



## Stability Properties of Waste Engine Oil Modified Asphalt Mixtures

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### Abstract

Nigerian automobile industries generate over 200 million liters of Waste Engine Oil annually. They cause environment pollution in terms of their disposal and soil degradation. Several studies have discussed the reuse of waste materials in road paving to minimize the use of bitumen. In this study, waste engine oil was used at 0,2,4,6,8% to modify 20/30 penetration grade bitumen, the modified bitumen samples were then used to produce dense graded asphalt mixtures and the stability and volumetric properties of the mixtures were evaluated. The addition of WEO to bitumen changes the properties of bitumen with penetration, softening point, flash point, fire point and viscosity changing by 44, -22, -16.8, -15.7, -9% respectively. The covariance between WEO and bitumen properties has positive value with penetration while it has negative covariance with all other properties. The modified bitumen becomes softer and this type of bitumen are primarily used in cold climates. The relationship between stability properties of the mix and WEO percentage has a strong coefficient of determination across all properties. The stability, flow, voids in total mix, VTM, voids filled with bitumen, VFB of the mixtures produced from neat bitumen changed by 2.05, 15.2, -134.01, -32., 27.08% respectively at 8% WEO replacement. Based on stability, VFB and VTM, the optimum binder content that yields best results is at 8% WEO replacement. This study can serve as a preliminary laboratory experiment for evaluating its potential.

## 1 INTRODUCTION

Optimizing bitumen's engineering qualities requires a thorough understanding of its many kinds, including cutback bitumen, emulsion bitumen, polymer-modified bitumen, and bitumen grades. Several studies have been conducted to discuss reusing waste materials in road paving to minimize the use of bitumen [1]. Nigerian automobile industries generate a lot of waste engine oils to the extent of over 200 million liters annually [2], while smaller country by population like Kenya produces over 30 million liters per year of WEO [3]. These oils find its application in the modification of bitumen in modern development of asphalt technologies ([4], [5], and [6]). Few studies on the use WEO modified can be found in Nigeria like [7] evaluated the properties of WEO modified 60/70 penetration grade bitumen but did not evaluate the marshal properties of WEO modified asphalt mix. Nigeria mostly uses 60/70 and 80/100 grade bitumen for road purposes [8]. One of the major causes of road failure in Nigeria is using inappropriate materials such as using wrong grade of bitumen [9].

Therefore, investigating the use WEO in the modification 20/30 penetration grade bitumen in asphalt production can broaden the application of penetration grade bitumen in flexible pavements.

## 2 MATERIAL AND METHOD

The WEO utilized in the study was collected from a local auto repair shop. The basic properties of WEO. The WEO was be filtered using cotton wool as filter in order to remove solid impurities to ensure regeneration effectiveness. It was also being boiled at temperature greater than 100 degrees to make sure the water is removed

from the engine oil. However, for this study, the optimum bitumen content was assumed to be 5% [8]. The asphalt samples were made by mixing six aged asphalts with five WEO contents (2%, 4%, 6%, and 8%, by mass of asphalt). High shear mixer at constant speed of will be used for 30 minutes at 135 °C. During the mixing, the time and temperature should remain stable to ensure good experimental results.

## 2.1 Material Testing

For the purpose of this research, the following materials were used, aggregates, bitumen, waste engine oil. The physical properties of the aggregates were determined and the aggregate gradation has been chosen as a wearing course (dense gradation) based on the Nigerian Specifications. Some of the conventional tests have been conducted for the base bitumen such as Penetration test, Softening Point test to measure the bitumen characteristics. The following test will be conducted according to the ASTM specification. The WEO utilized in the study was collected from a local auto repair shop. The basic properties of WEO was determined. The WEO will be filtered using cotton wool as filter in order to remove solid impurities to ensure regeneration effectiveness. It should also be boiled at temperature greater than 100 degrees to make sure the water is removed from the engine oil.

**Table 1.** Tests on WEO

S/N	Tests	Purpose
1.	Penetration test (ASTM D5 EN 14264)	Determines bitumen consistency to ensure suitability for construction applications.
2.	Softening point test (ASTM D36 EN 1427)	Evaluates bitumen's temperature susceptibility for application and performance.

**Table 2.** Tests of bitumen and modified bitumen

S/N	Tests	Purpose
1.	Penetration test (ASTM D5 EN 14264)	Determines bitumen consistency to ensure suitability for construction applications.
2.	Softening point test (ASTM D36 EN 1427)	Evaluates bitumen's temperature susceptibility for application and performance.
3.	Specific gravity (ASTM D113)	Measures bitumen density for quality and performance assessment.
4.	Flash point (ASTM D92)	Determines bitumen's flammability and safety for handling and storage.

## 2.2 Methodology

In this study, the Marshall method of mix design (ASTM D 1559) has been adopted to find the required optimum binder content for each asphalt mixture. The determination of optimum binder content/WEO can be done through drain down test of uncompact mix or marshal stability test. However, for this study, the optimum bitumen content was assumed to be 5% [8]. The generators of the design in our case are WEO/bitumen content with different are presented in Table 3.

