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Determination of Suitable Proportions of Stabilizing Materials based on Soaking and Infiltration Rate Parameters

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Abstract

Material stabilization and the rate of moisture absorption are critical factors in enhancing road infrastructure performance. To evaluate these aspects, laboratory tests were conducted to determine the engineering characteristics of materials prepared with specific ratios of blended gravel and sand. Stabilization, in this context, involves blending aggregates or soil with additives such as bitumen, ground granulated blast furnace slag (GGBS), Portland cement, lime, or sludges to improve mechanical strength.

This research particularly emphasizes the optimization of mix proportions using GGBS and Ordinary Portland Cement (OPC) as stabilizers, with a focus on the partial substitution of cement with GGBS. Laboratory test results demonstrate the potential of these blends to enhance the resistance of road materials to water infiltration and traffic-induced loading. The study ultimately identifies best strategies for improving the quality of fill material and its application in embankment construction, especially in waterlogged areas.

Keywords: *Ordinary Portland Cement (OPC), Ground Granulated Blast Furnace Sludge (GGBS), Soil Stabilization, Unconfirmed Compressive Strength (UCS), soaking rate, Infiltration.*

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1.0 INTRODUCTION

This study investigates the early deterioration and prevalent vulnerabilities observed in road embankments built in swampy areas. In lowland and wetland areas, particularly within river valleys, elevated groundwater levels are a primary factor contributing to road failures. These failures occur due to the unrestrained movement of water through material layers and the voids formed by excessive infiltration, high permeability, and capillary action. Initially, these problems manifest in the wearing course of the road surface, leading to significant deformations such as

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depressions, cracks, potholes, ruts, heaves, and uneven settlements of the embankment. These surface irregularities greatly affect ride quality and the safety of road users.

The objective of this research is to improve the selection process for suitable materials used in road embankment construction in areas prone to excessive moisture conditions. While earlier studies (e.g., Anochie-Boateng et al., 2015) primarily concentrated on forensic examinations related to the failure of pavement layers and evaluations of asphalt concrete premix designs, this research shifts its focus to the selection of appropriate fill materials. Testing was conducted on both stabilized and blended materials to assess their suitability, particularly in scenarios where water has infiltrated or soaked into the materials. This investigation emphasizes the characteristics and properties of these materials.

Specifically, the study examines the use of Ground Granulated Blast Furnace Slag (GGBS) as a substitute for Ordinary Portland Cement (OPC) in stabilization blends. GGBS improves the strength and stability of materials and simultaneously decreases reliance on cement-based additives. This decrease not only lowers construction costs but also contributes to a decrease in CO_2 emissions. The incorporation of GGBS as a partial cement replacement in stabilization blends is essential for enhancing material strength and promoting sustainable road construction methodologies (Ayu et al., 2013; Dom et al., 2015)

2.0 MATERIALS AND METHODS

2.1 Description of the Study Area

Mlandizi is a medium-sized town located in the Pwani Region of Tanzania along the Dar es Salaam–Morogoro Trunk Road, commonly known as the TANZAM Highway. According to the 2022 Tanzania Housing and Population Census, Mlandizi has an estimated population of approximately 29,394 residents. This study area encompasses a 6.35 km stretch of the trunk road between Mlandizi and Ruvu on the TANZAM Highway. The region is characterized by rolling, level landscapes with a high-water table and several river crossing points. It experiences a relatively wet climate due to consistent rainfall and features a serpentine river channel that contributes to sustained moisture throughout the landscape (Coast Region Investment Profile, 2015).

2.2 Data Collection

Strategies for the collection of quantitatively representative samples of selected materials for the research and development of enhanced materials are outlined as follows:

2.2.1 Sampling Strategies

Natural gravel samples (G15) were collected from a borrow pit located near Soga Village along the Mlandizi–Maneromango Road. The material exhibited a brownish hue and consisted of sandy, silty gravel extracted from a depth range of 0.2 to 0.7 meters. Geotechnical evaluations were conducted on these samples, intended for use in fill and improved subgrade sections. The evaluations included particle size distribution (PSD) testing, Atterberg limits testing, maximum dry density (MDD) testing, California Bearing Ratio (CBR) testing, swell testing, assessment of the physical properties of the materials, and analysis of the chemical composition and properties. Unconfined compressive strength (UCS) tests were performed to assess the strength criteria of the stabilizing materials. Additionally, the drainage capacity of the materials was evaluated through permeability, capillarity, and infiltration tests.

