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Application of Bio-Based Rejuvenator in Reclaimed Asphalt Pavement

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Abstract: **This paper presents an experimental work on the evaluation of reclaimed asphalt pavement mixture that was rejuvenated using Jatropha Curcas oil. The amount of Jatropha oil used was four percent of aged bitumen content by weight. Series of strength tests were conducted to evaluate the performance of jatropha oil rejuvenated reclaimed asphalt mixture. The Indirect tensile strength of rejuvenated reclaimed asphalt mixture was found to be 96N/mm^2, which is capable of withstanding repetitive traffic loadings imposed on it. Average Marshall flow value of the Jatropha rejuvenated reclaimed asphalt mixture is 4mm, this implies that, the RAP mixture has been rejuvenated by Jatropha oil through the improvement of its ductility without compromising its resistance against fatigue cracks as shown in its average stability value of 456kg. The Jatropha curcas oil rejuvenated reclaimed asphalt pavement has an average tensile strength ratio of 88.6%, this is an indication of the mixture's resistance to moisture damage.**

Keywords: **Rejuvenator, Jatropha curcas oil, moisture susceptibility, indirect tensile.**

I. INTRODUCTION

The construction and maintenance of road infrastructure have significant environmental and economic impacts. Traditional methods of road construction rely heavily on the use of virgin materials, leading to depletion of natural resources and increased greenhouse gas emissions. As a response to these challenges, the use of Reclaimed Asphalt Pavement (RAP) has emerged as a sustainable alternative. RAP involves recycling existing asphalt pavement, which can significantly reduce the need for new materials and lower the environmental footprint of road construction projects [1]. The development of recycling processes results in a rapid reduction of natural resources and energy and has led to the search for new and sustainable alternatives [2]. For RAP to be cost-effective, good in performance and environmentally friendly, the Federal Highway Administration (FHWA) recommends the 'use of recycled materials in the construction of highways to the maximum economical and practical extent possible with equal or improved performance [3].

However, the effectiveness of RAP is often limited by the aging and hardening of the asphalt binder, which occurs due to long-term exposure to traffic loads and environmental conditions. This aging process reduces the binder's flexibility and adhesion properties, leading to potential performance issues in the recycled pavement [4]. To address these challenges, the incorporation of rejuvenating agents has been explored to restore the original properties of the aged asphalt binder. Among these agents, bio-based oils have gained attention due to their environmental benefits and effectiveness in rejuvenating RAP [5].

Bio-based oils, derived from renewable sources such as plant and animal fats, offer a sustainable and eco-friendly solution for asphalt rejuvenation. These oils are not only biodegradable and non-toxic but also locally available, reducing the carbon footprint associated with their transportation [6]. Recent studies have demonstrated that bio-based oils can effectively soften the aged binder, improve its rheological properties, and enhance the overall performance of RAP mixtures [7].

Research conducted by [8] found that the addition of bio-oil significantly improved the low-temperature performance and fatigue resistance of RAP mixtures. Similarly, studies by [9] and [10] reported that bio-oils effectively reduced the stiffness

of aged binders, enhancing their flexibility and adhesion properties. Additionally, the use of bio-based oils has been shown to improve the moisture resistance and durability of recycled asphalt pavements [11.

Despite these promising findings, there remains a need for comprehensive studies to evaluate the long-term performance and economic viability of using local bio-based oils in RAP rejuvenation. This research aims to investigate the effectiveness of various locally sourced bio-based oils in rejuvenating RAP, focusing on their impact on the mechanical and durability properties of the recycled asphalt mixtures. By exploring the potential of local bio-based oils, this study seeks to provide a sustainable solution for the rejuvenation of RAP, contributing to the advancement of green construction practices and the circular economy in the pavement industry [12].

II. MATERIALS

A. Aggregates

Aggregates are the highest constituents of asphalt concrete mixture, their strength plays significant role in the overall pavement strength. Weak aggregates produce flexible pavement of potential cracks and or rutting as form of distress that undermines the integrity of pavements. The strength of aggregates in the reclaimed asphalt pavement was evaluated and the result is presented in Table I.

