using different stabilizers, with most applications resulting in improved performance. The enhanced performance of the application of the stabilizers indicates that their use may improve rutting resistance and reduce resultant potholes, resulting in a longer lifetime and cheaper operational and maintenance costs.

Ancrum Amunza Amunga[9] researched the stabilization of laterite soil for unpaved roads using molasses. He carried out tests on the particle size distribution, atterberg limit tests, compaction tests, California Bearing Ratio test, Unconfined compressive strength and chemical analysis for both treated and untreated laterite.

From his study, he concluded that the laterite gravel had considerable amounts of aluminum oxide, iron and calcium oxide, indicating good binding ability similar to cement[10]. Adding molasses to the laterite gravel did not alter the particle size distribution. Adding an optimum percentage of 2% of molasses to the laterite gravel resulted in a reduced plasticity index of 10.7 from 15, which is ideal for the gravel wearing course in the area.

Abdul et al. [11] conducted a study on molasses' effectiveness in improving the shear strength and CBR value of two types of fine-grained soils: intermediate compressible and highly compressible clay soil. After applying molasses in his research, both soils' unconfined compressive strength and California bearing ratio improved. This is an indicator that the incorporation of molasses into road construction will result in significant improvement in road performance.

Gacheru[12] studied geosynthetics in road pavement design and construction in Kenya to determine the feasibility of incorporating geosynthetics in road design and construction. His research found that geosynthetic materials in Kenya meet the mechanical property requirements for pavement reinforcement function.

The elongation, grab breaking load and puncture strength were all found to be adequate. Placement of a geotextile below the pavement subbase will result in significant savings in construction costs and eventual life-cycle costs. This is in addition to associated savings due to reduced pollution and a shortened construction period.

Kumar[13], in his study on review on soil stabilization in road construction by using a bituminous mixture, found out that the application of bitumen increased the stability of the soil mechanically. There was considerable improvement in the California bearing ratio by up to 50 % of the unmodified gravel soil. The California bearing ratio increased with the amount of bitumen used. However, the increase in bitumen will lead to an increase in the cost; hence, there is a need to know the budget and the importance of the concerned structure. All these studies indicate that soils can be improved upon stabilization using suitable additives. This study seeks to determine the suitability of using top seal white additive to improve the road wearing course in Kenya. This material has not been used in Kenya and other East African countries; hence, this study seeks to unravel the appropriateness of top seal white additive in Kenyan soils, mainly laterite gravel.

3. Materials and Methods

The desired improvement in the engineering properties of any soil used for pavement wearing course, base, sub base courses, and subgrades will depend on the type and criteria used in injecting the additive into the soil.

3.1. Top Seal White

Top seal white is a chemical formulated for stabilizing haul roads and heavy traffic areas manufactured by Terra Pave International. Top seal white soil stabilizer and sealant is non-caustic and contains no chloride, lignosulfonate or petroleum-based components. It is non-hazardous, non-flammable, non-corrosive and non-toxic [9].

3.2. Lateritic Gravel

The lateritic gravel used for this research was sourced from the Mirimaini area of Kiambu County in Kenya. Lateritic gravel used in the entire experiment was obtained from one source.

3.3. Water

Portable water used in this experiment was obtained from the Jomo Kenyatta University of Agriculture and Technology.

3.4. Methodology

The study employed experimental research divided into two parts; the first part was investigating the physical and chemical properties of top seal white and lateritic gravel collected from Mirimaini in Kiambu county of Kenya; the second part involved determining the effects of top seal white treatment on the properties of laterite gravel. Neat lateritic gravel was prepared and tested for physical and chemical properties. The physical properties determined were particle size distribution (done in accordance with BSI 2012), compaction test (done in accordance with BS EN1097–3:1998), permeability (done in accordance with BS 1377-5:1990), atterberg properties (done in accordance with BS 1377-2:1990), compressive strength (done in accordance to BS EN12390-3:2009) and California bearing ratio (done in accordance to BS 1377-9:1990). Both the laterite gravel and top seal white were subjected to x-ray fluorescence analysis to determine their chemical contents (according to BS EN1744 – 1-9:2009). The top seal white was also subjected to the wet chemistry method to determine its physical properties. In the second part, the lateritic gravel was mixed with top seal white while varying the top seal white concentration(1:3,1:5,1:7 and 1:9) and also varying the fines passing 200 sieves (at 15%, 20%, 25% and 30%). Top seal white achieves optimum results with soils containing at least 15% fines passing the 200 sieve, which was used to determine the percentage of fines to be used. The top seal white concentrations of 1:3, 1:5, 1:7 and 1:9 were chosen because it has been determined that the additive is highly effective at application rates having dilution of 1 part top seal white to 3 to 10 parts water[16]. The material was then subjected to physical tests. The material to be subjected to compressive strength and California bearing ratio test was made into cylinders.