The imported materials were classified as A-2-4 under the American Association of State Highway and Transportation Officials (AASHTO) classification system, indicating that they are silty sand gravel suitable for subgrade and embankment fill. In contrast, materials excavated from existing embankments (designated as G15) and obtained from trial pits were classified as A-2-6. Nevertheless, both types of materials met the specified requirements outlined in the Standard Specifications for Road Works (SSRW, 2000). Sand was sourced from Chekereni

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Village, located approximately 10 kilometers from Mlandizi town along Maneromango Road. Laboratory tests conducted on the sand included assessments of particle size distribution and specific gravity. Ordinary Portland Cement (OPC) was supplied by Lake Cement Company, now rebranded as Nyati Cement, which is situated about 44.3 kilometers from Kimbiji in the Kigamboni District of Dar es Salaam. Additionally, Ground Granulated Blast Furnace Slag (GGBS) was provided by QUAIM Steel Limited, located in the Keko area of the Temeke District, Dar es Salaam.

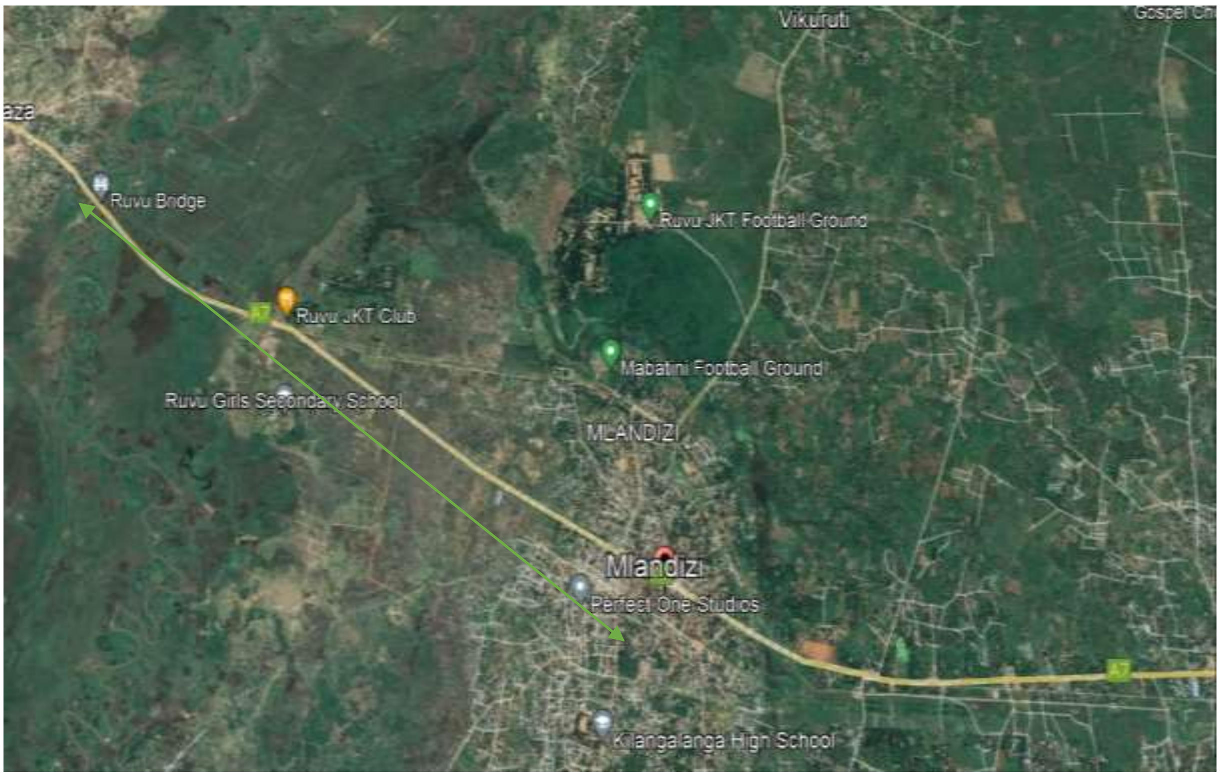

Figure 1: A Google Maps representation of Mlandizi - Ruvu Road section ©2008 – 2024

2.2.2 Laboratory Tests and Blending Techniques

Laboratory experimentation and material blending involve the mechanical stabilization of two or more substances with distinct physical and engineering characteristics. These substances are combined in precisely determined proportion ratios to produce a composite material that demonstrates enhanced performance qualities. This study focuses on the mixing of sand and gravel at incremental weight percentages of 5%, 10%, 15%, 20%, 30%, and 40%. These specific ratios were selected to evaluate the effects of varying sand content on the mechanical properties and drainage capabilities of the gravel-based material. The primary objective is to enhance the suitability of naturally available materials for application in road embankments, particularly in areas susceptible to flooding or waterlogging, where conventional materials frequently underperform.

Blending technology modifies several critical soil properties, including gradation, density, compaction characteristics, and moisture sensitivity. Most significantly, it affects permeability, infiltration rates, and absorption characteristics—parameters that are vital for the long-term serviceability and stability of road subgrades and embankments. Hinga (2021) suggests that

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integrating finer materials, such as sand, into a coarse gravel matrix significantly decreases infiltration and absorption rates, thereby improving resistance to water-induced degradation. This study focuses on optimizing sand-to-gravel ratios to strike a balance between achieving desired structural strength and preserving adequate drainage capacity and durability. The ultimate goal is to enhance performance in saturated conditions and extend the longevity of road structures.