TABLE I: CHRACTERISTICS OF RAP AGGREGATES

Characteristics	Value
Specific gravity	2.5
Aggregates impact value (AIV)	15
Aggregates Crushing Value (ACV)	20.5
Los Angeles Abrasion Value	25

B. Reclaimed Asphalt Pavement (RAP)

Reclaimed asphalt pavement used in this study was secured from the road rehabilitation site along Katsina – Kano Road in north western region of Nigeria. Bitumen extraction test was conducted to determine the percentage of aged bitumen in the reclaimed asphalt pavement material. Table II present the sieve analysis and bitumen percentage in the collected RAP material.

TABLE II: SIEVE ANALYSIS AND BITUMEN CONTENT OF RECLAIMED ASPHALT PAVEMENT

Sieve Size (mm)	Percentage Retained (%)
19	0
12.5	11
9.5	11
6.4	16
2.8	13
1.25	11
0.6	9
0.3	5
0.15	8
0.075	11
Filler	5
Bitumen content	3.8

C. Jatropha Curcas Oil

Jatropha Curcas is a plant that belongs to the Euphorbiaceous family originated from tropical America and distributed to Africa, Asia and other part of the world. Jatropha curcas seed oil is toxic to animals, hence, there is the need to study various methods of its usage. Jatropha Curcas seed oil use as human food or animal feed sources are presently limited. Also, jatropha curcas is easy to establish and grows relatively quickly. Jatropha Curcas can excellently adapt to to various soil conditions. Table III present the properties of Jatropha Curcas oil.

TABLE III: PROPERTIES OF JATROPHA CURCAS OIL [12] (Ahmad 2018)

Property	Value
Boiling point	124°C
pH	5.2
Free fatty acids	0.0718 mg KOH g–1 oil
Specific gravity	0.8480
Flash point	150°C
Cloud point	14°C
Saponification value	155 mg KOH g–1 oil
Peroxide value	7.20 meq g–1 oil
Iodine value	51.27 g 100 g–1 oil
Dielectric strength	22 kV
Pour point	4°C
Density at 27°C	0.725 g cm–
Acid value	0.1428 mg KOH g–1 oil
Viscosity	8.2 cst

III. METHOD

A. Sample preparation

Reclaimed asphalt pavement mixture was prepared based on the aged bitumen content and aggregates gradation shown in Table II. The amount of Jatropa oil used in the rejuvenation was 4% of bitumen weight in the mixture. Also 1.2% of bitumen was added to the mixture in order to attain a minimum required bitumen content of 5% as stated in Nigerian General Specifications for Roads and Bridges [13]. The samples were produced at the required density to produce an air void between 3% to 5% for indirect tensile, Marshall flow and stability tests.

B. Indirect Tensile Test

Indirect tensile test (IDT) was conducted on the reclaimed asphalt pavement rejuvenated using jatropha oil, the method used was ASTM D6931 – 12 [14]. In this test, 100mm diameter asphalt concrete samples were prepared and tested at a loading rate of 50 mm/min at 25℃.

C. Marshall Flow and Stability

Marshall flow and stability test was conducted on RAP materials rejuvenated using 4% jatropha oil of the weight of bitumen content as suggested by [15]. The test was conducted in accordance with **ASTM D6927-15** [16]**,** standard test method for Marshall stability and flow of asphalt mixtures. Marshall briquettes were produced at 4% air void and conditioned in water at 60 ºC for 30 to 40 minutes, the samples were tested across their vertical diametrical plane at a loading rate of 50mm/min using Marshall load jig. The maximum load at failure was considered as Marshall stability while the deformation is recorded as Marshall flow.

D. Moisture Susceptibility test

Moisture susceptibility test was conducted on the reclaimed asphalt pavement using modified Lottman method known as AASHTO T – 283 [17]. In this method, asphalt concrete samples are produced at 7% ± 0.5% air voids, four samples are water conditioned and saturated between 70% and 80%. Four other samples were produced at same air void without conditioning and saturation. The samples were then tested across their vertical diametrical plane at a loading rate of 50mm/min.at 25 oC.

