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THE EFFECT OF WASTES ENGINE OIL AS A REJUVENATOR ON HIGHLY RECLAIMED ASPHALT PAVEMENT ON THE PROPERTIES OF HOT MIX ASPHALT

Otuoze, H. S., Ashiru, M., *Sheriff, M. and Ibedu, K. E.

Department of Civil Engineering, Ahmadu Bello University, Zaria

*Corresponding authors' email: mohammedmodusheriff@gmail.com

ABSTRACT
This study aims to improve the sustainability and performance of asphalt mixtures by extracting binder from Reclaimed Asphalt Pavement (RAP) and incorporating waste engine oil. Centrifuge, reflux, and vacuum extraction methods are used, with centrifuge preferred for preserving binder properties. Characterization of asphalt concrete components, including bitumen and aggregates, is crucial for optimizing mixture performance. A mixture was formulated with 25% RAP and 75% fresh aggregates, incorporating varying percentages of waste engine oil to enhance flowability and resistance to cracking. The Marshall Stability test showed that stability decreased with increased waste engine oil, while flow, air voids, and VMA increased. The extracted binder content from RAP was 4.53% by weight. This research supports sustainable infrastructure development by reusing RAP and waste engine oil, reducing environmental impact such as energy conservation, reduced pollution, resource recovery, wastes reduction, carbon footprint reduction and promoting durable pavements. It contributes to more efficient asphalt pavement construction practices, aligning with sustainable infrastructure goals by enhancing the reuse of recycled materials and minimizing waste. The study provides valuable insights into innovative methods for sustainable asphalt construction, promoting environmentally friendly practices in the infrastructure sector.

Keywords: Hot mix asphalt, Wastes engine oil, Reclaimed asphalt pavement, Rejuvenator, Sustainability

INTRODUCTION

Highway mode of transport is crucial for economic development, most especially in developing countries like Nigeria where it's the most common means of transportation. However, the over usage of the roads lead to unavoidable consequences of pavement failures caused due to material properties, excessive traffic loading, and environmental factors (Otuoze and Shuaibu, 2017). To build and maintain roads, the road sector is thus looking forward to alternative materials and construction technologies that are economical, energy-efficient, and environmentally friendly (Taherkhani and Farid, 2020). Natural aggregates found in quarries are the main source of materials used in the majority of modern road construction techniques. The process of removing these aggregates from their natural sources causes widespread pollution and the loss of forest cover, which deteriorates the ecosystem (Xing et al, 2023). As a result, environmental concerns have grown around the world Natural resources are finite and rapidly diminishing, so to maintain them, adequate reserves must be guaranteed to meet aggregate demands both now and, in the future, (Surehali et al, 2023). However, the cost of asphalt binder has also been known to fluctuate. Therefore, research is required to find ways to lower the amount of fresh asphalt binder used in rehabilitation techniques by using alternative technologies, which will lower the cost of both construction and maintenance. Many Departments of Transportation (DOT) are exploring using Reclaimed Asphalt Pavement (RAP) material as an alternative and considering their use at an increasing proportion for Hot Mix Asphalt (HMA) to meet the demand for aggregates to conserve and maintain the assets of the road system. Reusing asphalt pavement materials has shown to be a beneficial strategy for both environmental and financial reasons (Lee *et al*, 2023).

Due to its many positive attributes, including ease of recycling, minimal noise, safety, and ease of maintenance, asphalt pavement is utilized extensively across the world. Between 2008 and 2017, Europe generated more than 260 million tons of hot and warm mixed asphalt mixtures annually (Rafiq and Madzlan;2021). Because asphalt pavement typically lasts 10 to 15 years, there were a lot of removed pavement materials created each year that contained aged asphalt and aggregates. Reclaimed asphalt pavement (RAP) is the term used to describe the reprocessing of these materials. Over the past three decades, RAP has been extensively studied due to its economic and environmental benefits (Jizhe and Xiaomeng, 2020). Aggregates and asphalt binders are nonrenewable resources. Their amounts can be reduced during the production of hot mix asphalt (HMA) by applying RAP to a new pavement. Additionally, the use of RAP will reduce construction debris that needs to be dealt with. Ultimately, using RAP makes the best utilization of natural resources and promotes the sustainable development of the asphalt industry (Wei and Yudan 2023).

Chen et al (2021) indicate that reclaimed asphalt pavement (RAP) is one of the materials that are recycled the most globally. Asphalt pavement is defined as having been removed or torn down from the road but still containing valuable gravel and asphalt that can be used to make new asphalt mixtures. RAPs are, in general, materials that have been taken out of new combinations and not used because they are excess or don't fulfill project requirements (Wang and Huailei; 2022). For modifying RAP, the Asphalt Recovery and Recycling Association has identified four main methods of recycling asphalt pavement: (1) hot in-plant recycling, (2) cold in-plant recycling, (3) hot in-place recycling, and (4) full-depth cold recycling. However, the particular subject of this study is dense-graded recycled asphalt mixes that were created and assessed in a lab to be manufactured in a hot plant. This decision is based on the notion that RAP can be used to its fullest advantage in this particular situation.

Studies on HMA performance in the lab with elevated RAP contents have been carried out. When the RAP concentration was raised, its recycled combinations were more prone to low-temperature cracking (Aliyu *et al* 2020). While a fine aggregate matrix's modulus grew along with increasing RAP concentration, its fatigue performance decreased. Moreover, the rejuvenator improved the fatigue performance of a fine aggregate matrix (Hasan and Zhanping, 2019). Pavements are made primarily of asphaltic concrete all over the world. The increase of the world's population as well as the drive for economic prosperity have been major factors in the development of road networks, particularly asphalt and highways. Asphaltic concrete is used to pave more than 3.68, 0.41, 4.68, 0.17, and 3.8 million km of roads in the US, Canada, Europe, Mexico, and Asia (Wentong and Meng, 2020). Thus, the building of new roads, as well as their upkeep, repair, rehabilitation, and reconstruction, as well as the preservation of aging pavement, necessitate a massive amount of materials and the use of nonrenewable energy sources, all of which have a significant financial impact on the economy. In addition to these procedures for constructing and maintaining new roads, the greatest way to maximize the impact and cost of an infrastructure project is to combine virgin and recycled materials (Zahoor and Sabzoi, 2021).