2.2.3 Stabilization of Materials

Stabilization is a technique used to modify soil in order to enhance its engineering properties and characteristics. A mixture of GGBS and cement can be used for the modification of soil or the improvement of fill materials. The stabilization process employs Ordinary Portland Cement (OPC) and GGBS in carefully planned proportions (Pandey and Rabbani 2017). GGBS is incorporated as a cement replacement in stabilization stages at varying ratios of 2%, 4%, and 6%. Cement replacement with GGBS is carried out in each stabilization stage at ratios of 20%, 30%, 40%, and 50% of the weight of the cement. The curing period for the stabilized specimens lasts seven days. This stabilization results in a significant reduction in the effects of water penetration caused by capillarity, permeability, and the rate of infiltration (Obuzor and Kinuthia 2011).

2.2.4 Unconfined Compressive Strength (UCS) Tests

The laboratory procedure employed to determine the Unconfined Compressive Strength (UCS) of a stabilized material is derived from guidelines established by Hinga (2021). UCS represents the maximum axial compressive stress that a specimen can withstand without any confining stress. The Unconfined Compression Test, also referred to as the Uniaxial Compression Test, is conducted using standardized molds with a diameter of 152.4 mm, a height of 152.4 mm, and a base plate measuring 25.4 mm in height. This test adheres to the protocols outlined in CML Tests 1.21, ref TMH1 – 1986: A14 and BS 1924: Part 2: 1990. The laboratory testing procedure is executed in a series of methodical steps as follows:

i. Laboratory tests for soil stabilization were conducted with ratios of 2%, 4%, and 6%.
ii. At each stabilization level i.e. 2%, GGBS replacement ratios of 20%, 30%, 40%, and 50% of the cement weight were evaluated.
iii. The entire procedure, which included preparation, mixing, watering, and compaction of the stabilized materials, was completed within four hours, in accordance with the specified requirements outlined in CML Tests 1.21.
iv. Following compaction, the stabilized specimen was stored in water-tight containers at room temperature and subsequently immersed in water for a curing period of seven days.
v. Upon completion of the seven-day curing process, the specimens were removed from the containers and immersed in water for an additional four hours. Afterwards, each specimen was weighed prior to undergoing testing for compressive strength using a compression machine.
vi. The strength of the stabilized materials was primarily assessed through the Unconfined Compressive Strength (UCS) test, a recognized method within the field of geotechnical engineering.
vii. The test results were represented graphically, illustrating the relationship between GGBS-cement ratios and unconfined compressive strength (Pandey and Rabbani 2017).

3.0 RESULTS AND DISCUSSION

This section outlines the objectives underlying the findings, results, and outcomes of the research, employing descriptive analytics illustrated through tables, graphs, and formulas.

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3.1 Compaction studies of Cement Stabilized

The stabilization of materials enhances their properties, characteristics, and overall strength, particularly in relation to fill materials. The variation in material strength is fundamentally linked to the chemical bonding mechanisms established between soil particles and Ordinary Portland Cement (OPC). This interaction facilitates the formation of cementitious hydrate gels, which serve to cohesively bind the particles together (Obuzor and Kinuthia, 2014). The effectiveness of this material enhancement is contingent upon the materials' behavior under traffic loads and their ability to manage water drainage effectively. The outcomes of stabilization achieved through OPC alone without additive incorporation are detailed in Table 1.

Table 1: Unconfined compression Test Results of Cement stabilization

Sample Nos.	Curing Time (Days)	Stabilization ratio (%)	MDD (Kg/m³)	OMC (%)	Load Standard (kN)	UCS Average (Mpa)	Remarks
1	7	2	1,993	6.5	26		
2	7	2	2,692	6.5	23	1.3	Class C1
3	7	4	2,011	6.5	40	2.2	Class C2
4	7	4	2,006	6.5	42		
5	7	6	2,011	6.5	59		
6	7	6	2,019	6.5	55		

3.2 Compaction studies of replacement of Cement with GGBS stabilization

Stabilization mixing ratio has demonstrated a marked enhancement in soil strength, correlating with the increased use of GGBS within the cement mix proportions (Bandyopadhyay, 2016).

3.2.1 2 % Materials Stabilization

The substitution of cement with varying proportions of Ground Granulated Blast-furnace Slag (GGBS) at 20%, 30%, 40%, and 50% resulted in compressive strength values of -1.07 MPa, 1.17 MPa, 1.37 MPa, and 1.07 MPa, respectively. Notably, the introduction of GGBS at 20%, 30%, and 40% enhanced the Unconfined Compressive Strength (UCS). However, a transition from a 40% to a 50% substitution ratio led to a decline in UCS values, as depicted in Figure 2.

