Performance of Bitumen Emulsion Mixtures utilized as Gravel Road Base incorporating Lateritic Clay Soil and Calcined Sugarcane Bagasse Ash Filler

David Kakpama Sam
Department of Civil Engineering, Pan African University Institute for Basic Sciences, Technology, and Innovation (PAUSTI), Nairobi, Kenya
samdave0319@gmail.com (corresponding author).

Timothy Nyomboi
Department of Civil Engineering, Pan African University Institute for Basic Sciences, Technology, and Innovation (PAUSTI), Kenya | Kenya Urban Roads Authority (KURA), Nairobi, Kenya
tnyomboi@hotmail.com

Christopher Kanali
Department of Agricultural and Biosystems Engineering, Jomo Kenyatta University of Agriculture Technology (JKUAT), Nairobi, Kenya
ckanali@jkuat.ac.ke

Mung'athia M'tulatia
Department of Civil and Environmental Engineering, Jomo Kenyatta University of Agriculture and Technology (JKUAT), Nairobi, Kenya
mungathiatulatia@jkuat.ac.ke

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ABSTRACT

This study investigates the usage options of Bitumen Emulsion (BE) mixtures composed entirely of Lateritic Clay Soils (LCS) using Calcined Sugarcane Bagasse Ash (CSCBA) as a filler. The LCS was chemically stabilized with 4% CSCBA to meet the plasticity index requirement of a maximum of 7% for BE stabilized materials as set out in the South African Bitumen Association (Sabita) Technical Guideline: Bitumen Stabilized Materials (TG2) and the Kenya Pavement Design Guideline for Low Volume Roads (TG1). The soil was then bound with a medium setting A4-60 anionic bitumen emulsion consisting of 60% base bitumen and 40% water. Varying proportions of BE (11%, 12%, 13%, 14%, and 15%) were mixed with LCS at a constant pre-mix water content of 12.9% to produce Marshall specimens cured for 72 hours at 40°C. The bulk density, dry density, soaked and unsoaked Indirect Tensile Strength (ITS), and Tensile Strength Ratio (TSR) were determined for the cured specimens. The optimum bitumen emulsion content was 13.82%, which gave the highest dry and wet ITS of 183.9 kPa and 132 kPa, respectively, and a TSR of 71%, meeting all specifications when compared to the TG2 and TG1 specifications. The compound also had reduced air voids, which when combined with a higher TSR, demonstrate resistance to moisture damage.

Keywords-bitumen emulsion stabilized materials; cold-mixes; lateritic clay soil; sugarcane bagasse ash; Indirect Tensile Strength (ITS); tensile strength ratio; bulk density

I. INTRODUCTION

In underdeveloped nations, unpaved gravel roads, often constitute between 70% and 90% of the officially recognized road network [1]. Such routes play an important role in the socioeconomic development of the nation, typically facilitating the integration of productive agricultural communities into the broader road network. [2, 3]. However, due to the gravel wearing course's high permeability and the weak strength of the gravel road base, these roads deteriorate at an accelerated rate as a result of the stripping effect of water and traffic attrition [4, 5]. Although laterites are widely distributed across several nations, their characteristics vary depending on the specific location. [6] Consequently, the performance of these materials is variable and unpredictable. The aforementioned variations have resulted in certain shortcomings when used in road construction. The incorporation of stabilizing chemicals into the soil can enhance its workability, thereby addressing several of these deficiencies. A number of previous studies have examined the strength and instability of lateritic clay in construction applications [7-9]. One of the principal techniques for enhancing the characteristics of laterite soils with a high clay content is chemical stabilization [10]. Chemical stabilization with lime and cement remains the most prevalent technique for stabilizing soils [11, 12]. However, studies have revealed that the production of one ton of cement generates one ton of carbon dioxide [13, 14]. Additionally, it has been reported that, when land-use change is excluded, approximately 5% of the global anthropogenic CO_2 emissions can be attributed to the cement industry, due to the energy-intensive nature of the binder production process. It is imperative to identify, develop, and implement an alternative, cost-effective, unconventional, and locally accessible stabilizing material due to the rising costs of cement and the environmental risks associated with its usage [15, 16].