However, one challenge of using RAP is that the aged binder within it can become increasingly stiff and brittle, negatively affecting the performance and longevity of the new pavement. This is where the innovative use of waste engine oil (WEO) offers a compelling solution. By incorporating WEO into the asphalt mix, the stiffness of the aged binder can be effectively reduced, restoring its flexibility and improving its overall performance characteristics (Behnood, 2019).

This rejuvenating effect allows for a higher percentage of RAP to be used in new asphalt mixes, promoting a more sustainable approach to pavement construction by recycling waste materials that might otherwise contribute to environmental pollution(Mohajerani and Kavindha, 2017). Additionally, waste engine oil helps maintain the integrity and durability of the pavement, providing economic benefits by lowering material costs associated with the production of new asphalt (Chris and Emmanuel, 2019). Wastes engine oil is considered better to other rejuvenators in certain contexts, especially for industrial applications or when trying to reduce costs or environmental impact(Cengiz and, Erol, 2019). Wastes engine oil is typically more suitable for non-sensitive application where cost savings or recycling benefits are prioritized but it depends on the context and the specific case use, such as cost effectiveness in certain industries, environmental benefit, alternative uses beyond engine lubrication, availability and accessibility, energy efficiency in specific industrial context and less dependency on new resource (Atajeromavwo *et al*, 2024). This study also addresses the broader implications of using WEO in asphalt mixtures, including its potential to reduce environmental impact by re-using wastes materials, and it also advances existing knowledge by demonstrates the potential of WEO as a sustainable rejuvenator, by promoting recycling and reducing wastes in asphalt production, and its shows that incorporating WEO can enhance the mechanical properties and moisture resistance of asphalt mixtures containing high RAP content and lastly it explores innovative methods to repurpose wastes oils, mitigating environmental contamination from improper disposal in Nigeria (Khoaele and Ipoteng , 2024) , where environmental degradation from used engine oil is a significant concern, this approach offers a dual benefits of enhancing pavement performance while mitigating ecological damage. Overall, this research aims to provide valuable insight into innovative methods for sustainable asphalt construction, supporting the goal of creating more durable and sustainable pavements in Nigeria.

MATERIALS AND METHODS

Materials

The materials used in this research are bitumen, fresh aggregates, reclaimed asphalt pavement, waste engine oil and trichloroethylene (ccl_4). The bitumen was obtained from Mother Cat Construction Company, the reclaimed asphalt pavement was readily available at the Departmental Civil Engineering laboratory (A.B.U Zaria), and the Mineral filler to be used in the research is Ordinary Portland Cement. The filler (ordinary Portland cement) was procured within Zaria, Nigeria. Wastes engine oil will be sourced from a mechanic workshop in Zaria.

Properties of constituent materials

Tests on bitumen are

i. Penetration accordance with ASTM D5/D5M –20 (2020)
ii. Ductility by ASTM D113 – 17 (2017)
iii. Softening point by ASTM D36/D36-14 (2020)
iv. Flash and fire point by ASTM D92 – 18 (2018)
v. Specific gravity, by ASTM D70 – 18a (2018)

The tests conducted on the fine and coarse aggregate are:

i. Aggregate impact value by BS 812-112 (1990)
ii. Aggregate crushing value by BS 812-110 (1990)
iii. Elongation index by ASTM D4791-19 (2019).
iv. Flakiness index by BS EN 933-3 (2017)
v. Specific gravity by ASTM C127-15 and ASTM C128-15 (2015)
vi. Sieve analysis by (ASTM C136/C136M-19, 2019)

Test on wastes engine oil

i. Physical properties of wastes engine oil (ASTM d445, ASTM DI298 and ASTM D93)
ii. SARA COMPONENT and element present in weo (ASTM D2007 and ASTM D5185)

Test on Hot Mix Samples

i. Marshall Stability and flow by ASTM (ASTM D6926-20, 2020)
ii. The bulk density by (AASHTO T 166, 2016; ASTM D2041/D2041M-19, 2019)
iii. Voids in the mineral aggregate by (ASTM D6995-21, 2021).
iv. Percent air voids, by (ASTM D3203 / D3203M-17, 2017).
v. VFB is the voids filled with bitumen by (ASTM D6927-15, 2015).

Mix design

The combined gradation percentages were determined using the Asphalt Institute chart (Table 1). The Recycled Asphalt Pavement (RAP) was analyzed for particle size distribution by sieving it through a series of sieves with the following sizes: 12mm, 9.5mm, 6.4mm, 3.2mm, 1.25mm, 0.6mm, 0.3mm, 0.15mm, and 0.075mm

Table 1: Asphalt Institute chart

Material	Blend percentage	Stockpile percentage for determining combined gradation
57 coarse aggregates	20%	20.4%
8 coarse aggregates	30%	30.6%
Fine aggregates	25%	25.5%
RAP	25%	23.5%

Numerous studies verified that using a low amount of RAP < 15% in hot mix asphalt, recycling would be having less effect on the mixture performance, and having high RAP percentage of >30% in the mix design will be leading to early fatigue and low thermal cracking. According to asphalt institute 2014 shown above, it is recommended that 25% RAP should be used for optimal balance. Studies also indicates that incorporating 7-13% WEO can effectively rejuvenate aged asphalt without compromising its high temperature performance.