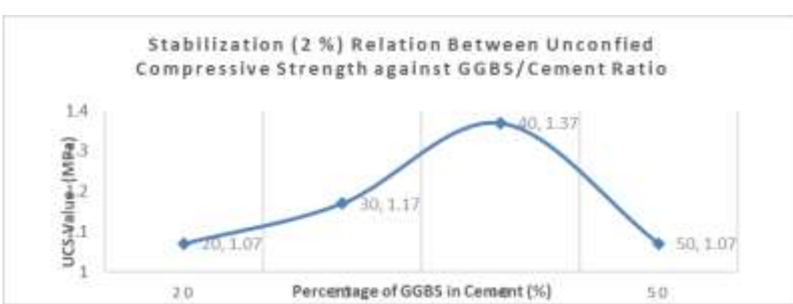

Figure 2: The Stabilization (2 %) relationship between UCS values against the GGBS-Cement mixing proportions

Dama Academic Scholarly Journal of Researchers
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3.2.2 4 % Materials Stabilization

The substitution of cement with Ground Granulated Blast Furnace Slag (GGBS) at replacement rates of 20%, 30%, 40%, and 50% yielded Unconfined Compressive Strength (UCS) values of 1.34 MPa, 1.53 Mpa, 1.67 Mpa, and 1.58 Mpa, respectively. The observed enhancement in UCS correlates with the additive effect of GGBS on the cement content. Notably, the strength improvement is significant as the GGBS content increases from 20% to 40%. However, a reduction in compressive strength occurs at the highest replacement rate, from 40% to 50% GGBS, indicating a limit to the beneficial effects of GGBS on cement strength as illustrated in Figure 3.

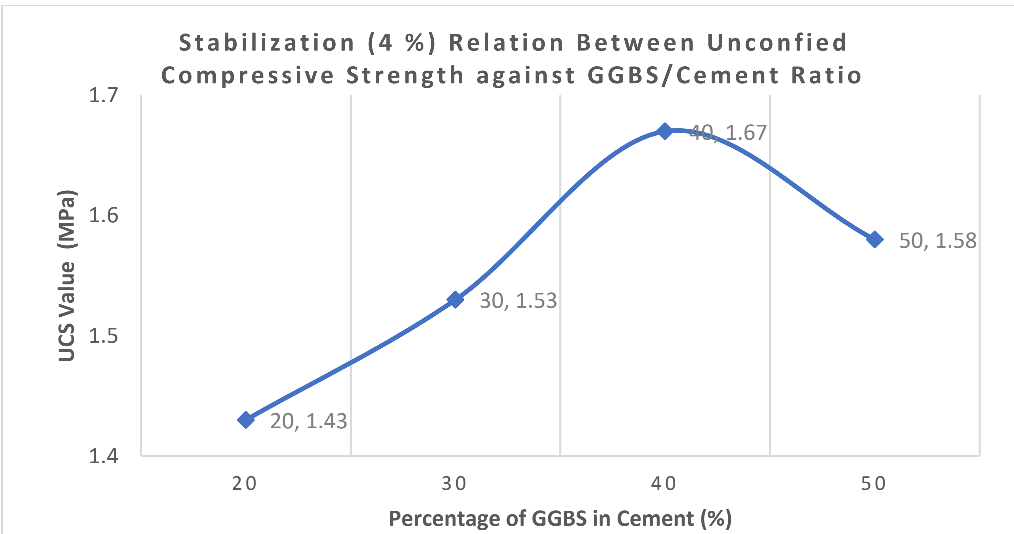

Figure 3: The Stabilization (4 %) relationship between UCS values against the GGBS-Cement mixing proportions

3.2.3 6 % Materials Stabilization

The study examined the effects of substituting cement with Ground Granulated Blast Furnace Slag (GGBS) at replacement rates of 20%, 30%, 40%, and 50% by weight of cement. The resulting unconfined compressive strength (UCS) values recorded were 2.67 Mpa, 2.83 Mpa, 1.9 Mpa, and 1.87 Mpa, respectively. The observed enhancement in UCS at 20% and 30% GGBS replacement signifies the beneficial role of GGBS in the cementitious matrix as illustrated in Figure 4. However, a decline in compressive strength is evident at higher substitution levels of 40% and 50%. This trend indicates that exceeding a GGBS replacement of 30% detrimentally affects the UCS. The findings highlight a critical inflection point between 30% and 40%, where performance begins to deteriorate with increased GGBS. Consequently, further investigations are warranted to analyze the chemical composition of both GGBS and cement to elucidate their interactions and optimize the blending proportions.