In recent years, bitumen stabilization has also gained considerable recognition as a viable technique. The most frequently deployed bituminous stabilization techniques encompass bitumen emulsions, cutback asphalt, and asphalt cement. The use of Bitumen Emulsion (BE) is becoming increasingly prevalent due to its ability to extend the lifespan of roads, while simultaneously addressing energy constraints and pollution control efforts [17]. Additionally, BE has been demonstrated to enhance surface interactions, reduce atmospheric pollution, and offer economic and energy-saving benefits. Its resilience to the effects of rain during and after use provides waterproofing quality [6]. In contrast to hot-mix asphalt, which reaches its optimal engineering characteristics when batching is complete, cold bitumen advances at a rate determined by the emulsion breaking and subsequent water evaporation. Furthermore, the incorporation of marginal and secondary materials into cold bitumen mixtures, such as lateritic soil and natural gravel, has the potential to result in significant financial and environmental savings. [18]. Bitumen Emulsion Mixtures (BEMs) are frequently simple to prepare and well-suited to medium-to-low traffic scenarios [19], including small-scale projects such as reinstatement works [20]. Nevertheless, there is currently no universally accepted procedure for the design of cold bitumen emulsion mixtures. A number of countries have successfully devised methodologies for the stabilization of Bitumen Emulsion Materials (BESMs) that align with the specific requirements of their local environments. In South Africa, technical guidelines have been established (TG1) [21]. The design of BESMs follows a similar process in various countries. In Kenya, the pavement design guideline for low volume sealed roads (TG1) follows a similar approach to that used in South Africa, while in Germany, the M KRC (FGSV, 2005) and M VB-K (FGSV, 2007) [22] guidelines also adhere to a similar design path. In France, the AIPCR-PIARC C7/8 CFTR–SETRA (2003) [23] guidelines and in the United States, the Asphalt Institute MS 14 [24] also follow a similar approach. These guidelines all adhere to the same design path for figuring out the best gradation, optimum pre-mix water content, optimum bitumen application rate, and best compaction effort for the mixture.

The introduction of fillers, such as lime and cement, is frequently employed as a means of reducing the Plasticity Index (PI) of the soil. In instances where the soil does not meet the requisite grading specifications, mechanical stabilization is used to achieve the desired grading envelope. In the majority of cases, cement and lime have been employed for this purpose. However, authors in [21] recommended an investigation into the potential use of alternative natural fillers to determine their optimal application rate in BESM, with the exception of cement and lime, which have established application rates of 1% and 1.5%, respectively. This highlights the necessity for an investigation into the potential use of materials with analogous properties to those of cement as partial or complete replacements for filler in BESM. In this regard, ASTM C618 stipulates that a material must contain a minimum of 70% of $SiO2+ Al2O3+ Fe2O3$ in order to be classified as a pozzolanic material [25]. Additionally, the silica and sesquioxide content in SCBA collectively constitute 78.59% (59.92% SiO_2, 11.58% Fe_2O_3, and 7.09% Al_2O_3), exceeding the requisite 70% minimum [26, 27]. Given the considerable production of sugarcane bagasse throughout Kenya, with an estimated 1.6 million metric tons generated annually and over 60% discarded in holding sites, there is a pressing need to explore the potential applications of Sugarcane Bagasse Ash (SCBA) in promoting environmental sustainability [28].

II. MATERIALS AND METHODS

A. Materials

The materials used in this study were A4-60 Medium Setting (MS) cold bitumen emulsion, LCS, and CSCBA. The LCS utilized in this research was procured from Juja, Kiambu County, Kenya. The bitumen emulsion was procured from Quality Bitumen Products Ltd., which is situated in Nairobi, off Thika Road. The medium-setting A4-60 anionic bitumen was selected for its stability, high solid content, and its suitability for mixing with natural gravels or crushed aggregates for the stabilization of bases [2, 29, 30]. Moreover, as indicated by authors in [21], the MS emulsion requires approximately six hours to set. The extended setting time allows for sufficient time to cast the samples before the emulsion solidifies. Sukari Industries Ltd. in Western Kenya was the source of the raw SCBA.

B. Methods

a) Bitumen Emulsion Mix Design

This study employed the Asphalt Institute Method (AIM), designated as AI MS 14. [24] In conjunction with the South African technical guideline, TG2 [21], cold bitumen emulsion mixes were developed for use as gravel road bases. The preparation of the LCS to meet the requirements of bitumen emulsion stabilized materials represents a significant undertaking within the design process. The mix design encompassed the assessment of LCS and bitumen quality, as well as the identification of the optimal bitumen and Pre-Mix Water Content (PMWC).

b) CSCBA and Lime Treatment

As indicated in the pavement design guideline for low-volume roads bitumen emulsion stabilized materials must exhibit a PI within the range of 7% to 12%. TG2 had established that the PI be reduced to a maximum of 6% [21], while the Ministry of Transport, Materials and Research Division had suggested a maximum PI of 7% [31]. The lateritic clay soil was subjected to a pre-treatment process involving the application of varying proportions of CSCBA, with a constant lime content of 1%, in order to achieve the aforementioned requirements.

c) Grading of the Mixes

The soil used in this investigation was employed in its natural state, as it met the requisite grading criteria. However, Cooper's formula (1) was employed to verify the lateritic soil gradation of the design mix utilized in this study [20]:

$$\mathrm{P} = \frac{(100-F)(d^{n}-0.075^{n})}{D^{n}-0.075^{n}} + F \qquad (1)$$

The concavity of the gradation line is determined by an exponential value, *n*, *P* denotes the proportion of soil passing sieve size *d* (mm), *D* is the maximum aggregate size (mm), and *F* is the percentage of the filler. The exponential factor n, which generates an aggregate packing of satisfactory quality, was 0.45 [32]. The maximum aggregate size (*D*) was 20 mm, and the filler percentage (*F*) was 4%, corresponding to the selected optimum SCBA content. This resulted in a maximum PI of 6.2, which satisfied the allowable limits for filler content [20, 33]. Figure 1 shows the gradation obtained with the upper and lower recommended specification limits of TG1.