Table 2 shows the summary of the Test result for sample modified with WEO. Knowing the optimum bitumen content to use with the specified aggregate gradation, the Marshall stability, flow and volumetric test were performed on specimen whose bitumen had partially been replaced by WEO. The bitumen content as percentage of the mass of aggregates were replaced with 0%, 2%, 4%,6%,8% of WEO to determine the optimum WEO percentage. the test result is summarized below

Table 2: Summary of the test result for sample modified with WEO

% WEO content	BUW	Vim (%) (3-5%)	VMA (>14) (%)	VFB (75-82) (%)	stability	Flow
0	2.35	3.87	21.99	79.89	10.8	2.39
2	2.34	4.12	22.82	79.27	8.25	3.01
4	2.32	4.42	23.38	78.11	7.9	3.42
6	2.31	4.66	23.85	76.03	7.05	3.65
8	2.30	4.87	24.03	75.25	6.57	3.89

RESULTS AND DISCUSSION

Particle size distribution

Particle size distribution (PSD) of aggregates, also known as gradation, is crucial for determining the suitability of aggregates for various applications, such as construction and engineering projects. It involves analyzing the dispersal of individual particle sizes across the entire sample. The particle size distribution (PSD), or gradation, of reclaimed asphalt pavement (RAP) is a critical parameter in asphalt mix design, influencing mixture stability, durability, and workability. This study employed sieve analysis, conforming to the Asphalt Institute (2014) method for combined gradation, to characterize the PSD of the RAP material. A representative sample of RAP was sieved through a series of sieves with the following nominal sizes: 12.0 mm, 9.5 mm, 6.4 mm, 3.2 mm, 1.25 mm, 0.6 mm, 0.3 mm, 0.15 mm, and 0.075 mm. The mass of material retained on each sieve was recorded and used to calculate the percentage of material passing each sieve size. This data was then compared to target gradation bands specified in the FMWH (2016) and Asphalt Institute (2014) guidelines to ensure the suitability of the RAP for incorporation into the designed asphalt mixture.

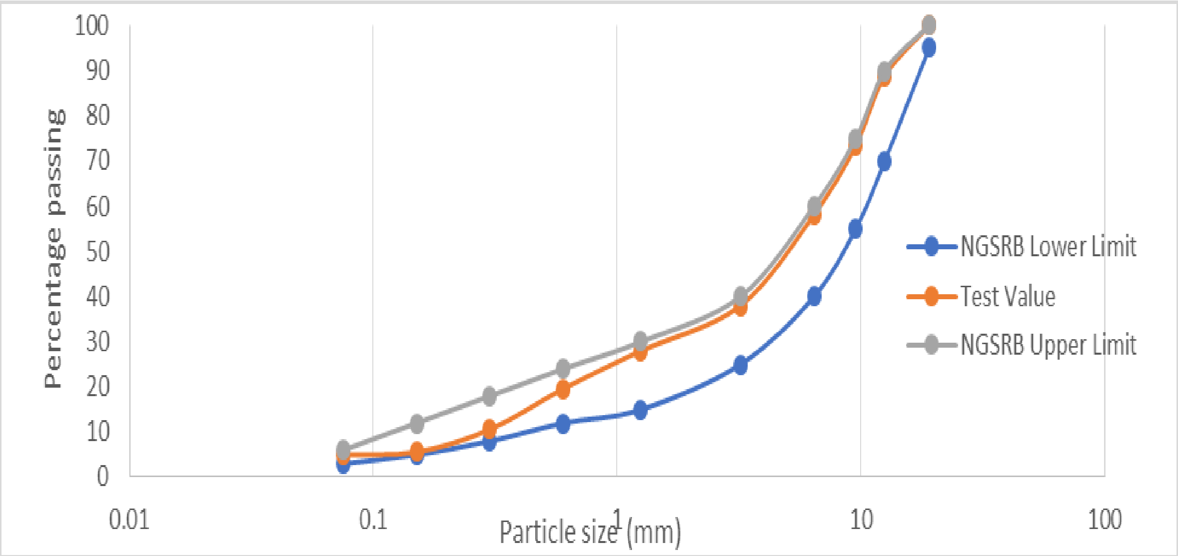

Figure 1: Particle size distribution

Table 3: Asphalt job mix design in accordance with FMWH (2016)

Sieve size (mm)	Upper limit	% passing	Lower limit	(%) retained	25% RAP content	Total of RAP	75% NA	Total of NA	Grand total aggregates (%)
19	100	100	100	0	0	0	0	0	0
12.5	95	98	100	2	0.5	5.64	1.5	16.92	22.56
9.5	70	81	90	17	4.25	47.94	12.75	143.82	191.76
6.4	55	65	75	16	4	45.12	12	135.36	180.48
3.2	25	38	40	27	6.75	76.14	20..25	228.42	304.56
1.25	15	25	30	13	3.25	36.66	9.75	109.98	146.64
0.6	12	18	24	7	1.75	19.74	5.25	59.22	78.96
0.3	8	14	18	4	1	11.28	3	33.84	45.12
0.15	5	7	12	10	2.5	28.2	7.5	84.6	112.8
0.075	3	5	6	2	0.5	5.64	1.5	16.92	22.56
Pan				2	0.5	5.64	1.5	16.92	22.56
Total				100	25	282 g	75 g	846 g	1128g

Physical properties of aggregates

The physical properties of aggregates are vital in determining their suitability for use in construction materials like concrete and asphalt. The shape and size of aggregates play a significant role in the workability and strength of the mixture. For instance, angular aggregates tend to provide better interlock and strength compared to rounded ones, while the size distribution affects the overall stability and durability of the structure. The results of aggregates physical property test for fresh aggregates and RAP are presented in the table below.

Table 4: Physical properties of aggregates

Properties	Test values		FMWH (2013) Standard spec.		Remarks
	Rap	Fresh aggregates	Min.	Max.	
Specific gravity (coarse)	2.52	2.86	2.5	3.0	Satisfactory
Specific gravity (fine)	2.38	2.77	N/S	N/S	Satisfactory
Specific gravity (filler)	2.64	2.81	N/S	N/S	Satisfactory
Flakiness index (%)	22.50	20.30	N/S	35	Satisfactory
Elongation index (%)	21.42	19.43	N/S	25	Satisfactory
Aggregates crushing value (%)	19.55	22.58	N/S	30	Satisfactory
Aggregates impact value (%)	21.67	22.54	N/S	35	Satisfactory

Physical property on bitumen

Bitumen exhibits several key physical properties that are crucial for its performance in various applications, particularly in construction and asphalt production. The preliminary tests conducted on bitumen, along with the results used for comparison with FMWH (2016), are presented in Table 4. This table displays the test results for pure bitumen, which align with the FMWH (2016) standards for 60/70 penetration grade bitumen. Therefore, it is deemed suitable for use in hot mix asphalt production.