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Dama Academic Scholarly Journal of Researchers
DASJR 2025, Volume 10, Issue 06, Page 01-15
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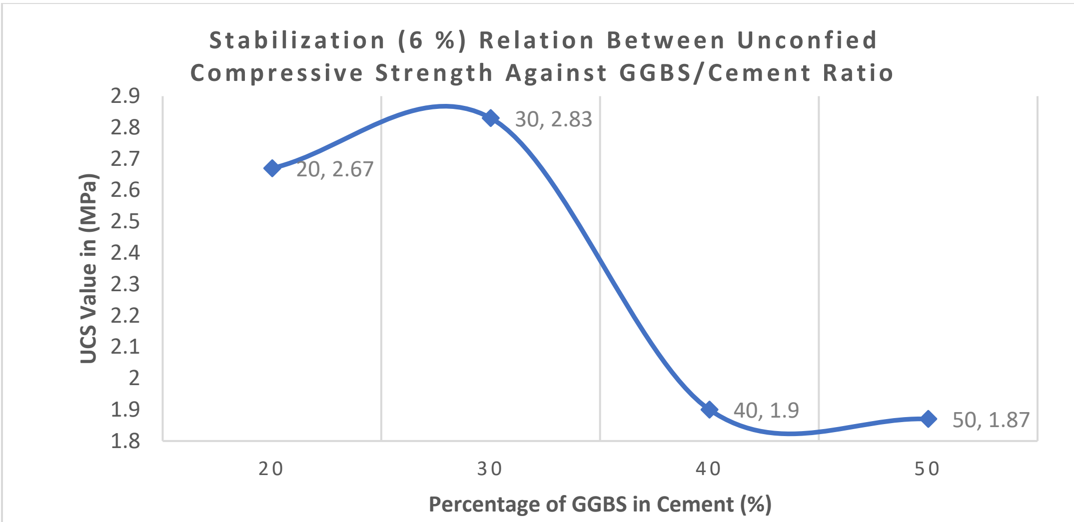

***Figure 4**: The Stabilization (6%) relationship between UCS values against the GGBS-Cement mixing proportions*

3.3. Physical and Chemical Characteristics

GGBS is characterized as a fine to coarse blackish granular material that exhibits properties similar to those of course to fine sand, with a typical specific gravity of 4.81. A series of physical tests were conducted to evaluate the properties of GGBS in comparison with OPC.

Table 2: Physical characteristics of Ordinary Portland Cement and Ground granulated blast furnace Sludge

S/No	Physical characteristics	Ordinary Portland Cement (OPC)	Ground Granulated Blast Furnace Sludge (GGBS)
1	Specific Gravity	3.16	4.81

3.4 Chemical Composition of GGBS and Cement

The UCS test results illustrate a notable trend of both incline and decline in strength as the cement replacement level varies between 40% and 50%, particularly with 2% and 4% stabilization. Additionally, analysis of the UCS at mixing ratios of 30%, 40%, and 50% with 6% stabilization reveals similar patterns (refer to Figures 2, 3, and 4). It is critical to examine the chemical composition of GGBS in conjunction with OPC. A detailed comparison of the elemental composition of GGBS relative to OPC will provide valuable insights for optimal selection of mix ratios for stabilization additives, specifically the GGBS-cement ratio.

3.5 Chemical Composition Test

The chemical composition test involves the precise identification and quantification of specific elements within various mixtures and compounds through analytical techniques applied to collected samples.

3.5.1 Chemical Characteristics of Stabilizing Agents

The chemical characteristics and ingredients of OPC and GGBS were analyzed in the laboratory, with the results presented in Table 3. The comparison of the chemical compounds in

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GGBS to those in OPC has informed our determination of the appropriate mix proportions for the stabilization additives.

Table 3. Tests results for Chemical compounds of Ordinary Portland Cement (OPC) and ground granulated blast furnace sludge (GGBS) in Mass (%)

Chemical Compound names	**Ordinary Portland Cement (OPC) Results in (Mass in %)**	**Ground granulated blast furnace sludge (GGBS) Results in (Mass in %)**	**Test Method**
SiO2	19.97	2.05	Axios XRF machine is a Wavelength Dispersive X-ray Fluorescence (WDXRF) spectrometer designed for high-speed analytical control
Al2O3	4.95	0.42	
Fe2O3	3.26	77.17	
CaO	62.9	2.25	
MgO	0.57	0.58	
SO3	1.99	0.24	
Na2O	0.07	0.01	
K2O	0.41	0.01	
P2O5	0.22	0.03	
LOI	5.3	6.26	

Note: LOI – Loss on Ignition

3.6 Hydration Properties and Characteristics of Stabilized Materials

The relation between GGBS and OPC in stabilizing stages and during hydration process are as follows:

- The hydration process of Ground Granulated Blast Furnace Slag (GGBS) blended with Ordinary Portland Cement (OPC) is greatly influenced by the dissolution characteristics of the materials. Ferric III Oxide (Fe2O3) plays a key role in stabilizing the system, contributing to color, strength, and affecting hydration kinetics and microstructural development. Ferric Oxide constitutes 77.17% of GGBS, compared to only 3.26% in conventional cement, highlighting its significant impact on the performance and characteristics of the blended material during hydration.