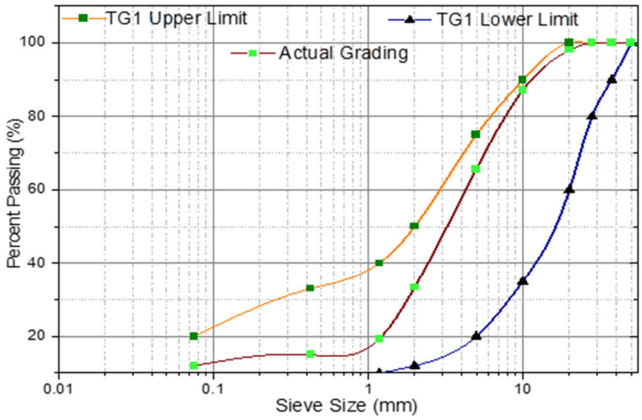

Fig. 1. Gradation for the LCS.

d) Initial Emulsion Content

According to AI MS 14, the Initial Residual Binder Content (IRBC) and Initial Emulsion Content (IEC) were determined empirically using AI MS 14 [24], (2) and (3):

$$P_b = (0.05A + 0.1B + 0.5C)\ X\ 0.7 \qquad (2)$$

where *A* is the percent retained on a 2.0 mm sieve, *B* is the percent passing a 2.0 mm sieve and retained on a 0.075 mm sieve, and *C* is the percent passing a 0.0075 mm sieve. P_b is the original residual binder content by mass of the total mix. The Initial Emulsion Content (IEC) was calculated using (3), which takes into account the base bitumen composition of the emulsion:

$$IEC = \left(\frac{P_b}{X}\right) \times 100 \qquad (3)$$

where P_b is the percentage of IRBC and the bitumen content of the emulsion is *X*. Using (2) and the design gradation in Figure 1, the IREC was determined. With a gradation of 67.4% coarse fraction (retained at 2.0 mm), 21.2% fine fraction (2.0-0.075 mm), and 11.4% passing 0.075 mm (4% filler + 7.44% clean soil all passing 0.075 mm), an IREC of 7.83% was determined, giving an IEC of 13% to the nearest whole number, considering 60% base bitumen in the emulsion.

e) Total Fluid Content Optimization

Bitumen emulsion mixtures were prepared with a pre-mix water content of between 9% and 13% by mass of the soil, with an interval of 1%, while maintaining the emulsion content at a constant IEC. The Optimum Moisture Content (OMC) of the laterite soil, which is 18.1%, was used as a reference for selecting the ranges [6, 20]. The Total Fluid Content (TFC) is defined as the summation of the present water content of the material, the pre-mix water content, and the initial emulsion content. This resulted in a TFC of 24%, 25%, 26%, 27%, and 28%, respectively, considering the present moisture of the material determined to be 1.9%. Subsequently, the Marshall procedure was employed to prepare six cylindrical samples for each total fluid content, resulting in a total of 30 samples for the determination of bulk density and soaked and unsoaked indirect tensile strength (ITS) testing. Subsequently, the wet and dry ITS values were optimized to identify the optimal overall fluid content. The Optimal Pre-Mix Water Content (OPMWC) was determined by subtracting the total fluid content from the initial emulsion content:

$$OPMWC = OTFC - IEC \qquad (4)$$

f) Specimen Curing and Testing

The performance of bitumen emulsion mixtures is significantly affected by the curing process, which includes the curing temperature, curing length, and curing conditions (wet/dry). Furthermore, the parameters for evaluating the performance of the test sample and the curing method have been established in accordance with the stipulations set forth in several guidelines. This study employed the technical guidelines for curing and conditioning test specimens established by the South African Bitumen Association [21]. The specimens were initially cured in their respective molds for a period of four hours. Subsequently, the specimens were extruded and cured for 72 hours at a temperature of 40°C [20, 21]. Following the curing period, the specimens were conditioned prior to testing. Before testing, specimens intended for the wet ITS test were placed in a water bath maintained at 25°C for a period of 24 hours. The specimens for the dry ITS were removed from the oven and one specimen was weighed for each batch over the course of two four-hour cycles. After four hours, the specimens were weighed, and the mass was compared to that obtained in the last two weighing cycles. This was done to ensure that no specimen lost more than 10 g or that a constant mass was achieved [21]. After the respective curing regime and following the testing of the specimens, the tensile strength was calculated using:

$$S_t = \frac{2\,x\,G\,x\,10^6}{\pi\,x\,d\,x\,h} \qquad (5)$$

where G is the maximum load (kN), S_t is the specimen's tensile strength (kPa), d is the diameter (mm), and h is the height (mm).