Table 5: Physical properties of bitumen

S/N	Properties	Results	Min	Max	Remark
1	Penetration @ 25°C	67.5	60	70	Satisfactory
2	Softening point @ °C	50.5	48	56	Satisfactory
3	Ductility @ 25°C	103	100	-	Satisfactory
4	Specific gravity	1.03	1.01	1.06	Satisfactory
5	Flashpoint °C	254	250	-	Satisfactory
6	Fire point °C	259	99	-	Satisfactory

Physical properties of wastes engine oil

Waste engine oil, like other lubricants, exhibits several key physical properties that are altered from its original state due to degradation and contamination during use. The color of WEO changes significantly from its original amber hue to darker shades (brown or black) due to contamination and oxidation during use. Color can be assessed visually or using spectrophotometric methods. Density is another important physical property that affects the performance of engine oils. It is typically measured using ASTM D1298 or similar standards. The density of WEO can range from approximately 0.870 to 0.895 g/cm³, depending on its composition and condition. The flash point indicates the temperature at which vapors from the oil can ignite. It is measured according to ASTM D93 or similar methods. Flash points for WEO are generally lower than those of fresh oils, often around 200°C to 232°C for used oils, depending on their level of contamination and degradation. Viscosity is a critical property that indicates the oil's resistance to flow. It is usually measured at specific temperatures (e.g., 40°C and 100°C) using ASTM D445 or similar standards. Studies have shown that the viscosity of WEO can vary significantly based on its condition. For instance, fresh oils may have a viscosity around 18 cSt at 100°C, while used oils can exhibit much higher values due to contamination and degradation. The physical properties of waste engine oil are critical for assessing its usability and safety for further applications or recycling processes. Various standards guide the measurement of these properties, ensuring consistency and reliability in results across different studies. Regular testing helps monitor oil quality, enabling timely maintenance actions in engines and machinery.

Table 6: Physical properties of wastes engine oil

Property	Test values	Range	Standard for testing
Color	Dark brown	Dark brown, black, black brown	Color can be assessed visually or using spectrophotometric methods.
density	0.875g/cm3	0.870 - 0.895g/cm3	ASTM DI298
Kinematic viscosity @ 40 °C	64.2	40-100	ASTM D445
Flashpoint °C	221	200-232°C	ASTM D93

SARA COMPONENT and element present in wastes engine oil together with their specification

Table 7: SARA component and element present in wastes engine oil

Property	Test value	Range	ASTM standard
Asphaltenes (%)	12.5	5-15	ASTM D2007
Aromatics (%)	27.02	30-50	ASTM D2007
Saturates (%)	25.10	20-40	ASTM D2007
Resins (%)	11.27	10-20	ASTM D2007
Lead (%)	7.78	0.9-13.71	ASTM D5185
Nickel (%)	0.35	0.14-0.75	ASTM D5185
Copper (%)	44.8	16.5-76.87	ASTM D5185

Extraction of binder from RAP and determination of binder content

The RAP material is initially heated in an oven to eliminate moisture and facilitate crushing. For the extraction process, approximately 1 kg of RAP was utilized. The crushed RAP was placed in a centrifuge vessel along with a selected solvent, trichloroethylene. About 600 ml of solvent was added, and the mixture was allowed to soak for approximately one hour. The centrifuge was then operated at speeds, reaching up to 1800 rpm, to separate the asphalt binder from the aggregates. Following centrifugation, sedimentation was used to remove mineral fines from the binder-solvent solution, and this was followed by filtration to further purify the extracted binder.

RAP binder content was determined by following the asphalt extraction standards AASTHO T 164. The extracted binder content of RAP after aging on-site was recorded as 4.53% by weight of the asphalt mix.

"Plates one, two and three illustrate the condition of the Reclaimed Asphalt Pavement (RAP) material before and after the extraction process. These images provide a clear comparison of the RAP's appearance prior to treatment and the extracted asphalt binder following centrifugation and purification.

Plate 1: Before extraction

Plate 2: During extraction

Plate 3: After extraction

Preparation and conventional characterization of binders

Wastes or recycled engine oil and control bitumen are heated respectively to a certain temperature and then using shear mixer to mix at a certain temperature with a shearing rate for a certain period. Many researchers have their own ideas for the preparation methods as varying the shearing rate ranging from 200 rpm to 5000 rpm, shearing time from 10 to 60 min, and temperature 105 °C to180 °C. The wastes engine oil under high shearing rate and temperature showed good workability and mixing with asphalt is easier. The wastes engine oil presents good performance under suitable shearing time. Preparation of wastes engine oil modified binder, Multmix laboratory high shear mixer was used for this purpose. Preheating bitumen 60/70 was done in the oven at a temperature of 150 °C to make it adequately fluid for mixing. Using a steel container, the required quantity of control bitumen was measured and poured in it, where the temperature of the container was maintained at 135°C. The next step was to measure wastes engine oil with different percentage (0, 2, 4, 6, 8,) and the required quantity was added gradually to the bitumen. High shear rate of 1800 rpm at shearing rate temperature of 135°C for 30 min for the homogenous mixture was done for the blending of wastes engine oil and bitumen

Binder Tests results

When wastes engine oil is combined with bitumen commonly for applications like asphalt modification or paving road, the optimal balance criteria involve a mix of environmental, technical, and performance consideration, such as rheological and mechanical performance, compatibility and stability, regulatory compliance and economic and practical consideration. The optimum wastes engine oil content was determined to have the same penetration value as the control binder by the modification process. Table below represents the penetration test results of rejuvenated binders with different Blends of WEO contents. The optimum WEO content was Determined as 10% by weight of RAP binder corresponding target Penetration value of 64. It showed that the penetration values for different WEO rejuvenated RAP binders, based on this optimum WEO percentage was derived from the penetration values equivalent to the same penetration value of the control/fresh binder. Therefore, it is possible to attain the desired penetration value by Suitability adding the WEO percentage Modified RAP binder with optimum WEO oil properties is shown below. Results showed that the addition of oil increase aged binder penetration values. Softening point value indicated that using oil, it can also be lowered near to the softening values of fresh binder.