- Silica, chemically identified as silicon dioxide (SiO2), plays a crucial role in the development of strength and the setting time of cement. The content of silica in cement is 19.97%, whereas it constitutes only 2.05% by mass in ground granulated blast-furnace slag (GGBS). This significant difference in silica content has implications for the hydration process and setting time of GGBS, which is adversely affected due to its lower concentration of silica.

- Calcium Oxide (CaO), commonly referred to as quicklime, is an essential constituent of cement that significantly influences its mechanical properties and overall performance. It is instrumental in enhancing the strength, regulating the setting time, and improving the durability of cement. In GGBS, CaO constitutes approximately 2.25% of its mass, whereas in conventional cement, it comprises about 62.9% of the total mass.

- Aluminum oxide (Al2O3), commonly referred to as alumina, is a chemical compound resulting from the reaction between aluminum and oxygen. In cement formulations, alumina plays several critical roles, notably enhancing quick-setting properties and

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influencing the overall strength of the material. It is a vital component in the formation of calcium aluminate hydrates, which serve as the primary cement agent. For ordinary Portland cement, the alumina content is approximately 4.95% by mass, whereas GGBS contains a significantly lower alumina percentage of about 0.42% by mass.

Table 3. Comparison of potential effect of Major chemical compounds in Ordinary Portland Cement (OPC) and Ground granulated blast furnace sludge (GGBS)

S/No	Compound name	Another name	Chemical formula	Properties	OPC results in (mass %)	GGBS Results in (mass %)
1	Ferric Oxide	Iron (III) Oxide	Fe2O3	Color and Strength	3.26	77.17
2	Silica	Silicon Dioxide	SiO2	Strength and setting time	19.97	2.05
3	Lime	Calcium Oxide	CaO	Strength, setting time, and durability	62.9	2.25
4	Alumina	Aluminium Oxide	Al2O3	Quick setting and Strength	4.95	0.42

3.7 Hydration Properties of GGBS and Cement

The hydration behavior of Ground Granulated Blast Furnace Slag (GGBS) in combination with Ordinary Portland Cement (OPC) can be understood through the dissolution of its chemical components. Both OPC and GGBS are primarily composed of essential oxides: Calcium, Silica, Alumina, and Magnesium, with their typical proportions specified in Table 3.

Table 4. Comparison of Unconfined Compressive Strength (UCS) Values between Cement Part and Replacement of Cement by GGBS Stabilization

Description	Cement			GGBS (30%) + Cement (70%)		
Stabilization (%)	2%	4%	6%	2%	4%	6%
Strength (MPa)	1.3	2.2	3.1	1.17	1.53	2.84

The comparison of UCS results from cement stabilization versus cement replacement with GGBS has demonstrated remarkable performance, as shown in Table 4. Consequently, the replacement of cement with GGBS at a ratio of 30% has been identified as the optimal solution for stabilization.

3.8 Determination of Infiltration Rates of Materials

Infiltration rate assessments of materials serve to determine the horizontal and vertical penetration of water or moisture through embankment fill layers over a specified duration.

3.8.1 Soil Soaking Rate

The properties and characteristics of materials that enable water absorption at the particle and layer levels are crucial for various applications. Parameters such as permeability, infiltration, and capillarity serve as key examples of the absorptive properties observed in different soil types.

3.8.2 Permeability of Soil by Falling Head Test

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The falling head test for permeability is conducted under conditions where the water head is not constant. The initial and final heads are recorded in relation to the time elapsed (Lu et al., 2024). This test is particularly suitable for granular soils, such as sands and gravels, as exemplified by BS 1377: Part 5: 1990, CML test method 1.15, and ASTM D2435 – 04.

3.8.2.1 Falling-Head Test Method of Permeability

Darcy' law v = ki or q = kiA where
q = flow quantity in a unit time.
v = flow velocity
i = hydraulic gradient = h/L
h = total head difference
L = flow path
A = cross-sectional area of soil mass –

Obtaining a reliable value of permeability (k) through conventional laboratory testing methods poses significant challenges, with variations potentially reaching one order of magnitude. To ascertain accurate results, the permeability of materials was evaluated using the falling head method.

Table 5: Permeability Test results by a Method of for Falling Head Test

Soil description	**British Soil Classification System**		**Free Swell**	**Permeability**
	Description	**Group**	**(%)**	**Coefficient of Permeability**
Symbols				K
Units			%	cm/sec
Black	Very Silty Gravel	GCL	0.09	$8.5X10^{-6}$
Reddish	Very Silty Gravel	GCL	0.15	$4.4X10^{-5}$
Borrow pit 2% Stabilization of Mixed 30% GGBS +70% Cement	Very Silty Gravel	GCL	0.08	$4.2X10^{-6}$

3.8.3 Infiltration Rates

Infiltration refers to the process by which water enters the soil, typically moving horizontally, although it can also move vertically downward (Wu et al., 2020). The rate of infiltration is influenced by several factors, including soil texture (the size of soil particles), surface conditions, and the overall structure of the soil. The minimum infiltration rate for stabilized materials is established according to specific limits outlined in ASTM D 5126, Section 4.1.2.1. Initially, water penetrates the soil surface and subsequently moves through the soil layers via capillary and permeability actions (Ayu et al., 2013). Soil texture significantly impacts the infiltration rate, as highlighted by Mangala et al. (2016). As water displaces air in the soil pores, the infiltration rate gradually decreases until it stabilizes at a steady value. Laboratory observations indicate that the infiltration rate tends to increase over time, leading to higher moisture content within the materials, as shown in Figure 5.