g) Bitumen Emulsion Content Optimization

The BE content was optimized by maintaining the water content at the OPMWC level, while varying the BE content between 11% and 15% at intervals of 1%. The proportions were selected to ensure that two BE contents were positioned on either side of the IEC of 13%. Three specimens were prepared for each BE, cured for 72 hours at 40°C, and tested for dry ITS, percentage air voids, and dry density. The remaining triplicate samples were subjected to a 24-hour conditioning process in water at 25°C prior to being crushed for the purpose of determining the soaked ITS.

h) Water Sensitivity/Moisture Susceptibility Test

The water sensitivity of an asphalt emulsion residue is a determining factor in whether or not the material may continue to adhere to an aggregate surface when in a wet state. In addition, it signifies the capacity of bitumen mixtures to withstand the effects of water-induced stripping. The process whereby the bitumen binder becomes separated from the mineral aggregate in an asphalt mix is referred to as stripping [21]. The moisture sensitivity of the bitumen emulsion mixes under investigation was determined employing the TSR test, as delineated by AASHTO T-283 [34], and the resulting value was calculated using (6). The tensile strength of the soaked specimen (kPa) is indicated by ITS Soaked and the tensile strength of the dry specimen (kPa) is shown by $\mathrm{ITS_{Dry}}$:

$$TSR = \frac{\mathrm{ITS_{Soaked}}}{\mathrm{ITS_{Dry}}} \qquad (6)$$

i) Volumetric Properties

The bulk density and porosity (or air voids) of the asphalt mixture serve as indicators of its volumetric characteristics. The specimens were weighed and their dimensions were recorded immediately following compaction but prior to testing. Subsequently, the bulk densities were calculated in accordance with the methodology delineated in TG2 [21] and expressed as:

$$BD = \frac{4x10^6 x M_c}{\pi\,x\,d^2\,x\,h} \qquad (7)$$

where BD is the bulk density of the treated specimen, expressed in kilograms per cubic centimeter, M_c is the mass of the specimen, expressed in grams, d is the diameter of the specimen, expressed in millimeters, and h is the height of the specimen, also expressed in millimeters.

The density of a material (mass per unit volume) is determined in relation to the density of water at 73.4°F (23°C) by measuring its bulk specific gravity. The AASHTO T 166 standard [35] saturated surface dry (SSD) water displacement method was employed to ascertain the specific bulk density and, subsequently, the air voids. Equations (8) and (9) were deployed to ascertain the air void content and bulk specific gravity, respectively. The variables G_{mb}, A, B, and C represent the bulk specific gravity, the mass of the sample in air (g), the mass of the SSD sample in air (g), and the mass of the sample in water (g), respectively.

$$G_{mb} = \frac{A}{(B-C)} \qquad (8)$$

$$V_a = \frac{G_s - G_{mb}}{G_s} \times 100 \qquad (9)$$

where V_a is the percentage of air void (%), G_{mb} is the maximum specific density (kg/m^3), and G_s is the theoretical specific gravity (kg/m^3).

III. RESULTS AND DISCUSSION

A. Material Characterization

a) Lateritic Clay Soil

The lateritic clay soil was classified as a low-plasticity clay (CL) according to the Unified Soil Classification System (USCS), which defines CL as gravelly clay. Given that the soil's liquid limit was 46.9%, which exceeds the recommended minimum of 41% set forth by the AASHTO, it was classified as silty, clayey, gravel sand (AASHTO A-2-7). Table I portrays the physico-mechanical properties of the soil. Table II presents a summary of the chemical oxides identified in the lateritic clay soil through X-ray Fluorescence analysis (XRF). It is evident that the soil used in this investigation is predominantly composed of iron, aluminum, and silicon oxides. The lateritic soil under examination is characterized by a high concentration of iron and aluminum oxides, which exert a cementing effect, commonly referred to as 'cladding' [8, 36]. The cementation effect enables the fine particles of the lateritic clay to aggregate. In accordance with the silica–sesquioxide ratio ($SiO_2/Al_2O_3+Fe_2O_3$), authors in [37, 38] postulated that true laterites, lateritic clays, and non-lateritic, typically weathered soil, exhibit ratios of less than 1.33, between 1.33 and 2, and more than 2, respectively. The silica-sesquioxide ratio of the soil used in this investigation was determined at 1.35, indicating that it is a lateritic clay soil, a finding that is consistent with the observations [39].

b) Sugarcane Bagasse Ash

Table II also presents the oxide composition of the raw SCBA, the ground SCBA, and the calcinated SCBA. The SCBA sample was subjected to further grinding using a ball mill and a subsequent calcination at 800°C for 30 minutes utilizing the bogie hearth furnace (BHF-1200-175) in order to maximize the pozzolanic reactivity. Al_2O and SiO_2 are essential for achieving enhanced strength over extended curing periods [40].

c) Bitumen Emulsion

In accordance with the specifications set forth in BS EN 1428, the quantity of bitumen present in the emulsion was determined through the process of evaporation [41]. The particle charge and residue on the 500 µm BS sieve were determined in accordance with the specifications set forth in BS EN 1430 [42] and BS EN 1429 [43], respectively. Table III provides a summary of the properties of the A4-60 anionic bitumen emulsion.