Table 8: Binder test result

WEO Content (%) by weight of RAP Binder	Penetration (25 C;0.1) mm ASTM D5	Remarks
2	39	Moderate increase in penetration
4	45	Noticeable softening effect
6	51	Significant improvement in flexibility
8	57	Optimal balance for performance
10	65	Maximum penetration observed
12	72	Diminishing returns in performance

Marshall Stability

Figure 2 shows the stability values against the bitumen content for all the samples. The results of Marshall stability show 0.9, 3.45, 3.8, 4.65, 5.13% decrease in strength in comparison to the control. The stability value dropped from 10.8, 8.25, 7.9, 7.05 and 6.57kN. this decline is attributed to the excessive maltene content which could lead to a loss of cohesion and structural integrity in the asphalt mixture. Such a mixture would likely suffer from poor mechanical properties, including reduced stability and increased susceptibility to rutting and deformation. All mixes containing modified bitumen and RAP satisfy the FMWH (2016) minimum Marshall Stability requirement of 3.5kN. Higher stability indicates better resistance to rutting and shoving (awan *et al* 2022). Similar result was obtained by (Murana *et al*., 2019).

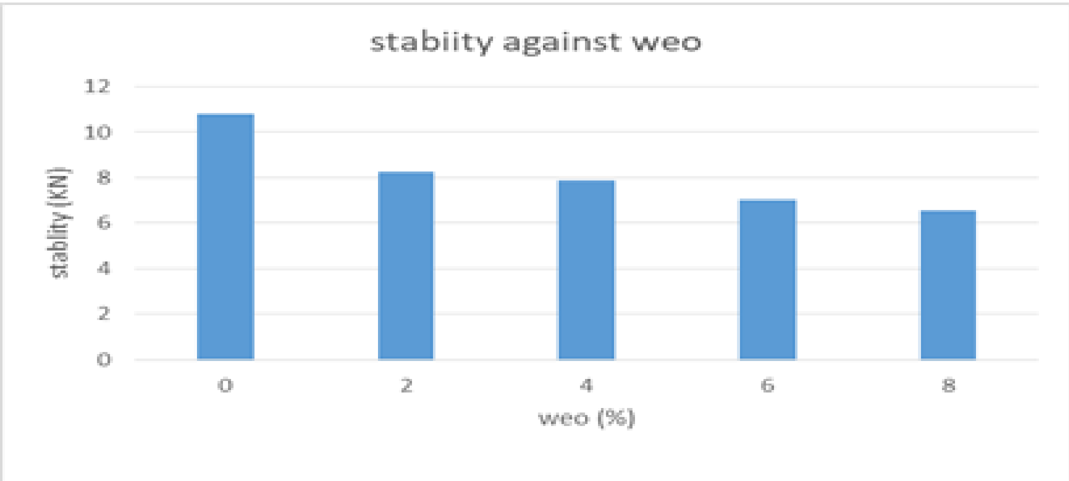

Figure 2: Variation of stability with WEO

Marshall Flow Results

The results of Marshall Flow with variation of WEO content are displayed in Figure 3. From the flow results obtained, it was noticed that all modified hot mix asphalt had higher flow values than the control. The increments can be attributed to the lubricating effect of the oil which allows for easier movement of aggregates. Furthermore, the flow values of modified hot mix asphalt were within the requirement of 2mm-4mm range set by FMWH (2016). This suggests that WEO improve the overall viscosity of asphalt concrete. Flow is an interpretive guide for assessing the possibility of rutting in asphalt mixtures. The same trend was obtained by (Odunfa & Gbadewole, 2018).

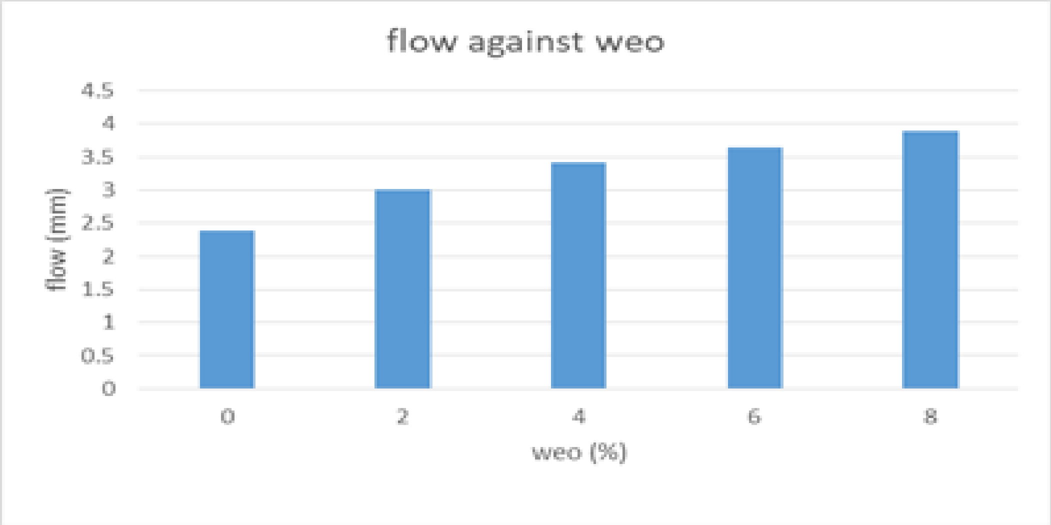

Figure 3: Variation of flow with WEO

Unit Weight Results

The results of unit weight with variation of WEO content are displayed in Figure 4. The results of the unit-weight test showed a continuous decrease with increase in WEO content. The unit weight values recorded are 2.35, 2.34, 2.32, 2.31 and 2.30g/cm^3. Comparison of the unit weight of control to the unit weight of modified asphaltic mixtures shows a decrease in 2, 4, 6 and 8% WEO content. This is because the addition of wastes engine oil, which has a lower density (approximately 700-950kg/m^3), reduces the overall density of the mixture. consequently, the modified sample has lower unit weight due to the lighter weight of the oil compared to the control, leading to increase in voids and reduced overall mass per volume in the control mix. Similar result was obtained by (Electricwala, *et al*., 2014).