Dama Academic Scholarly Journal of Researchers
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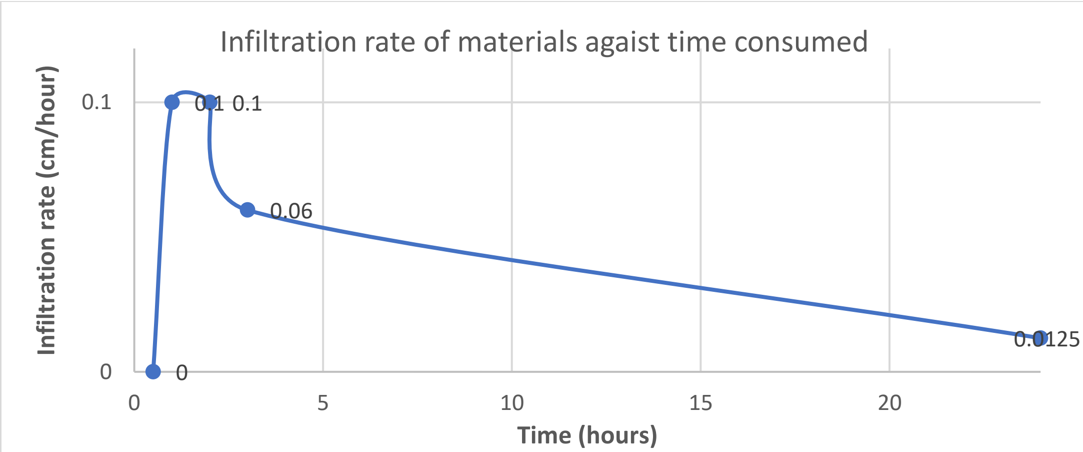

***Figure 5**: Relationship between infiltration rate of materials against time*

3.8.4 Soil Capillarity

Soil capillarity refers to the ability of water to ascend through soil layers against the force of gravity, a phenomenon that occurs in unsaturated soils known as capillary rise. This process involves the movement of pore water from lower to higher elevations, driven by the hydraulic head gradient established across the curved air/water interface within soil pores. Capillarity can be characterized by the absorption of water through narrow capillary pathways created by the soil's texture and stratification (Barghi, 2018).

The capillary properties of stabilized materials are evaluated in accordance with established standards, such as those outlined in BS EN 15801:2009. The number of tests required can vary based on the consistency of the results obtained. Experimental data indicate that the capillary action in stabilized soils correlates with the rate at which water penetrates the material. Over time, there is a notable increase in moisture capillarity, signifying an enhanced upward movement of moisture against gravitational forces, as demonstrated in Figure 5.

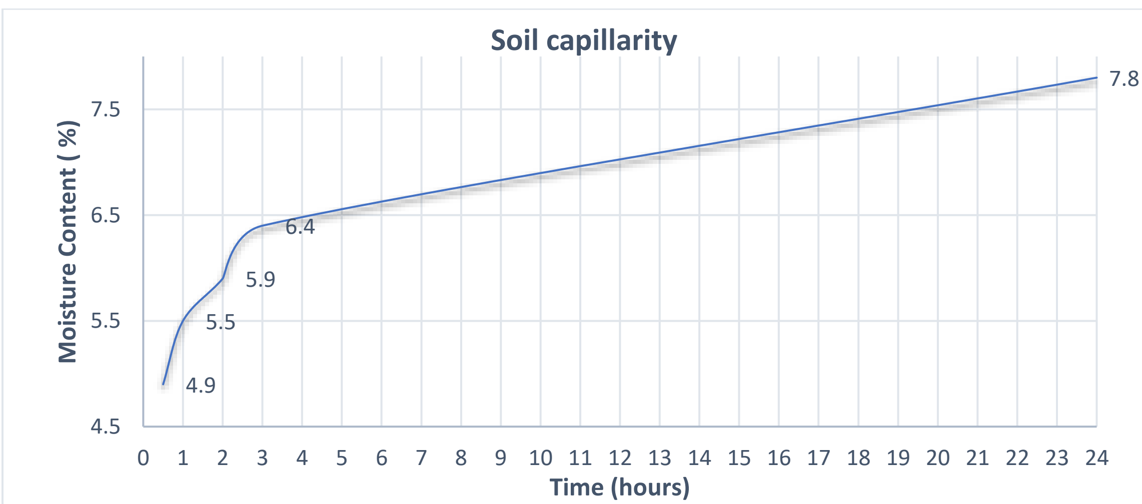

Figure 6: The relationship between gravitational moisture against time.