TABLE I. PHYSICO- MECHANICAL PROPERTIES OF LATERITIC SOIL

Properties	**Result**	**Test standard (BS/ASTM)**
USCS Classification	CL	-
AASHTO Classification	A-2-7	-
Specific gravity (g/cm3)	2.66	-
Gravel fraction (retained on 2mm) %	67.4	BS1377
Fine fraction (2mm-0.075 mm) (%)	25.16	-
Passing 0.075mm (%)	7.44	-
Liquid Limit (%)	46.9	BS 1377 Part 2
Plastic Limit (%)	25.7	BS 1377 Part 2
Plasticity Index (%)	21.2	BS 1377 Part 2
Free Swell Index (%)	15.38	
Maximum Dry Density (g/cm3)	1.76	BS1377
Optimum Moisture Content (%)	18.1	BS1377
California Bearing Ratio (%)	18.28	BS 1377 - 9
Average Unconfined Compressive Strength (Mpa)	0.23	ASTM D2166
Grading Modulus	2.4	-

TABLE II. CHEMICAL COMPOSITIONS OF LCS AND SCBA

Oxides	**Composition**			
	LCS	Raw SCBA	CSCBA	ASTM Spec Class *F* ash
SiO_2	50.743	55.529	85.142	-
Al_2O	12.998	6.775	3.833	-
Fe_2O	24.703	8.705	5.229	-
TiO_2	3.226	-	-	-
CaO	4.057	7.840	1.671	10% Max
SO_3	0.136	0.907	0.006	-
K_2O	1.777	19.645	2.544	-
MnO	1.027	0.517	0.291	-
SiO_2+Al2O3 + Fe_2O_3		71.009	94.204	70% Min
LOI	-	6.37	1.72	6% Max

TABLE III. PROPERTIES OF THE BITUMEN EMULSION

Property	**BS Designation**	**Test Result**	**BS Specification**
Residue on 500 micro meter BS sieve (% m/m)	BS EN 1429	0.07	0.1 max
Particle charge (litmus paper)	BS EN 1430	-ve	-
Viscosity [Degrees Engler (°E) at 20°C]		7.5	8 Max
Binder Content [% (m/m)]	BS EN 1428	60	56 Min

B. CSCBA and Lime Pre-Treatment

Given the elevated PI of the neat soil (21.2%), the neat LCS was treated with varying CSCBA contents, ranging from 1.5% to 7.5% in 1.5% increments. It was observed that although the CSCBA significantly reduced the PI to 10.8% at a 4.5% CSCBA content by mass of LS, the PI requirement of BESM (maximum 7), as evidenced in Figure 2, could not be achieved. In accordance with the recommendations set in the South African Bitumen Association Technical Guideline (SABITA TG2) [21], the technical design guideline for low-volume sealed roads (TG1), and the materials and research division of the Ministry of Transport and Infrastructure in Kenya [31], 1% of lime was incorporated into each proportion of the SCBA to serve as an active filler. Moreover, the sample was permitted to cure for a period of 12 hours prior to conducting the Atterberg limits test, ensuring complete hydration. The aforementioned treatment resulted in a PI of 5.2 at a CSCBA content of 4.5% in conjunction with 1% lime. Upon plotting the CSCBA Lime contents against the respective PI, it was observed that a PI of 6.2 was yielded by 4% SCBA, which was selected as the optimum rather than the 4.5%. This is due to the fact that the maximum filler requirement for cold emulsion mixtures, whether corresponding to partial or full replacement, is 4% [21]. The addition of more filler will result in a greater retention of water, which will consequently prolong the curing process [21].

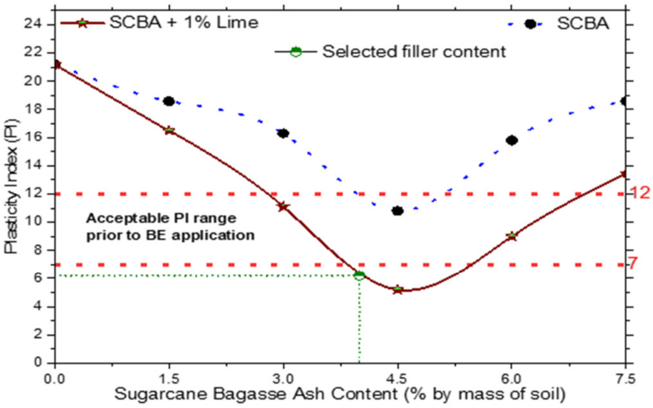

Fig. 2. Plasticity index ilots for CSCBA and CSCBA+ 1% constant lime.