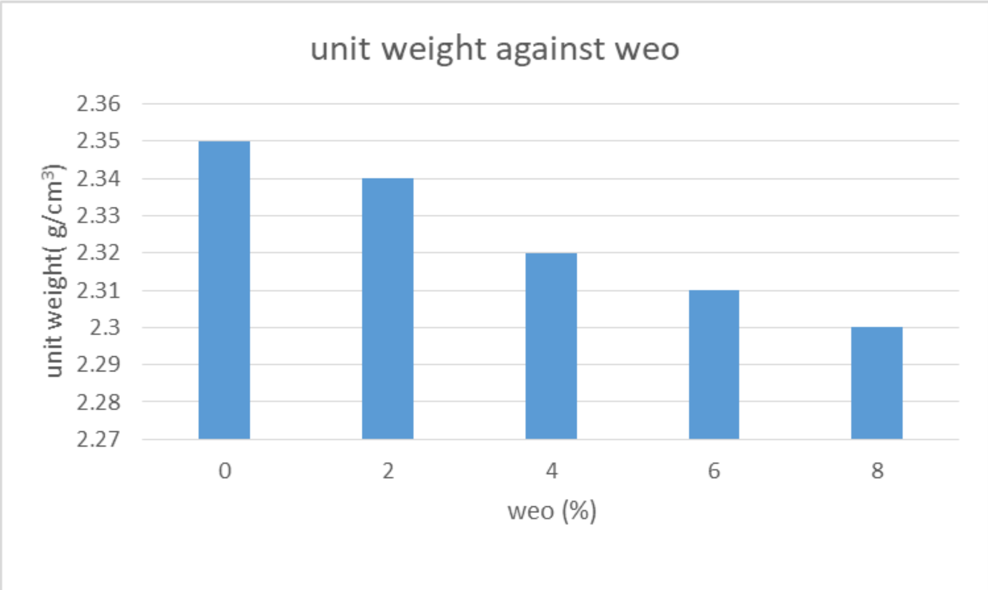

Figure 4: Variation of unit weight with WEO

Voids in Mineral Aggregate (VMA) Results

The results of void in mineral aggregates with variation of WEO content are displayed in Figure 5. The values of voids in mineral aggregate recorded are 21.99, 22.82, 23.38, 23.85 and 24.03%. The values of voids in total mixture for the modified mixture improved with respect to the control except for 0% WEO content. This is because the addition of wastes engine oil increases the volume of voids slightly due to its lower density and it also create additional air spaces within the mixture. As the percentage of WEO increases VMA increases, because the oil adds volume without contributing to the binder capacity, there by affecting the overall void structure. Thus, the modified mix has a higher VMA due to increased voids, while the control mix maintains a lower VMA due to its denser composition. The values of voids in mineral aggregate are inversely related to the values of the unit weight. Voids in mineral aggregate represent an indicator of asphalt content and directly relates to durability performance of the mixture. Similar result was obtained by (Electricwala, *et al*., 2014).

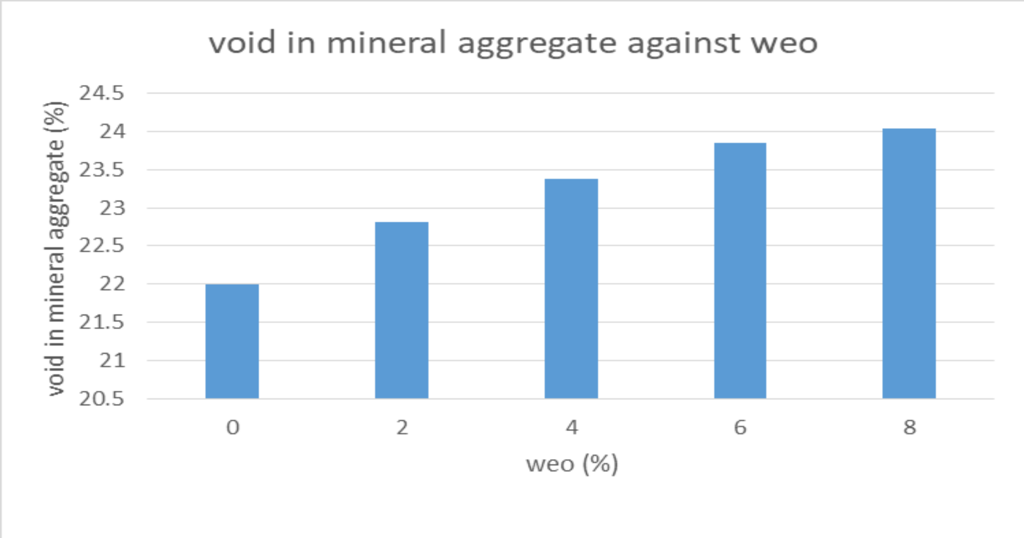

Figure 5: Variation of void in mineral aggregates with WEO

Air Voids (Va) Results

Figure 6 shows the variation of voids in mix with variation of WEO content. The results of the voids in total mixture showed an increase with the increase in WEO content, as the void in total mixture recorded are 3.87,4.12,4.42,4.66,4.87%. All values of voids in total mixture for the modified mixes are higher than the values of the control except for 0% WEO content. this is because the presence of wastes engine oil displaces some of the void space initially occupied by the binder and aggregates which leads to lower density. As the percentage of WEO increases the air voids increases, which is as a result of displacement of binder and changes in mix density and void structure. The results obtained from this analysis indicate the ability of the modified mixture to resist ingress of moisture within the matrix of the mixture. The higher the Pa values, the lower the voids in the mixture. The values of voids in total mixture for 0,2, 4, 6 and 8% are within the FMWH (2016) requirement range of 3%-5%. The same trend was obtained by (Odunfa & Gbadewole, 2018).