Dama Academic Scholarly & Scientific Research Society

DASJR 2025, Volume 10, Issue 06, Page 01-15

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3.9. Discussion

The increase in GGBS as a replacement for OPC significantly influences the hydration kinetics, particularly when the substitution level surpasses 40% to 50%. This is evidenced by the data presented in Figures 2 and 3, which reveal that a consistent hydration rate is attained at approximately 6% GGBS content, highlighting a marked decrease in hydration rates for mixes with 30% to 50% replacement, as shown in Figure 4.

Furthermore, substituting up to 50% of OPC with GGBS also results in a reduction in the workability of the cement blend. This decline in workability prompted us to conduct a thorough analysis of the chemical compositions of both OPC and GGBS. The hydration of GGBS is primarily influenced by the presence of Iron (III) oxide (Fe_2O_3), which constitutes a significant 77.17% of its chemical composition, as indicated in Table 3. However, the stabilization process is hindered due to an insufficient quantity of calcium oxide (CaO), the predominant component of Ordinary Portland Cement (OPC). CaO is critical for regulating setting times and enhancing the mechanical properties of cementitious materials.

Analysis demonstrates that the substitution of GGBS for OPC yields optimal results at mixing percentages between 20% and 30%. Specifically, a 30% substitution emerged as the most effective, balancing hydration, workability, and compressive strength. Additionally, the implementation of GGBS at these optimized levels resulted in enhanced capillary action, reduced permeability, and improved moisture resistance in the stabilized material, facilitating better infiltration properties.

4.0 CONCLUSION AND RECOMMENDATIONS

This section outlines the outcomes of the research findings, provides a discussion aimed at clarifying the overall objective, and presents recommendations for further exploration of issues related to problem-solving and the determination of results.

4.1 Conclusion

The study assessed the results from Unconfined Compression Strength (UCS) tests along with an evaluation of soil drainage characteristics, including permeability, infiltration rates, and capillarity of stabilized materials. This examination focuses on enhancing the performance of road materials in waterlogged environments. Data derived from the tests, supported by tables and graphs, demonstrate significant improvements in material quality and properties. The stabilization with Ground Granulated Blast-furnace Slag (GGBS) and cement markedly enhanced the mechanical performance of embankment fill materials, providing improved stability under traffic loads and reducing deformation risk.

A summary of key findings from previous research on GGBS-cement stabilized soils includes the following:

i. The UCS of stabilized materials plays a crucial role in enhancing material properties and overall structural integrity. These materials present a viable alternative for improving performance in road construction, offering significant advantages in durability and load-bearing capacity.

ii. The study investigated the substitution of cement with GGBS at replacement levels of 20%, 30%, 40%, and 50%. This modification was assessed for its effects on strength characteristics, as GGBS is frequently used to mitigate soil infiltration rates by reducing the proportion of permeable materials present.

iii. The incorporation of GGBS-cement in soil stabilization mixes leads to a significant enhancement in strength compared to alternative stabilizing agents. This underscores the necessity of utilizing cement in projects where other additives fall short of meeting the required performance criteria.

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iv. The findings from the UCS tests indicate that a replacement of 30% of cement with Ground Granulated Blast-furnace Slag (GGBS) is the optimal ratio for the stabilization of materials used in road construction.

4.2 Recommendation

i. The stabilized materials will improve the stability of load distribution and water seepage within the road embankment.

ii. The substitution of OPC with GGBS in material stabilization has demonstrated comparable effectiveness in reducing the total infiltration rate within embankment layers. Using GGBS as a partial replacement for OPC not only maintains performance standards but also contributes to environmental sustainability by mitigating the pollution associated with cement production and application.

iii. The use of stabilized materials will lead to a reduction in construction costs associated with cement by serving as a viable substitute in the road construction sector.

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6.0 conflict of interest

The authors declare no conflict of interest.

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8.0 Author Contributions

All authors, Mr. Joseph Francis, Dr. Duwa H.Chengula and Dr. Mgaza S. Muya, were instrumental in the conception and analytical framework of the study. Joseph Francis initiated the manuscript by drafting the first version, while Dr. Duwa H.Chengula and Dr. Mgaza S. Muya provided critical feedback and revisions on subsequent drafts. All Authors comprehensively reviewed and approved the final manuscript prior to submission.

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Availability of data and materials.

10.0 Declarations

10.1 Conflict of interest.

The authors declare that they have no competing interests pertinent to the content of this article.

- Ethical approval: The research adheres to established ethical standards.
- Consent to participate: Authors have provided their consent to engage fully in the review process.
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11.0 Ethical Approval

The study complies with recognized ethical guidelines, and all authors have confirmed their willingness to participate comprehensively in the review process. Furthermore, the authors authorize the publication of this research.

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