C. Optimum Total Fluid Content (OTFC)

In optimizing the TFC, the ITS in both dry and wet conditions, as well as the bulk specific gravity, were taken into account. The ITS was employed to assess the augmentation of treated gravel road bases' strength under both dry and wet conditions. The effects of altering the moisture content while maintaining the bitumen emulsion concentration at the initial emulsion concentration of 13% were also examined. Similarly, variations in the moisture content were observed to affect the specific bulk density of the mixtures, as shown in Figure 3. The maximum values for bulk specific gravity (2.145 kg/cm³), mean bulk density (1.868 kg/cm³), and wet ITS (123.88 kPa and dry ITS (198.72 kPa) for the lateritic soil mixture were recorded at 25.69%, 25.75%, 26.04%, and 26.40% TFC, respectively, as presented in Figures 3-5. In order to accommodate all four conditions, the TFCs were averaged to obtain an OTFC of 25.97%. Subsequently, the optimal pre-water content was determined to be 12.97% in accordance with (4). It is important to note that the current moisture content of the dry material must always be determined and subtracted from the OPMWC in order to ascertain the quantity of water to be added. It is a common assumption that the OTFC is approximately equivalent to the OMC. However, a discrepancy was observed between the OMC and OTFC values when they were compared in this study. The OTFC value of 26.1% was found to be 44% higher than the OMC value of 18.1%. The aforementioned observation has also been documented by other researchers [21, 44] although their studies employed reclaimed asphalt and virgin aggregates, respectively. It is thus evident that, irrespective of the material undergoing stabilization by bitumen emulsion, the OTFC will invariably exceed the OMC.

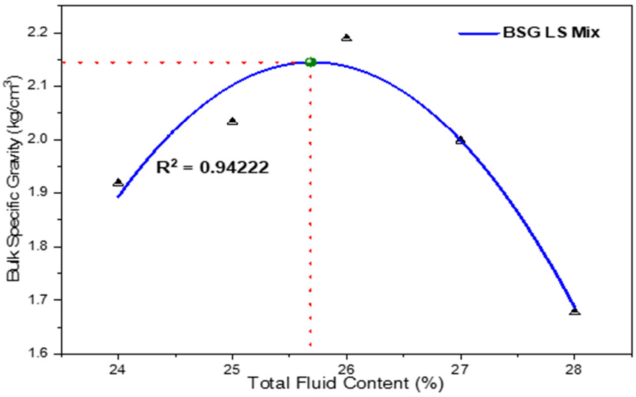

Fig. 3. Bulk specific gravity of lateritic soil at optimum TFC.

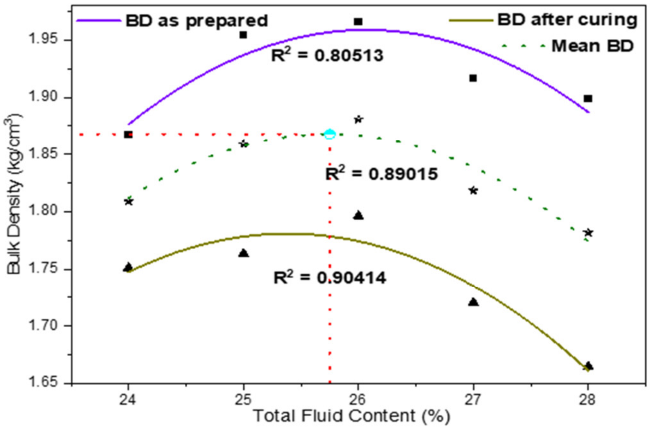

Fig. 4. Bulk density for LSM (as prepared, after curing and mean) at optimum TFC.

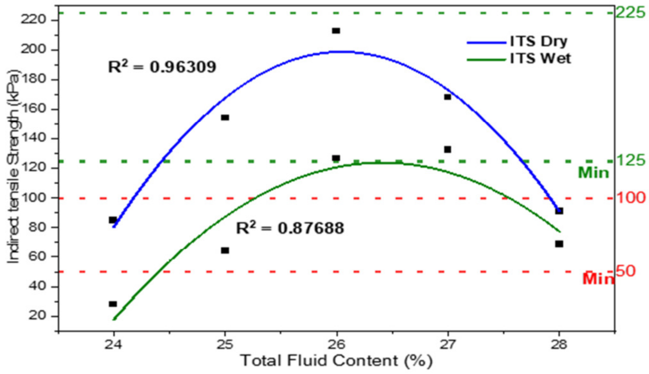

Fig. 5. Dry and wet ITS of lateritic soil at optimum TFC.

D. *Optimum Bitumen Emulsion Content*

Figures 6-8 show the peak values of the bulk specific gravity (2.174 kg/cm³), mean bulk density (1.8904 kg/cm³), dry indirect tensile strength (183.9 kPa), and soaked indirect tensile strength (132.0 kPa) obtained at varying bitumen emulsion contents.

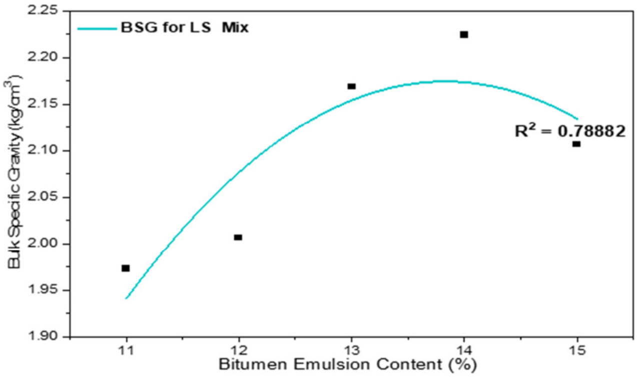

Fig. 6. Bulk specific gravity of the lateritic soil at optimum bitumen emulsion content.