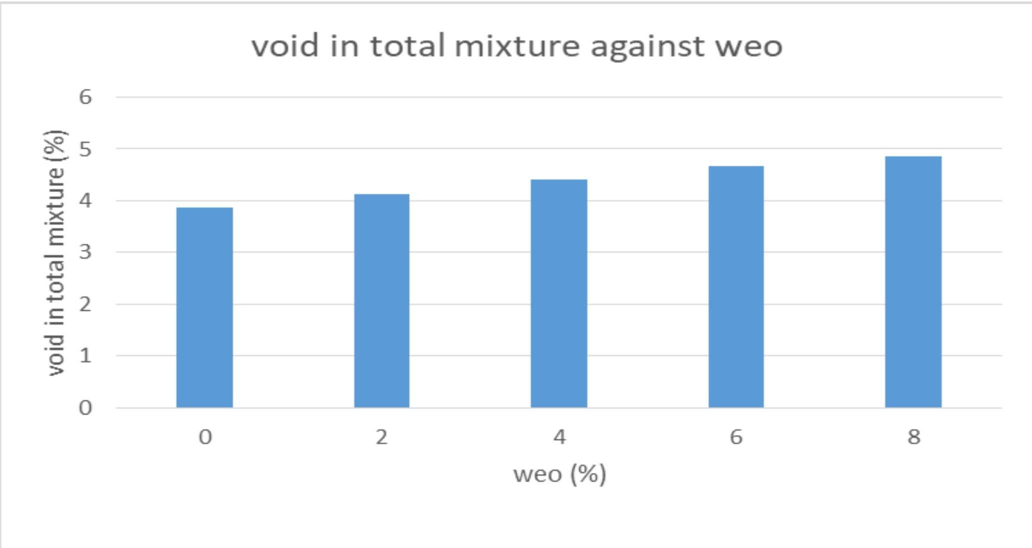

Figure 6: Variation of void in total mix with WEO

Voids Filled with Bitumen (VFB) Results

The results of voids filled with bitumen with variation of WEO content are displayed in Figure 7. The values of voids filled with bitumen for the modified mixes are 79.89, 79.27, 78.11, 76.03 and 75.25% for 0, 2, 4, 6, and 8 WEO content, respectively. The presence of WEO reduces the amount of bitumen that fills the voids because of the oil that occupy some of the void space, leading to a lower VFB. Therefore, the control mix typically has a higher VFB due to more efficient filling of voids with bitumen compared to the modified mix that includes WEO. The results of the voids filled with bitumen showed a continuous reduction with the increase in WEO content. All values of voids filled with bitumen for the modified mixes are lower than the values of the control. The reduction in VFB translates to an increase in the durability of asphalt concrete. These results can be attributed to the uniform dispersion of WEO in bitumen, which improved bitumen viscosity, causing an increased coating of bitumen around the aggregate. The results are within the range of 75%-82% specified by FMWH (2016) to avoid bleeding where there is rise in temperature. Similar trends were obtained by (Murana, *et al*., 2014).

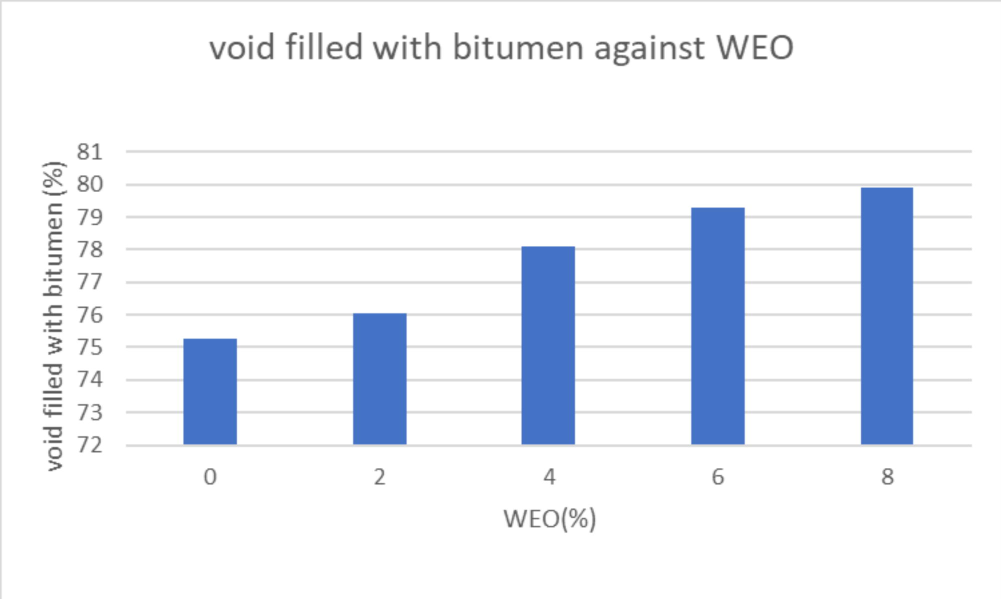

Figure 7: Variation of void with bitumen with WEO

CONCLUSION

The physical properties of the reclaimed asphalt pavement (RAP) were within the acceptable limits specified by the Federal Ministry of Works and Housing (FMWH, 2013), indicating that the RAP aggregates were durable and suitable for use in asphalt concrete production. The particle size distribution (gradation) of the RAP was determined using a series of sieves (12mm, 9.5mm, 6.4mm, 3.2mm, 1.25mm, 0.6mm, 0.3mm, 0.15mm and 0.075mm) and analyzed according to the Asphalt Institute (2014) method for combined gradation to determine the optimal blending percentages with other aggregates. Following AASHTO T 164 asphalt extraction standards, the extracted binder content of the RAP, after aging on-site, was determined to be 4.53% by weight of the asphalt mix. Marshall Stability testing of the control mix (without WEO) indicated an optimum bitumen content of 6%. This value served as a benchmark for determining the appropriate binder replacement when incorporating WEO. From the Marshall Stability test carried out on the modified mixes, it was found out that the stability of the mix decreases as the percentage of wastes engine oil increases, to about 0.9% compared to the control same as the vfb to about 2%. Flow, air voids, and VMA increases to about 0.31%, 0.21 %, 2.82%.