4. Results and Discussion

4.1. Chemical Analysis of Top Seal White and Laterite Gravel

The top seal white was subjected to two analysis methods: the wet chemistry method and X-ray fluorescence analysis. The lateritic gravel was also subjected to x-ray fluorescence analysis. The procedure followed in determining these properties is laid out in BS EN1744 – 1:2009, and the precise equipment used for the chemical analysis was the Bruker S1-Titan X-ray Fluorescence machine (XRF). The chemical analysis results are indicated in Tables 1 and 2.

Table 1. Top seal white physical analysis

Property	Value
pH	4.1
Color	White
specific gravity	1.082
Conductivity	1675
Total alkali as Na_2O,%m/m	23.88
Sulphate as SO_3, parts per million	36.02
Chlorides as Cl; parts per million	8.88

Table 2. Chemical analysis of top seal white and Laterite gravel

%m/m	Top seal white	Laterite Gravel
Fe_2O_3	1	64
SiO_2	18.2	21.4
CaO	3	5.9
MnO	0	4.3
K2O	0.4	2.7
TiO_2	0.3	1.1
Al_2O_3	4.4	-
S	9.4	-
MgO	63.2	-

Table 3. Chemical analysis of laterite gravel

%m/m	Laterite Gravel
Fe_2O_3	64
SiO_2	21.4
CaO	5.9
MnO	4.3
K2O	2.7
TiO_2	1.1
Al_2O_3	-
S	-
MgO	-

Top seal white was mainly composed of oxides of magnesium and silicon, and sulphur was the main constituent, with traces of oxides of iron, calcium, potassium, and aluminium (Table 2). On the other hand, laterite gravel had oxides of iron and silicon as the main constituents, with traces of calcium, manganese, potassium and titanium (Table 2). The chemical properties of top seal white and laterite gravel greatly influence strength development. The main chemical constituents of importance are silicon (IV) oxide, aluminum (III) oxide and calcium oxide, which influences strength development. Calcium oxide concentrations of 2-5% give early strength development [14]. The calcium oxide concentration observed led to an early strength development of the laterite gravel.

The laterite soil was subjected to x-ray fluorescence analysis to determine the chemical contents shown in Table 3.

The results obtained for the chemical analysis in Table 3 compare favorably with Ancrum [9] and Osuji and Akimwamide [15], whose findings were that laterite gravel mainly comprises iron, silicon and aluminium oxides. Soils with a silica (SiO2) to sesquioxide (Fe2O3+ Al2O3) ratio greater than two are considered non-lateritic. The silica to sesquioxides ratio for laterite soils lies between 1.3 and 2 [16]. The sample tested has a ratio of 1.3; hence, the soil collected is a true laterite soil.

4.2. Sieve Analysis

Soil stabilization is sometimes done to alter the gradation of soils. In such circumstances, a small amount of additives are added. Gradation often affects the workability and plasticity of soils. In this study, the stabilization was done to improve the soil strength and durability; hence, large quantities of additives were added. All the lateritic gravel used for this study had at least 15% fines passing the 200 sieve. The particle size distribution was done in accordance with BSI, 2012[17], where the laterite gravel was poured through a stack of sieves and the material retained at each of the sieves was computed to come up with the grading curve shown in Figure 1.

From the grading curves, the lateritic gravel was distributed as 58.9% gravel, 39.3% sand and 1.8% silt. The silt content was within the required limit of 4% [14]. The highest percentage of particles was retained in a 0.42mm sieve, meaning the aggregate has many fines. The material lost during the sieving process was 0.15%, less than the minimum allowable loss of 0.3%. The sample fell within the grading limits; hence, the lateritic gravel is suitable for wearing course materials and will improve the bonding. The results obtained from the sieve analysis show that 98% of the particles passed the 20mm sieve, 91% passed the 10mm sieve, 72% passed the 5mm sieve, 41% passed the 2mm sieve, 24% passed the 1mm sieve and 14% passed the 0.425mm sieve. Ancrum [9] found similar behavior with 100%,76%,60%,49%,33% and 21% of the particles passing the 20mm,10mm,5mm,2mm,1mm and 0.425mm sieves, respectively.

