

(RESEARCH ARTICLE)



BITUMEN STABILIZED LATERITIC SOIL REINFORCED WITH GRANITE POWDER AND RECYCLED STEEL FIBER AS BASE MATERIAL IN ROAD CONSTRUCTION

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ABSTRACT

This study investigates the geotechnical suitability of laterite soil from Ogbogoro, Obio-Akpor Local Government Area, Rivers State, Nigeria, stabilized with bitumen, granite powder, and recycled steel fiber (RSF) from vulcanized tyres, for flexible pavement use. The natural laterite was classified as a high-plasticity soil (plasticity index 26.91%), confirming the need for stabilization. A compaction test with bitumen contents of 0-10% was used to select an optimum binder content (OBC) of 6%, giving a favorable combination of maximum dry density and reduced optimum moisture content. Specimens prepared at the OBC were reinforced with RSF (0-3%, 0.5% intervals) and granite dust (0-30%, 5% intervals) and evaluated through water absorption, unsoaked and soaked California Bearing Ratio (CBR), and indirect tensile strength (ITS) tests. Water absorption decreased progressively with RSF content up to 2%, beyond which it rose slightly due to fiber clustering. Both unsoaked and soaked CBR improved substantially with RSF and granite dust addition, peaking at 2% RSF with 20% granite dust, an improvement of about three times the plain bitumen-stabilized soil. Indirect tensile strength followed a similar trend, rising consistently with RSF up to 2% before declining at higher fiber dosages. The results indicate that a blend of 2% RSF and 20% granite dust with bitumen-stabilized laterite gives the best composite strength and moisture-durability performance, and that combining these waste-derived materials offers a technically sound, environmentally beneficial option for subgrade and sub-base construction in tropical lateritic terrains.

Keywords: Laterite Soil; Bitumen Stabilization; Granite Powder; Recycled Steel Fiber; California Bearing Ratio; Indirect Tensile Strength.

1 INTRODUCTION

Laterite soils cover extensive parts of the tropics and are the most widely available natural material for road construction in Nigeria and much of sub-Saharan Africa, owing to their local abundance and relatively low haulage cost [1]. However, many lateritic deposits, particularly those with high fines content and elevated plasticity, do not meet the

strength and durability requirements specified for subgrade, sub-base, or base course materials, and typically require stabilization before use in flexible pavement construction [1], [2].

Several stabilization techniques have been investigated for improving the engineering behaviour of lateritic soils, including the use of cement, lime, fly ash, and bituminous binders. Bitumen and bitumen emulsion stabilization have received particular attention because they improve strength while reducing the moisture sensitivity that limits the performance of untreated fine-grained lateritic soils [2], [3]. Bitumen coats and binds soil particles, lowers water absorption, and increases resistance to softening under wet conditions, making it attractive for subgrade and sub-base improvement in high-rainfall tropical environments such as the Niger Delta region of Nigeria.

In parallel, growing environmental and economic pressure to manage industrial and post-consumer waste has motivated research into the use of by-product materials as soil additives. Granite dust, a fine waste generated in large quantities during the crushing and dressing of granite aggregate at quarries, has been shown to improve the compaction, shear strength, and bearing capacity of clayey and lateritic soils when used as a partial filler or additive, while simultaneously addressing a waste-disposal problem associated with quarrying operations [4], [5]. Similarly, recycled steel fiber (RSF) recovered from end-of-life vulcanized tyres has demonstrated considerable promise as a reinforcing inclusion in cementitious and geotechnical composites, improving tensile capacity, crack resistance, and post-peak ductility while providing a sustainable outlet for scrap tyre waste that would otherwise present a disposal and fire-hazard problem [6], [7], [8].

Despite the individual successes of granite powder and RSF as separate stabilizing or reinforcing agents, and the established performance of bitumen as a soil binder, there is limited published work that evaluates the combined effect of these three materials, waste-derived filler, waste-derived fiber, and bituminous binder, on the mechanical behaviour of Niger Delta lateritic soils. This represents a gap in the literature, particularly given the dual benefit such a combination could offer: improved pavement material performance and productive reuse of two abundant waste streams (quarry dust and scrap tyres) generated within the same urban corridor.