IV. RESULTS AND DISCUSSIONS

A. Indirect Tensile Test

Indirect tensile test was conducted to estimate fatigue resistance of rejuvenated asphalt mixture. Researchers such as [18] and [19] used indirect tensile test to evaluate fatigue resistance of bituminous mixture. Also, [20] used indirect tensile test to evaluate rut resistance of bituminous mixture. Table IV present the result of indirect tensile test conducted on Jatropha oil rejuvenated reclaimed asphalt pavement.

TABLE IV: INDIRECT TENSILE STRENGTH OF REJUVENATED RAP MIXTURE

RAP MIXTURE	Indirect Tensile Strength (N/mm^2)
A	95.57
B	96.5
C	96
Average	96

From IV, the average indirect tensile strength of Jatropha oil rejuvenated reclaimed asphalt pavement was found to be 96N/mm^2. The value indicated that, the rejuvenated RAP mixture would resist destresses that could result in fatigue cracks, this may have positive effect against moisture damage and rutting deformation of flexible pavement.

B. Marshall Flow and Stability

Marshall flow and stability test was conducted on rejuvenated reclaimed asphalt pavement. The aim of this test is to evaluate mixture resistance against rutting and fatigue cracks through measurement of deformation during loading of asphalt concrete mixture at 60^{o}C. The stability is considered to be the failure load while the deformation recorded as flow value of the mixture. Table V present the result of Marshall flow and stability test.

TABLE V: MARSHALL STABILITY AND FLOW OF REJUVENATED RAP MIXTURE

Rejuvenated RAP Mixture	Stability (Kg)	Flow (mm)
A	455	4.0
B	465	3.8
C	448	4.2
Average	456	4

From Table V, the average Marshall flow value of the Jatropha rejuvenated reclaimed asphalt mixture is 4mm. This shows that, the RAP mixture has been rejuvenated by Jatropha oil by improving its ductility without compromising its resistance against fatigue cracks as shown in stability value that is above minimum requirement of 350kg suggested by Nigerian General Specifications for Roads and Bridges [13].

C Moisture Susceptibility test

Moisture susceptibility test was conducted on the rejuvenated asphalt concrete mixture to determine its potentials in resisting moisture damage. The evaluation was performed using tensile strength ratio in which two set of asphalt concrete samples were prepared, one sub set of four samples were subjected to conditioning based on AASTHO T283 provisions and the other set of four samples was not conditioned. A tensile strength ratio of conditioned sub set and dry sub set was determined, the result is presented in Table VI.

TABLE VI: MOISTURE SUSCEPTIBILITY OF REJUVINATED RAP MIXTURE

RAP Mixture	Tensile Strength Dry Sub Set (KN/m^2)	Tensile Strength Saturated Sub Set (KN/m^2)	Tensile Strength Ratio (TSR) (%)
A	115	102	88.7
B	118	103	87.3
C	121	109	90.1
D	110	97	88.2
Average	116	102.8	88.6

From Table VI, the average tensile strength ratio of the Jatropha oil rejuvenated mixture is 88.6% which is an indication of mixture's resistance to moisture damage.

V. CONCLUSION

The aim of this research was achieved through laboratory evaluation of reclaimed asphalt pavement mixture that was rejuvenated using Jatropha Curcas oil. Four percent of aged bitumen weight was used for the rejuvenation of the RAP mixture. Indirect tensile strength of rejuvenated reclaimed asphalt mixture was found to be 96N/mm2, which is capable of withstanding repetitive traffic loadings imposed on it. The average Marshall flow value of the Jatropha rejuvenated reclaimed asphalt mixture is 4mm, this implies that, the RAP mixture has been rejuvenated by Jatropha oil by improving its ductility without compromising its resistance against fatigue cracks as shown in average stability value 456 kg. The Jatropha curcas oil rejuvenated reclaimed asphalt pavement has an average tensile strength ratio of 88.6%, this indicates mixture's resistance to moisture damage.

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