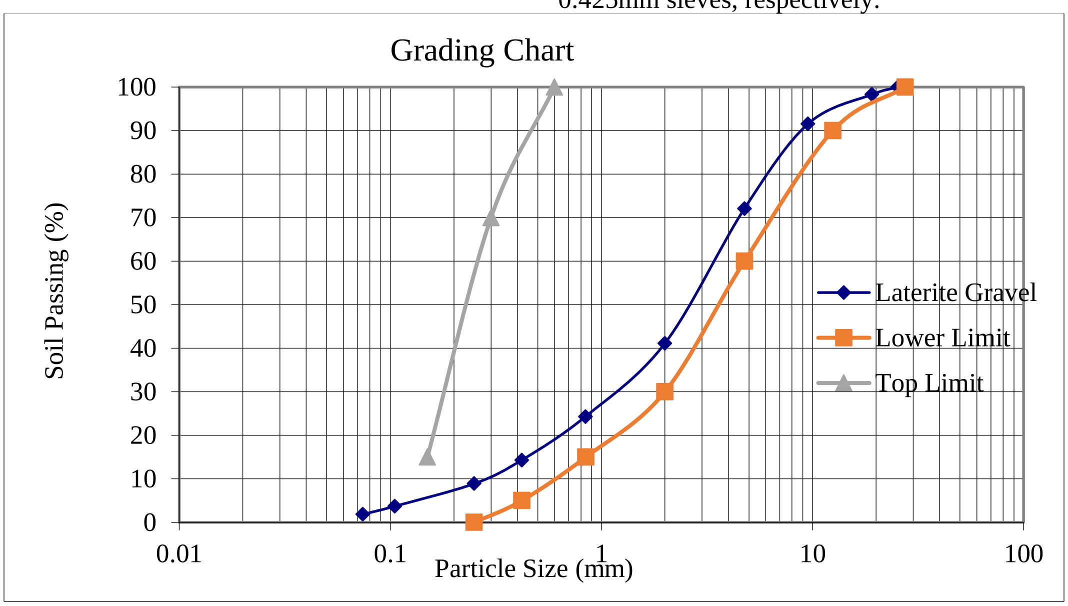

Fig. 1 Particle size distribution

Table 4. Optimum moisture content and maximum dry density

	Neat	1:3	1:5	1:7	1:9
Optimum Moisture Content (%)	20.5	19.5	19.5	18.5	18.6
Maximum Dry Density (g/cm3)	1.69	1.63	1.63	1.685	1.655

4.3. Compaction Test

The soil samples containing the top seal white in varying concentrations were subjected to the compaction test, and the results were tabulated in Table 4.

From the results, it is evident that the addition of a white top seal did not aid the compaction process.

4.4. Atterberg Limits

The atterberg limits of the soil sample were determined to determine the soil's suitability for stabilization. Figure 2 shows the graph used to determine the liquid limit of the laterite gravel. After determining the liquid and plastic limits, the difference between the two was obtained as the plasticity index of the gravel.

The Liquid Limit, Plastic Limit and Plasticity Index were determined as 48.5%, 23.51% and 24.99% respectively. The plasticity index was within the required maximum limit of 30% [7].

Upon treatment with top seal white, the plasticity index recorded was 15.91% at 1:3, 10.3% at 1:5, 10.81% at 1:7, and 12.73% at 1:9 chemical concentration. This indicates that top seal white reduces the range over which the soil remains in the plastic stage, becomes drier and less susceptible to water content changes [19]. The soil also becomes more workable, experiences less swelling and is stronger than in its untreated state [6].

The reduced plasticity index of the wearing course materials implies that the material will be less susceptible to water content changes, increasing its appropriateness in rural areas prone to flooding.