The objective of this study is therefore to experimentally investigate the physical and mechanical properties of laterite soil sourced from Ogbogoro, Port Harcourt, when stabilized with bitumen at an optimum binder content and reinforced with varying proportions of RSF and granite dust. Specifically, the study evaluates the effect of RSF content (0-3%) and granite powder content (0-30%) on water absorption, unsoaked and soaked CBR, and indirect tensile strength of the stabilized laterite, with a view to identifying the combination that offers the best strength and durability performance for use as a flexible pavement material.

2 MATERIALS AND METHODS

2.1 Materials

Four principal materials were used in this study: laterite soil, bitumen, granite powder, and recycled steel fiber (RSF). Laterite soil was sourced from a borrow pit in Ogbogoro community, Obio-Akpor Local Government Area, Rivers State, Nigeria. Bitumen, used as the primary binder, was obtained from a dealer at Mile 3 Market, Port Harcourt. Granite powder, a quarry waste by-product, was collected from granite dealers along the building materials line at Mile 3, Port Harcourt. Recycled steel fiber, with an aspect ratio of 1:40, was recovered from vulcanized tyres and sourced from the same building materials line.

2.2 Methods

Physical property tests were carried out in accordance with relevant British Standard (BS 1377), ASTM, and AASHTO procedures. Laterite soil was tested for moisture content, particle size distribution (sieve analysis), Atterberg limits, specific gravity, standard compaction, and water absorption. Recycled steel fiber was tested for specific gravity, bitumen was tested for penetration, softening point, specific gravity, and viscosity, and granite powder was tested for specific gravity and water absorption. Composite specimens prepared from the stabilized soil mixtures were tested for water absorption, California Bearing Ratio (CBR) under both unsoaked and soaked conditions, and indirect tensile strength (ITS).

2.2.1 Mix Design and Determination of Optimum Binder Content

A standard Proctor compaction test was first performed on the laterite soil with bitumen contents of 0%, 2%, 4%, 6%, 8%, and 10% by dry weight of soil, to establish the relationship between binder content, maximum dry density (MDD), and optimum moisture content (OMC), and thereby determine a practical optimum binder content (OBC).

2.2.2 Specimen Preparation and Test Matrix

Using the adopted OBC of bitumen, specimens were then prepared incorporating recycled steel fiber at seven contents (0%, 0.5%, 1.0%, 1.5%, 2.0%, 2.5%, and 3.0% by dry weight of soil) and granite dust at seven contents (0%, 5%, 10%, 15%, 20%, 25%, and 30% by dry weight of soil), giving a full factorial matrix of 49 mixture combinations. Each combination was compacted, cured, and subjected to water absorption, unsoaked CBR, soaked CBR, and indirect tensile strength testing following standard procedures. Data were analysed by plotting grouped graphs of each measured property against RSF content at each granite powder content, allowing the combined effect of fiber reinforcement and mineral filler addition to be visualized and compared.

3 RESULTS AND DISCUSSION

3.1 Physical Properties of Materials

Table I presents the physical properties of the laterite soil, granite dust, bitumen, and recycled steel fiber used in this study. The laterite soil recorded a liquid limit of 42.0%, a plastic limit of 15.09%, and a plasticity index of 26.91%, with 19.80% of material passing sieve No. 200. These values indicate a fine-grained soil of intermediate-to-high plasticity that, on its own, would generally require stabilization before use as a pavement material. The specific gravity of the laterite (2.71) falls within the typical range reported for tropical lateritic soils and it is classified as A-7-6 soil according to AASHTO soil classification. The bitumen exhibited a penetration value of 66.2 (in tenths of a millimetre), a softening point of 51.3°C, and a viscosity of 62 seconds, properties broadly consistent with a medium-penetration-grade bitumen commonly used for road stabilization work. Granite powder and RSF recorded specific gravities of 2.56 and 7.8 respectively, the high value for RSF reflecting its metallic composition.