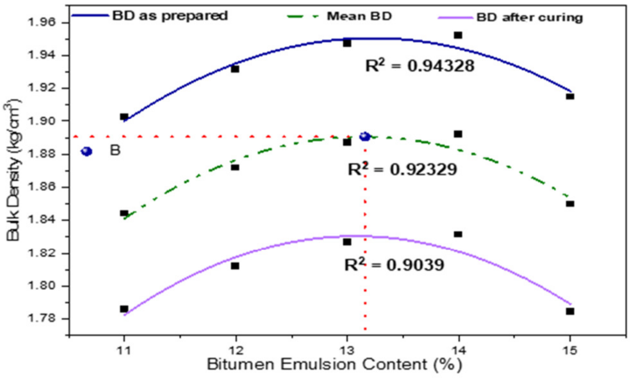

Fig. 7. Bulk density of the lateritic soil at optimum bitumen emulsion content.

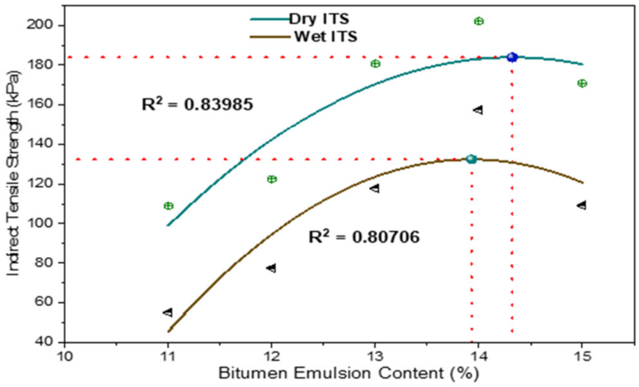

Fig. 8. Indirect tensile strengths of the lateritic soil at optimum bitumen emulsion content.

These values were obtained at 13.878%, 13.158%, 14.323%, and 13.931% bitumen emulsion contents, respectively, with an average of 13.82% representing the optimum bitumen emulsion content. In both dry and wet situations, the indirect tensile strength values were found to exceed the minimum values of 125 kPa and 50 kPa, respectively, for treated material used in the base construction of a T5-4 traffic class (with an ESA of less than 25,000) and a T5-3 traffic class (with an ESA of between 25,000 and 100,000), as specified by TG1 [45] and in accordance with other findings for low-volume road bases. This indicates that the mixture is suitable for use in both wet and dry climatic conditions.

E. Volumetric Properties

Figures 7 and 9 display the plots of bitumen emulsion content versus average bulk density and air voids, respectively. Considering the optimum bitumen emulsion content of 13.82% obtained, the lateritic soil mixture achieved an air void of 11.97%. The air void value at the optimum bitumen emulsion content is within the range of air voids typically seen in the field after 1 to 2 years of operation, 10% to 15% [21]. The air void (11.97%) obtained in this study also meets the target air void of 12% ± 1% reported by other researchers [46]. It was also observed that the bulk density was higher when the bitumen content was varied than when the water content was varied. The reason for this may be that during the mixing process, the bitumen content has a greater influence on the stiffness of cold bitumen mixes than the water content [47]. A higher rate of compaction is possible due to the lubricating effect of the asphalt emulsion coating on the aggregates, which makes the mix more workable.

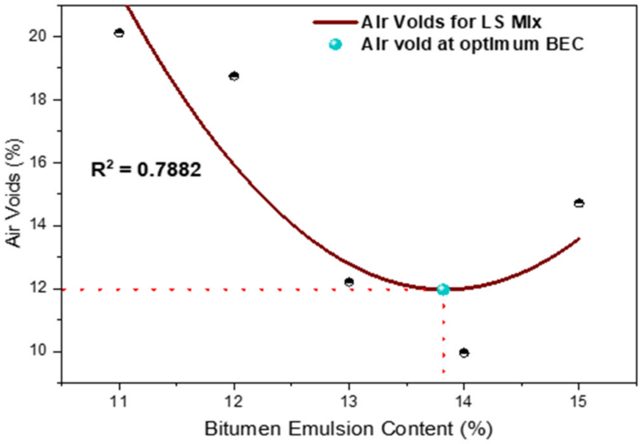

Fig. 9. Air voids of the lateritic soil mix at optimum bitumen emulsion content.