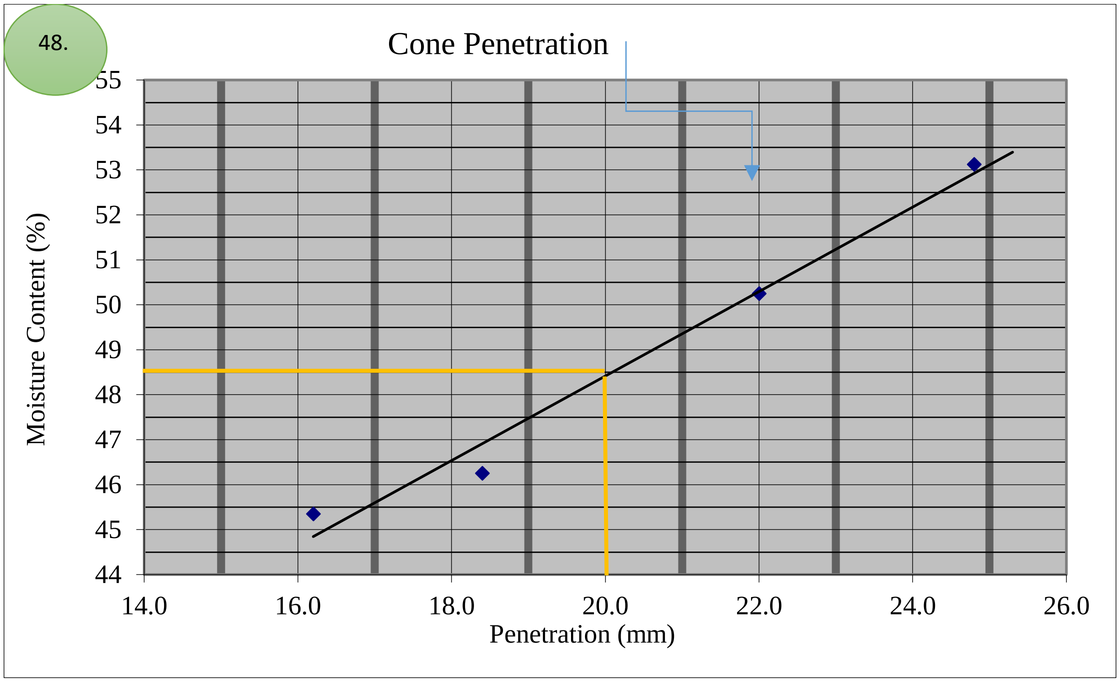

Fig. 2 Lateritic gravel liquid limit

Table 5. Permeability test after top seal white application

		Top Seal White(TSW):Water Ratio		
Material	Neat	1:5TSW	1:7TSW	1:9TSW
permeability (Cm/s)	3.64E-04	1.06E-04	2.41E-05	9.29E-05
Improvement (Cm/s)	0.00E+00	2.58E-04	3.40E-04	2.71E-04
Improvement (%)	0.00	70.88	93.38	74.47

4.5. Permeability

Top seal white was added to assess its impact on the permeability of the lateritic gravel. The overall impermeability of the soil is directly correlated to the concentration of top seal white. It indicates any strength increase upon adding top seal white additive [9]. Table 5 shows the improvement achieved by the top seal white addition into the laterite gravel. Adding a top seal white for the samples tested increased impermeability, as shown in Table 5. This indicates that adding a top seal white will increase strength, improving the wearing of course material's performance.

4.6. Compressive Strength

Cylindrical samples of the laterite gravel were prepared while varying the percentage of fines passing 200 sieves (15%, 20%, 25% and 30%) while also varying the concentration of top seal white(1:3, 1:5, 1:7 and 1:9). The samples were subjected to compressive strength tests at 7, 14 and 28 days for each of the varying fines and top seal white concentrations.

Figures 3, 4, 5 and 6 show the compressive strength for each of the laterite gravel samples at different percentage of fines passing sieve 200 and top seal white concentrations.