Table 1: Physical Properties of Laterite, Granite Powder, Bitumen, and Recycled Steel Fiber

Property	Laterite	Granite powder	Bitumen	RSF
Moisture content (%)	13.4	-	-	-
Passing sieve No. 200 (%)	19.80	-	-	-
Liquid limit (%)	42.0	-	-	-
Plastic limit (%)	15.09	-	-	-
Plasticity index (%)	26.91	-	-	-
MDD (kg/m ³)	2020	-	-	-
OMC (%)	16.0	-	-	-
Specific gravity	2.71	2.56	1.04	7.8
Penetration (0.1 mm)	-	-	66.20	-
Softening point (°C)	-	-	51.3	-
Viscosity (sec.)	-	-	62	-

3.2 Determination of Optimum Binder Content

Table 2: Compaction Test Results for Determination of Optimum Binder Content

Bitumen content (%)	MDD (kg/m ³)	OMC (%)
0	2020	16.0
2	1860	13.8
4	1880	13.2
6	2020	11.6
8	2040	10.8
10	2060	10.0

Table 2 present the results of the compaction test used to establish the OBC. Maximum dry density fell from 2020 kg/m³ at 0% bitumen to 1860 kg/m³ at 2%, before increasing steadily to 2060 kg/m³ at 10% bitumen, while OMC decreased monotonically from 16.0% to 10.0% over the same range. The initial reduction in MDD is attributed to the lubricating and lower-density nature of bitumen relative to soil solids at low binder contents, while the subsequent recovery reflects improved particle packing as bitumen progressively coats and binds the soil fines. The 6% bitumen content was selected as the OBC for the reinforced mixtures, balancing density recovery, moisture reduction, and binder economy.

3.3 Water Absorption

Figure 2 and Table 2 present the water absorption results. Water absorption of the plain bitumen-stabilized soil (0% RSF, 0% granite powder) was 3.10%. Absorption decreased consistently with increasing RSF content up to 2.0% RSF, reaching a minimum of 2.00% at 2.0% RSF combined with 20% granite powder (GP), before rising again at 2.5% and 3.0% RSF. The initial reduction is attributed to the fibers bridging pore spaces and restricting the ingress of water into the compacted matrix, while the increase beyond 2.0% RSF suggests that excessive fiber content promotes localized fiber clustering and increased void formation, which in turn creates additional pathways for water absorption. A similar pattern is observed across granite powder content, with absorption generally lowest around 20% granite powder and increasing again at 25-30%, indicating an optimum filler content beyond which excess fines increase the void ratio of the compacted mixture.

Table 3: Water Absorption Test Result

RSF (%)	Water Absorption (%)						
	0% GP	5% GP	10% GP	15% GP	20% GP	25% GP	30% GP
0	3.1	3.01	2.92	2.85	2.58	2.67	2.78
0.5	2.82	2.77	2.73	2.68	2.52	2.6	2.7
1.0	2.64	2.6	2.55	2.49	2.45	2.54	2.63
1.5	2.43	2.37	2.32	2.24	2.17	2.31	2.48
2.0	2.22	2.16	2.1	2.05	2	2.24	2.39
2.5	2.42	2.35	2.23	2.17	2.11	2.36	2.45
3.0	2.49	2.42	2.3	2.25	2.2	2.45	2.5

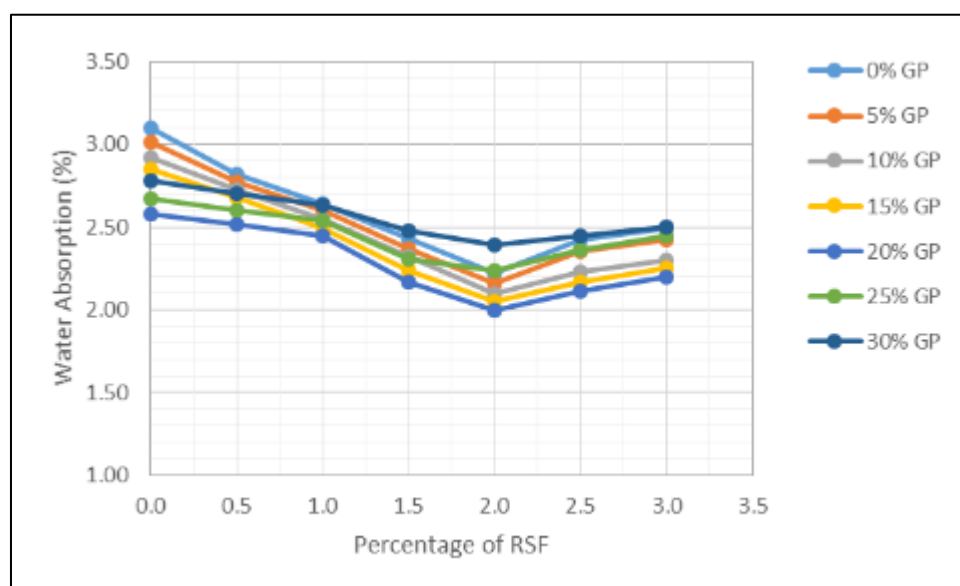


Figure 1: Water absorption against RSF content at varying granite dust (GP) content.