RECOMMENDATIONS

With the research showing that wastes engine oil can be used as partial replacement of bitumen in road construction. The following recommendation are made. Further studies should be done on the use and performance of WEO in the blend of bituminous mixes to develop standard procedure and application of the practice. Also, economic feasibility studies should be done to ensure that the economic benefits are realized when the technique is applied in road construction. For further research, rheological properties of wastes engine oil modified bitumen incorporating RAP, should be studied, since the science of rheology deals with the flow and deformation of materials and the interrelationship between time, force and deformation

REFERENCES

Atajeromavwo Okiemute Dickson; Yoro, Rume Elizabeth; Ukpenusiowho, Daniel; Oyewale, Mojeed Adebowale, E. J. O. (2024). ESTIMATION OF OIL SPILLAGE AND SALVAGE REVENUE IN KOKORI OIL FIELD USING NUMERICAL METHODS AND PYTHON ALGORITHM. *FUDMA JOURNAL OF SCIENCES*, *8*(5), 232–237. https://doi.org/10.33003/fjs-2024-0805-2686

Cengiz Ismail Emrah; Guler, Erol, C. K. (2019). On the shear failure mode of granular column embedded unit cells subjected to static and cyclic shear loads. *Geotextiles and Geomembranes*, *47*(2), 193–202. https://doi.org/10.1016/j.geotexmem.2018.12.011

Khoaele Ipoteng Justice; Gbadeyan, Oluwatoyin Joseph; Sithole, Bruce; Chunilall, Viren, K. K. M. (2024). Current Approaches on Natural Fiber Reinforcement Surface Treatment for Construction Material Application. *International Journal of Polymer Science*, *2024*(1), NA-NA. https://doi.org/10.1155/2024/1387468

Mohajerani Bao Thach; Tanriverdi, Yasin; Chandrawanka, Kavindha, A. N. (2017). A new practical method for determining the LA abrasion value for aggregates. *Soils and Foundations*, *57*(5), 840–848. https://doi.org/10.1016/j.sandf.2017.08.013

Atajeromavwo Okiemute Dickson; Yoro, Rume Elizabeth; Ukpenusiowho, Daniel; Oyewale, Mojeed Adebowale, E. J. O. (2024). ESTIMATION OF OIL SPILLAGE AND SALVAGE REVENUE IN KOKORI OIL FIELD USING NUMERICAL METHODS AND PYTHON ALGORITHM. *FUDMA JOURNAL OF SCIENCES*, *8*(5), 232–237. https://doi.org/10.33003/fjs-2024-0805-2686

Cengiz Ismail Emrah; Guler, Erol, C. K. (2019). On the shear failure mode of granular column embedded unit cells subjected to static and cyclic shear loads. *Geotextiles and Geomembranes*, *47*(2), 193–202. https://doi.org/10.1016/j.geotexmem.2018.12.011

Khoaele Ipoteng Justice; Gbadeyan, Oluwatoyin Joseph; Sithole, Bruce; Chunilall, Viren, K. K. M. (2024). Current Approaches on Natural Fiber Reinforcement Surface Treatment for Construction Material Application.

International Journal of Polymer Science, *2024*(1), NA-NA. https://doi.org/10.1155/2024/1387468

Mohajerani Bao Thach; Tanriverdi, Yasin; Chandrawanka, Kavindha, A. N. (2017). A new practical method for determining the LA abrasion value for aggregates. *Soils and Foundations*, *57*(5), 840–848. https://doi.org/10.1016/j.sandf.2017.08.013

Atajeromavwo Okiemute Dickson; Yoro, Rume Elizabeth; Ukpenusiowho, Daniel; Oyewale, Mojeed Adebowale, E. J. O. (2024). ESTIMATION OF OIL SPILLAGE AND SALVAGE REVENUE IN KOKORI OIL FIELD USING NUMERICAL METHODS AND PYTHON ALGORITHM. *FUDMA JOURNAL OF SCIENCES*, *8*(5), 232–237. https://doi.org/10.33003/fjs-2024-0805-2686

Cengiz Ismail Emrah; Guler, Erol, C. K. (2019). On the shear failure mode of granular column embedded unit cells subjected to static and cyclic shear loads. *Geotextiles and Geomembranes*, *47*(2), 193–202. https://doi.org/10.1016/j.geotexmem.2018.12.011

Khoaele Ipoteng Justice; Gbadeyan, Oluwatoyin Joseph; Sithole, Bruce; Chunilall, Viren, K. K. M. (2024). Current Approaches on Natural Fiber Reinforcement Surface Treatment for Construction Material Application. *International Journal of Polymer Science*, *2024*(1), NA-NA. https://doi.org/10.1155/2024/1387468

Mohajerani Bao Thach; Tanriverdi, Yasin; Chandrawanka, Kavindha, A. N. (2017). A new practical method for determining the LA abrasion value for aggregates. *Soils and Foundations*, *57*(5), 840–848. https://doi.org/10.1016/j.sandf.2017.08.013

Atajeromavwo Okiemute Dickson; Yoro, Rume Elizabeth; Ukpenusiowho, Daniel; Oyewale, Mojeed Adebowale, E. J. O. (2024). ESTIMATION OF OIL SPILLAGE AND SALVAGE REVENUE IN KOKORI OIL FIELD USING NUMERICAL METHODS AND PYTHON ALGORITHM. *FUDMA JOURNAL OF SCIENCES*, *8*(5), 232–237. https://doi.org/10.33003/fjs-2024-0805-2686

Cengiz Ismail Emrah; Guler, Erol, C. K. (2019). On the shear failure mode of granular column embedded unit cells subjected to static and cyclic shear loads. *Geotextiles and Geomembranes*, *47*(2), 193–202. https://doi.org/10.1016/j.geotexmem.2018.12.011

Khoaele Ipoteng Justice; Gbadeyan, Oluwatoyin Joseph; Sithole, Bruce; Chunilall, Viren, K. K. M. (2024). Current Approaches on Natural Fiber Reinforcement Surface Treatment for Construction Material Application. *International Journal of Polymer Science*, *2024*(1), NA-NA. https://doi.org/10.1155/2024/1387468

Mohajerani Bao Thach; Tanriverdi, Yasin; Chandrawanka, Kavindha, A. N. (2017). A new practical method for determining the LA abrasion value for aggregates. *Soils and Foundations*, *57*(5), 840–848. https://doi.org/10.1016/j.sandf.2017.08.013