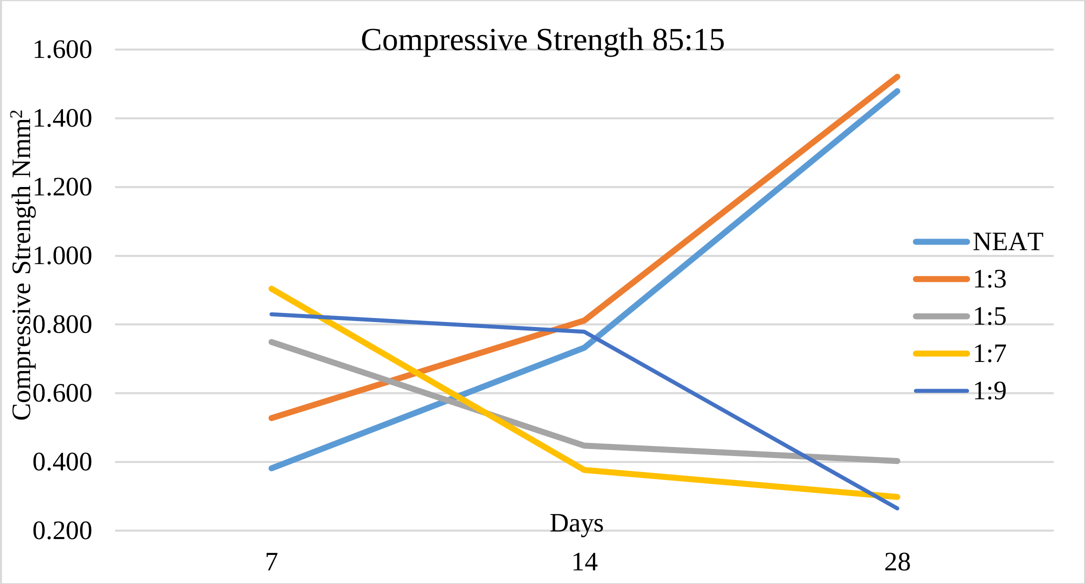

Fig. 3 Compressive strength with 15% fines

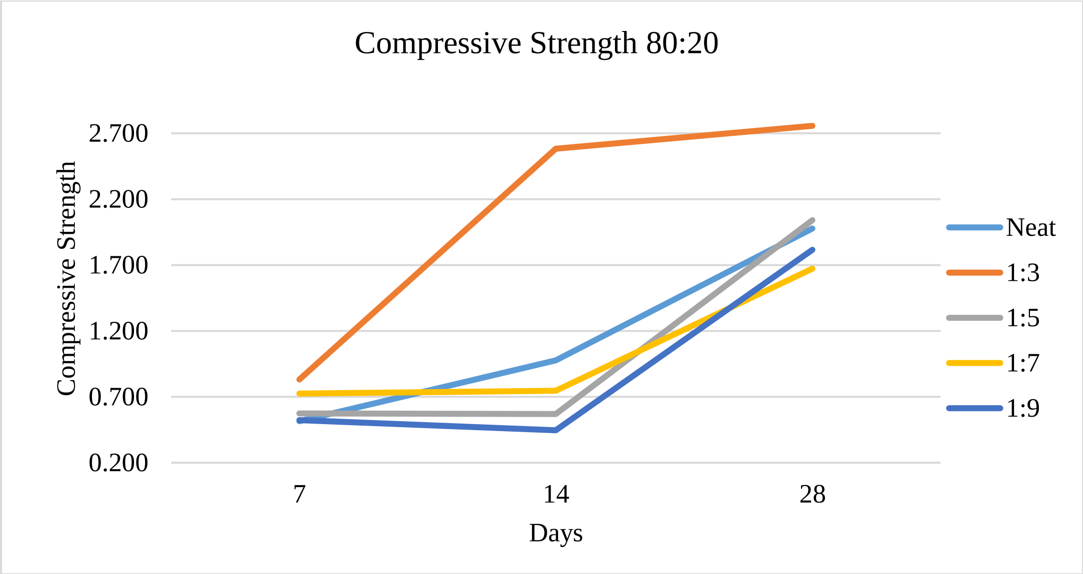

Fig. 4 Compressive strength with 20% fines

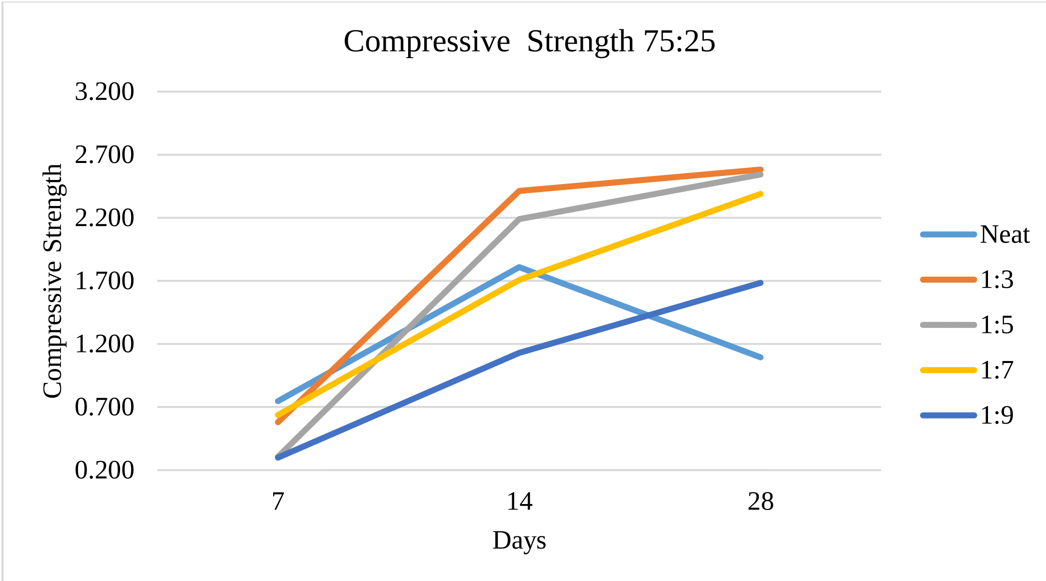

Fig. 5 Compressive strength with 25% fines

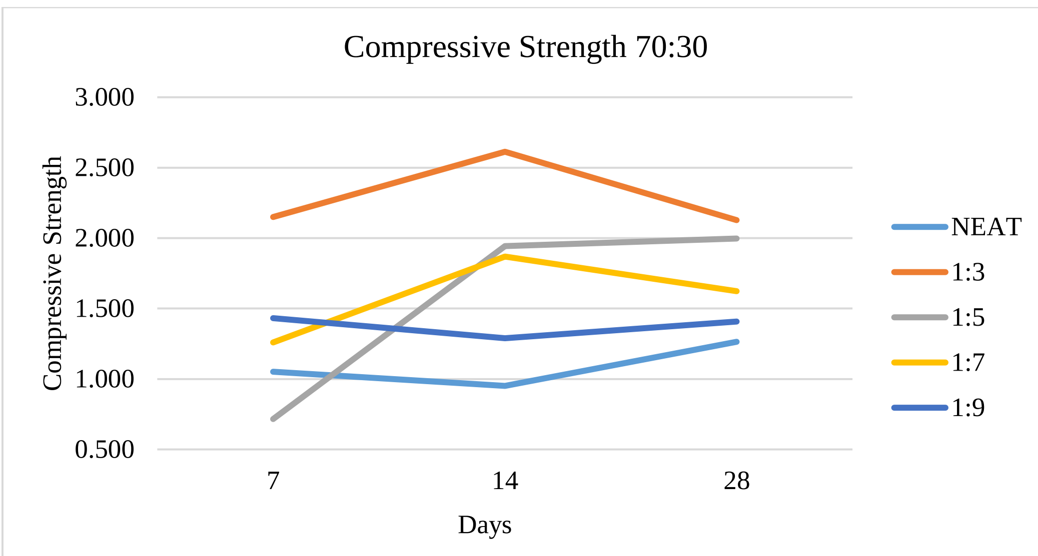

Fig. 6 Compressive strength with 30% fines

From the results shown in Figures 3, 4, 5 and 6, it is evident that the overall strength of the soil is directly correlated to the concentration of top seal white. Various concentrations should be used to achieve the best possible results from field applications [9]. The highest strength was achieved at the 1:3 ratio, the highest additive concentration, and at 20 and 25% fines passing the 200 sieve. At 20 and 25%, the air void content is at the optimum, resulting in a highly impermeable aggregate and high strength. The highest compressive strength improvement recorded was 136% at 25% fines passing the 200 sieve with 1:3 concentration of top seal white, while the lowest strength increase was at 54% with 1:9 concentration. The strength increase can be attributed to the calcium oxide concentration in top seal white.

4.7. California Bearing Ratio (CBR)

The CBR test was done for the different top seal white ratios of 1:3, 1:5, 1:7 and 1:9. The fines passing the 200 sieve also varied from 15%, 20%, 25% and 30%, and CBR values were determined as shown in Figure 7.

The 1:3 and 1:5 concentrations had the highest CBR values, indicating that the higher the top seal white concentration, the higher the strength. The CBR value was also high for the samples, having 20 and 25% passing the 200 sieve. At 20 and 25% passing the 200 sieve, the air void content is at the optimum, resulting in an impermeable aggregate, hence high strength.