3.4 California Bearing Ratio (CBR) Result

Figure. 2 and 3 and Tables 4 and 5 present the unsoaked and soaked CBR results respectively. Both unsoaked and soaked CBR increased substantially with RSF content up to 2.0%, before declining at 2.5% and 3.0% RSF, mirroring the water

absorption trend. The unsoaked CBR of the plain stabilized soil (22.05%) increased to a peak of 66.52% at 2.0% RSF and 20% granite powder, an improvement of approximately three-fold. Soaked CBR followed an almost identical trend, peaking at 65.25% under the same mix proportions. The ratio of soaked to unsoaked CBR at this optimum mix was approximately 98%, compared with about 97% for the plain stabilized soil, indicating that the RSF-granite powder (GP) combination did not compromise, and in fact marginally improved, the moisture-durability performance of the stabilized soil. The strength gain with RSF addition is consistent with the fiber-bridging and crack-arresting mechanisms widely reported for tyre-derived steel fiber reinforcement of geotechnical and cementitious composites [6], [7], while the parallel improvement with granite dust up to 20% reflects the pore-filling and densification effect of the fine mineral filler, consistent with observations reported for granite- and rock-dust-stabilized clayey soils [4], [5]. The decline in strength beyond the optimum RSF and GP contents suggests that excess fiber and filler beyond these levels disrupt particle packing and reduce the effectiveness of the bituminous binder in coating and bonding the soil-additive matrix.

Table 4: CBR Result (Unsoaked)

RSF (%)	CBR						
	0% GP	5% GP	10% GP	15% GP	20% GP	25% GP	30% GP
0	22.05	23.18	23.90	24.70	25.2	23.40	22.50
0.5	28.83	30.24	33.15	35.56	36.90	34.23	33.73
1.0	40.55	43.54	46.13	49.19	50.10	48.67	47.84
1.5	42.29	45.14	48.66	51.25	52.14	50.7	49.93
2.0	55.06	58.14	62.33	65.31	66.52	64.87	63.77
2.5	50.26	53.35	57.43	61.01	62.44	59.47	58.26
3.0	44.86	48.00	51.36	55.72	57.7	53.18	52.41

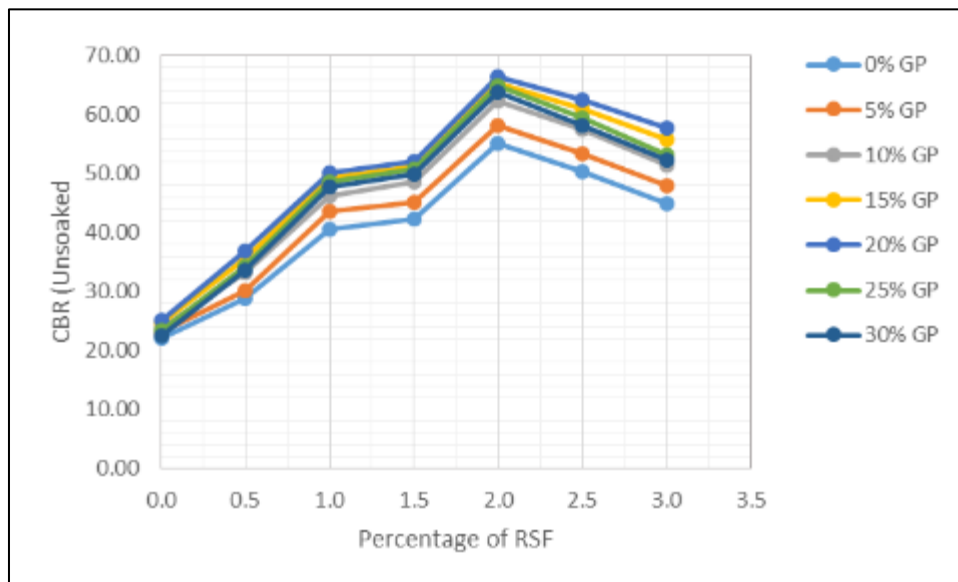
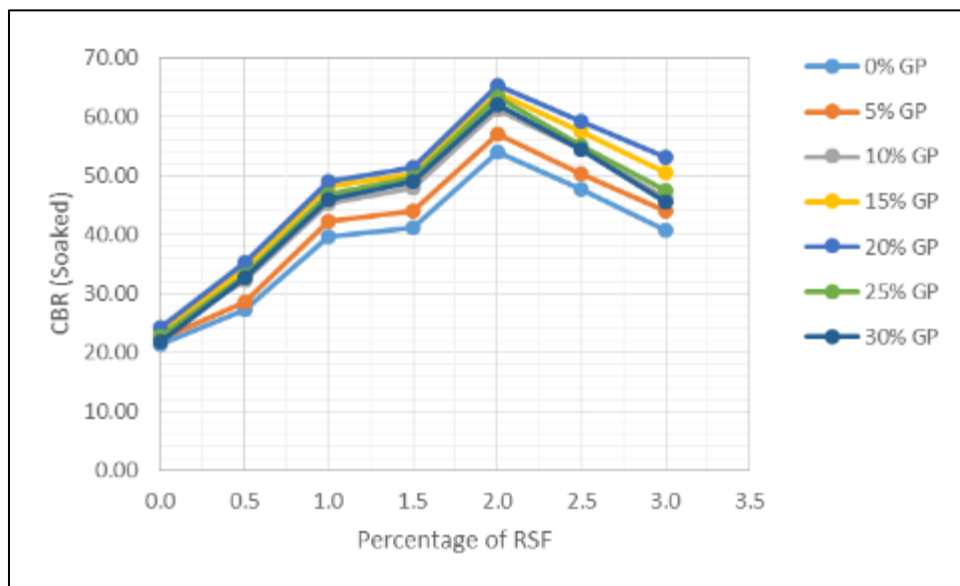