F. Water Sensitivity/Moisture Susceptibility of the Mixtures

It is frequently observed that traditional gravel roads exhibit a considerable loss of gravel material as a result of attrition and the stripping action of water. The binding effect and waterproofing quality of the BE will serve to reduce the loss of gravel material due to the attrition effects of traffic and the stripping effects of water. The durability of the mixture to the stripping action of water was determined through the use of a TSR test. The dry ITS and wet ITS were prepared with varying proportions of bitumen emulsion content, based on the aforementioned mix design procedure and at a constant OTFC. The resulting mixtures are detailed in Figure 8. For each emulsion content, triplicate samples were prepared for both dry and wet ITS and conditioned in accordance with the procedures outlined in the previous sections. The ITS for both dry and wet conditions demonstrated an increase with an increase in the bitumen emulsion content, reaching a maximum at 15% BE content. The observed increase in the ITS values suggests the formation of a robust bond between the asphalt emulsion and the lateritic soil. This phenomenon can be attributed to the mechanical interlock resulting from the enhanced absorption of the binder, rather than surface charge compatibility, as reported by other studies [20]. Following conditioning, the bitumen emulsion mixture (BEM) prepared with 13.82% BE content at a constant OPMWC of 13.105% exhibited enhanced resistance to moisture damage, as evidenced by a higher value of wet ITS (132 kPa) and TSR (71%) compared to the other proportions. The TSR obtained at the optimum BE content is consistent with the recommendations of the Kenya TG1 and South Africa TG2 guidelines for BESM, indicating that the material can be used for application as a road base material, as illustrated in Figure 10.

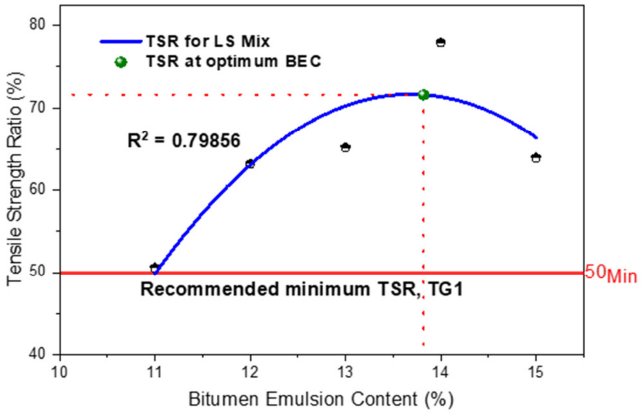

Fig. 10. Tensile strength ratio of the lateritic soil mix at optimum bitumen emulsion content.

IV. CONCLUSIONS AND RECOMMENDATIONS

The objective of this study was to evaluate the potential of bitumen emulsion mixtures incorporating lateritic clay soil and calcined Sugarcane Bagasse Ash (SCBA) as a stabilizing agent. To this end, a mix design was developed. In contrast to previous studies that employed cement, lime, or uncalcined SCBA, this study used calcined SCBA. The mechanical and volumetric properties, including indirect tensile strength, dry density, bulk specific gravity, and tensile strength ratio, were assessed. Additionally, the impact of calcined SCBA on soil plasticity and its potential to supplant conventional cement as a filler were investigated. The primary findings from the study, based on the specific materials used, are:

- The pre-treatment of sugarcane bagasse ash through grinding (using a ball mill) and re-calcination at 800°C for 30 minutes resulted in a significant increase in its amorphous silica content, from 55.5% to 85%. This process rendered the material more reactive than the raw form.

- The incorporation of lateritic soil into the bitumen emulsion mixture design resulted in a reduction in porosity and an increase in dry density, which led to a decrease in the moisture susceptibility of the mixture. This was reflected in an increase in the Tensile Strength Ratio (TSR) to 71%. This was accomplished through the effective optimization of the pre-mix water content and bitumen emulsion content.
- The findings of this research indicate that bitumen emulsion incorporating lateritic clay soil can be used as a material for the base construction of a T5-4 traffic class (with an ESA of less than 25,000) and a T5-3 traffic class (with an ESA of between 25,000 and 100,000), as outlined in TG1.
- The bulk density exhibited an 1.2% increase when the bitumen content was varied, as opposed to when the water content was varied. These findings indicate that the bitumen content exerts a more pronounced influence on the stiffness of cold bitumen mixes than the water component.
- When the Optimum Moisture Content (OMC) and the Optimum Total Fluid Content (OTFC) were compared, it was observed that the OTFC was 40% higher than the OMC.

As far as is known, no previous study has investigated the use of lateritic clay soil as bitumen emulsion stabilized material using calcined SCBA as a filler. The research achieves optimal bitumen content with high tensile strength and moisture resistance, promoting eco-friendly and cost-effective pavement solutions for low volume roads.

Given that there is no suitable technique for drying and burning bagasse ash to produce entirely burned bagasse that can provide a sugarcane bagasse ash with high pozzolanic reactivity, it is recommended that SCBA be pre-treated before being used as a filler material and a further study be done on the various SCBA pre-treatment. In chemically stabilizing the lateritic soil to achieve the plasticity index requirement for bitumen emulsion materials, it is recommended that 1% of lime be added to the varying proportions of CSCBA and allowed to cure for 12 hours to initiate pozzolanic reaction. To ensure the best possible aggregate covering and prevent emulsion breakdown, further studies on mixing phases and time are recommended.

DATA AVAILABILITY

The data presented in this study are available from the corresponding author upon request.

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