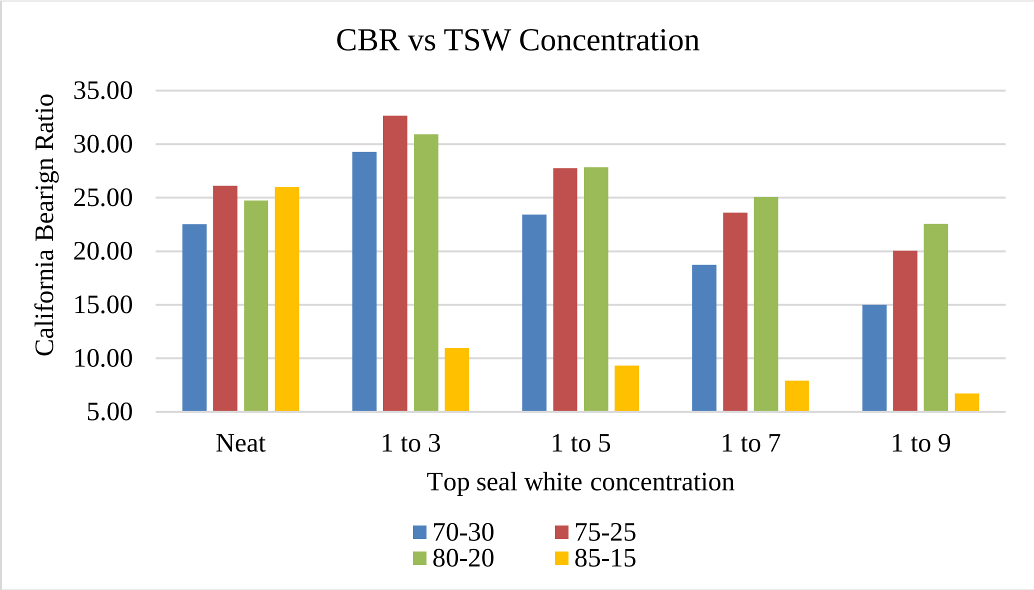

Fig. 7 California bearing ratio test with varying chemical concentration

The CBR values obtained for the 1:3 top seal white concentration was 32.66 for 25% of fines passing the 200 sieve, while a 1:5 concentration CBR value of 27.84 for 20% of fines passing the 200 sieve was obtained. The CBR values obtained are above the minimum of 20 recommended by the Ministry of Transport and Infrastructure Road Design Manual Part III [20].

5. Conclusion

Using the top seal white showed significant improvement in the properties of laterite gravel.

- The plasticity index was significantly reduced from 24.99% to a minimum of 10.3%. This shows that top seal white application made the laterite gravel less susceptible to water content changes. This is advantageous as road construction materials are destroyed when they hold water for longer periods. This is common during the rainy seasons in Kenya.
- The soil was also made more impermeable; hence, high strengths were achieved. The top seal white addition ensured the voids between the laterite gravel were occupied, resulting in a more solid material that can resist deformations due to rutting. This will also reduce the loss of the loose wearing course materials.
- The addition also increased the CBR and compressive strength of the lateritic gravel. The increase was experienced at the high top seal white concentrations (1:3 and 1:5) and 20% and 25% fines passing the 200 sieve. The highest increase in compressive strength was 136%, while the highest increase in CBR was 37%. The highest CBR was recorded with 25% fines passing the 200 sieve at 1:3 top seal white concentration. The increase in CBR results in a stronger pavement layer that can resist deformations such as potholes and ruts. However, the increase in compressive strength obtained from this study is more significant when top seal white is used for rigid pavements.

5.1. Recommendations for Future Research

While stabilization of base materials is a viable option for enhancing the characteristics of soil, the engineering properties that result from this treatment vary greatly due to the heterogeneity in soil composition, differences in the micro and macro structure of soils, heterogeneity of geologic deposits, and due to differences in the physical and chemical interactions between the soil and the candidate stabilizers. Therefore, the performance of top seal white additive can be tested on other soils such as red soil, which is very common in Kenya, as this research concentrated on laterite soil only. Further studies should be done to determine the long term performance of top seal white additive. This will help determine the durability, rutting resistance, and environmental impact. Comparative studies can also be done to determine the performance of top seal white against other additives. This can also help determine if top seal white can be blended with other additives for better performance.

Funding Statement

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References

[1] Institution of Engineers of Kenya, Engineering in Kenya, Nairobi: Institution of Engineers of Kenya, 2022. [Online]. Available: https://www.iekenya.org/

[2] Gülay Malkoc, The Importance of Road Maintenance, World Highways, 2015. [Online]. Available: https://worldhighways.com/wh8/wh9/wh10/feature/importance-road-maintenance#:~:text=G%C3%BClay%20Malkoc%20discusses%20the%20importance%20of%20investing%20in%20road%20maintenance.&text=Roads%20make%20a%20crucial%20contribution,a%20nation%20grow%20and%20develop.