Figure 2: Unsoaked CBR against RSF percentage content at varying GP content.

Table 5: CBR Result (Soaked)

RSF (%)	CBR						
	0% GP	5% GP	10% GP	15% GP	20% GP	25% GP	30% GP
0	21.38	22.21	22.93	23.54	24.09	22.65	21.77
0.5	27.17	28.50	32.24	34.28	35.16	33.01	32.68
1.0	39.52	42.27	45.30	48.00	49.00	46.68	45.91
1.5	41.23	44.04	47.78	50.26	51.25	49.6	48.89
2.0	54.01	57.04	61.17	63.93	65.25	63.38	62.06
2.5	47.62	50.32	54.29	57.48	59.14	55.06	54.34
3.0	40.62	43.93	46.24	50.43	53.13	47.45	45.58

**Figure 3: Soaked CBR versus RSF content at varying GP content.**

3.5 Indirect Tensile Strength Result

Table 6: Indirect Tensile Strength Result

RSF (%)	Indirect Tensile strength (MPa)						
	0% GP	5% GP	10% GP	15% GP	20% GP	25% GP	30% GP
0	0.28	0.3	0.31	0.33	0.35	0.34	0.33
0.5	0.35	0.4	0.43	0.46	0.49	0.47	0.46
1.0	0.45	0.5	0.54	0.57	0.58	0.57	0.57
1.5	0.57	0.62	0.65	0.67	0.71	0.7	0.68
2.0	0.66	0.7	0.74	0.76	0.79	0.78	0.76
2.5	0.65	0.68	0.69	0.7	0.73	0.67	0.66
3.0	0.64	0.65	0.67	0.68	0.69	0.67	0.65

Figure 4 and Table 6 present the indirect tensile strength results, which followed a trend consistent with the CBR data. Tensile strength increased from 0.28 MPa for the plain stabilized soil to a peak of 0.79 MPa at 2.0% RSF and 20% granite powder, before decreasing slightly at 2.5% and 3.0% RSF. This behaviour reflects the well-documented crack-bridging

contribution of steel fibers to tensile and flexural capacity in fiber-reinforced composites [7], [8], and confirms that the reinforcing benefit of RSF in the stabilized laterite matrix is optimized at a moderate fiber content rather than increasing indefinitely with fiber dosage.