[3] Wilson S.K. Wasike, *Road Infrastructure Policies in Kenya: Historical Trends and Current Challenges*, Kenya Institute for Public Policy Research and Analysis, pp. 1-97, 2001. [Google Scholar] [Publisher Link]

[4] Paul Gacheru Macharia, Simpson Nyambane Osano, and Sixtus Kinya Mwea, "Performance of Roads Implemented under the Roads 2000 Strategy in Central Kenya," *East African Journal of Engineering*, vol. 5, no. 1, pp. 163-173, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[5] Annual Public Roads Programme, Kenya Roads Board, pp. 1-41, 2021. [Online]. Available: https://www.krb.go.ke/img/advertdoc-20211027-6179ad419eeb9.pdf

[6] Ubani Obinna, Soil Stabilisation for Road Construction, Structville, 2022. [Online]. Available: https://structville.com/soil-stabilisation-for-road-construction

[7] J. Paul Guyer, Introduction to Soil Stabilization in Pavements, Continuing Education and Development Engineering, 2011. [Online]. Available: https://www.cedengineering.com/userfiles/An%20Introduction%20to%20Soil%20Stabilization%20for%20Pavements%20R1.pdf

[8] Peter Lugaria, Bamburi Cement Unveils New Binder for Kenya Roads, Construction Kenya, 2019. [Online]. Available: https://www.constructionkenya.com/6160/bamburi-special-products/

[9] Amunga Ancrum Amunza, "*Stabilization of Laterite Soil for Unpaved Roads using Mollases in Butere and Mumias Sub Counties*," Nairobi, Master of Science, Jomo Kenyatta University of Agriculture and Technology, pp. 1-108, 2020. [Google Scholar] [Publisher Link]

[10] Hassan Yildirim, and Baris Altun, "Usage of Molasses in Concrete as a Water Reducing and Retarding Admixture," *Indian Journal of Engineering and Material Sciences*, vol. 19, no. 6, pp. 421-426, 2012. [Google Scholar] [Publisher Link]

[11] E. Ravi et al., "Study on the Effect of Molasses on Strength of Soil," *An International journal of Advanced Research Trends in Engineering and Technology*, vol. 2, no. 2, pp. 57-61, 2015. [Google Scholar] [Publisher Link]

[12] Gacheru P. Macharia, "*Geosynthetics in Road Pavement Design and Construction in Kenya*," University of Nairobi, Department of Civil and Construction Engineering, pp. 1-77, 2019. [Google Scholar] [Publisher Link]

[13] Arun Kumar, "A Review on Soil Stabilization in Road Construction by using Bituminous Mixture," *Journal of Emerging Technologies and Innovative Research*, vol. 5, no. 1, pp. 877-883, 2018. [Google Scholar] [Publisher Link]

[14] Penn State University, The Effect of Aggregate Properties on Concrete. [Online]. Available: http://www.engr.psu.edu/ce/courses/ce584/concrete/library/materials/aggregate/aggregatesmain.htm

[15] O.S. Osuji, and J.T. Akinwamide, "Physico-Chemical Properties of Lateritic Soils in Ado-Ekiti, South Western Nigeria," *Universal Journal of Environmental Research and Technology*, vol. 7, no. 1, pp. 10-18, 2018. [Google Scholar] [Publisher Link]

[16] F.G. Bell, *Engineering Geology*, Blackwell Scientific Publications, 1993. [Google Scholar] [Publisher Link]

[17] BS EN 933-1:2012, Tests for Geometrical Properties of Aggregates - Determination of Particle Size Distribution, Sieving Method, Knowledge BSI Group, 2012. [Online]. Available: https://knowledge.bsigroup.com/products/tests-for-geometrical-properties-of-aggregates-determination-of-particle-size-distribution-sieving-method-1?version=standard

[18] BSI, Specifications for Aggregates from Natural Sources for Concrete, 1992. [Online]. Available: https://knowledge.bsigroup.com/products/specification-for-aggregates-from-natural-sources-for-concrete-1?version=standard

[19] C.D.F. Rogers et al., "Modification of Clay Soils Using Lime," *Lime Stabilisation: Proceedings of the Seminar Held at Loughborough University Civil & Building Engineering Department*, pp. 99-114, 1996. [Google Scholar] [Publisher Link]

[20] Giora Rozmarin, *Road Design Manual Part III, Materials & Pavement Design*, 1987. [Publisher Link]