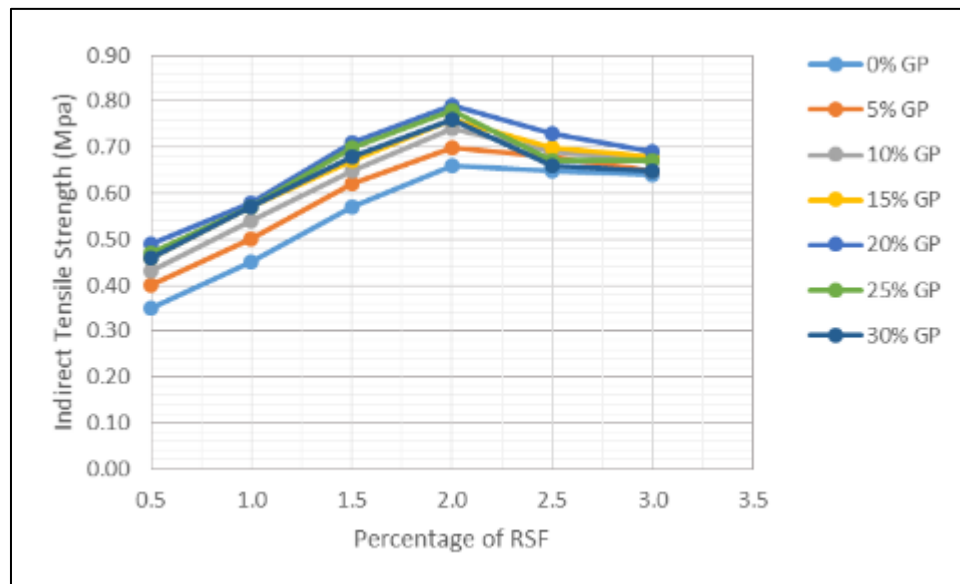


Figure 4: Indirect tensile strength against RSF content at varying GP content.

Overall, the results indicate that the combination of 2.0% recycled steel fiber and 20% granite powder, incorporated into laterite soil stabilized with 6% bitumen, produced the best balance of reduced water absorption, maximum bearing capacity, and maximum tensile strength among all forty-nine combinations tested. Beyond this optimum, both excess fiber and excess filler content resulted in reduced performance, most likely due to fiber clustering, particle interference, and an increase in the void ratio of the compacted matrix that outweighs any further reinforcing or filling benefit.

4 CONCLUSIONS

This study investigated the effect of recycled steel fiber (RSF) and granite powder (GP) on the physical and mechanical properties of bitumen-stabilized laterite soil from Ogbogoro, Port Harcourt, Rivers State, Nigeria, for potential use in flexible pavement construction. Based on the laboratory results, the following conclusions are drawn:

- The natural laterite soil was classified as a fine-grained, intermediate-to-high plasticity material (plasticity index of 26.91%) that requires stabilization prior to use as a pavement material.
- A compaction-based optimum binder content of 6% bitumen was adopted, providing a favorable balance between maximum dry density recovery and reduction in optimum moisture content.
- Water absorption of the stabilized soil decreased with increasing RSF and GP content up to 2.0% RSF and 20% GP respectively, beyond which absorption increased again due to fiber clustering and increased void content.
- Both unsoaked and soaked CBR improved substantially with RSF and GP addition, reaching a maximum of 66.52% (unsoaked) and 65.25% (soaked) at 2.0% RSF and 20% granite dust, an improvement of approximately three times the value obtained for the plain bitumen-stabilized soil, with retained (soaked/unsoaked) strength of about 98%.
- Indirect tensile strength followed a similar trend, increasing from 0.28 MPa to a peak of 0.79 MPa at the same optimum combination, confirming the crack-bridging contribution of the recycled steel fiber.
- A blend of 2.0% recycled steel fiber and 20% GP with 6% bitumen-stabilized laterite soil is recommended as the optimum mix design for improved strength and moisture-durability performance, offering a technically viable and environmentally beneficial route for reusing tyre- and quarry-derived waste in subgrade and sub-base pavement construction in tropical lateritic terrains.
- Further work is recommended to evaluate the long-term durability of the optimum mix under repeated wetting-drying and freeze-free tropical field conditions, to assess its performance under full-scale traffic loading, and to conduct a cost-benefit analysis comparing the optimum RSF-granite powder-bitumen blend with conventional cement- or lime-stabilized lateritic pavement layers

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

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Disclosure of conflict of interest

The authors declare that there is no conflict of interest, financial or otherwise, associated with this research

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