**Table 3.** Mixtures

S/N	WEO %	Optimum Bitumen Content %
1	0	100
2	2	98
3	4	96
4	6	94
5	8	92

## 3 RESULTS

### 3.1 Properties of Aggregates and Its Gradation

The aggregates used in this study is well graded and suitable for use as wearing course and it has sufficient strength, hardness, and toughness based on the standard specification for roads and bridges, 2013. See Tables 4 and 5

**Table 4.** Aggregate Properties

Test	Virgin Aggregates
Specific gravity	2.64
Water Absorption	1.41
Flakiness	10
Elongation	44
Aggregate Impact Value	

**Table 5.** Aggregate Gradation

Sieve Sizes(in.)	Selected Gradation
$\frac{3}{4}$	100
$\frac{1}{2}$	92
$\frac{3}{8}$	73
No.4	44
No.10	33
No.40	13
No.80	8
No. 200	5

**Table 6.** Aggregate Gradation

Test	Base	WEO 2%	WEO 4%	WEO 6%	WEO 8%	Standard
Penetration (dmm)	20.7	22.7	25	27.3	30	ASTM D5(20/30)
Softening point (Degree Celsius)	62.5	57	53.5	51	47.5	ASTM D36(32 )
Flashpoint(Degree Celsius Min)	237	232	226	216	197	ASTM D92 (177 )

### 3.2 Descriptive Statistics

ANOVA output provides an estimate of how much variation in the dependent variable that can be explained by the independent variable. Single factor anova was used to describe each property as it changes with percentage WEO. The larger the F value the more likely it is that the variations due to the independent variables of softening point, penetration, and flashpoint is not due to chance. All P- values are significantly lower than 0.05 significance level, which implies that percentage of WEO has significant effect on the the responses bituminous properties.

**Table 7.** Descriptive statistics

	<i>P-value</i>	Mean	Variance	<i>F</i>	<i>F crit</i>
Softening Point	2.68E-08	54.3	33.07	445.05	5.31
Penetration	3.34E-07	25.14	13.49	233.44	5.31
Flashpoint	1.18E-09	221.6	250.3	980.59	5.31

**Table 8.** Covariance Matrix

	<i>WEO</i>	<i>Penetration</i>	<i>Softening point</i>	<i>Flashpoint</i>
WEO(%)	8			
Penetration	9.28	10.7944		
Softening point	-14.4	-16.612	26.46	
Flashpoint	-38.4	-45.204	67.32	200.24

**Table 9.** Correlation Matrix

	<i>WEO</i>	<i>Penetration</i>	<i>Softening point</i>	<i>Flashpoint</i>
WEO(%)	1.00			
Penetration	1.00	1.00		
Softening point	-0.99	-0.98	1.00	
Flashpoint	-0.96	-0.97	0.92	1.00

The correlation matrix which is used to measure the strength of linear relationships between pairs of variables. The results are presented in Table 3.4. A correlation of coefficient of +1 indicates a strong positive relationship and -1 a perfect negative relationship.

Covariance matrix is used to describe variance between multiple variables. It also shows how much two random variables change together. See Table 4.5. The covariance between WEO and bitumen properties has positive value with penetration i.e. as WEO content increases so does the penetration value of the samples. This also implies that addition of WEO makes the bitumen softer. While the covariance with softening point, flash point, fire point, viscosity all have negative covariance. This shows that as WEO percentage in bitumen increases it causes a decrease in these parameters.

### 3.3 The Effect WEO Portion on Marshal Stability Properties

Similarly, the larger the F value the more likely it is that the variations due to the independent variables of stability, flow, VMA, VFB, VTM is not due to chance. All P- values are significantly lower than 0.05 significance level, which implies that percentage of WEO has significant effect on the responses of stability properties.

**Table 10.** Descriptive statistics and Single factor ANOVA

	<i>P-value</i>	Mean	Variance	<i>F</i>	<i>F crit</i>
Stability	0.009907	2.5125	1.75	13.80	5.98
Flow	1.08E-09	6.875	0.046	3967.12	5.98
VTM	0.000232	5.932043	2.26	61.05	5.98
VFB	2.35E-07	17.03556	1.76	654.44	5.98
VMA	2.35E-07	17.03556	1.76	654.44	5.98

It can be seen from the graph in Figure 1, that the stability for all mixes increases up to an optimum percent of WEO content from which further increase in the WEO content causes a reduction in the stability value of the mix. A WEO content of 8% gives the highest stability value. The flow value increased with increasing WEO content. The results showed that when samples were prepared upon the addition of WEO along with bitumen binder, the Flow Value of samples was increased as the content of WEO was increased. This indicates that upon the addition of WEO fluidity of bitumen was enhanced. This indicates that the partial replacement of Bitumen with WEO increased the workability of the mix. The maximum deformation at which a Marshall specimen fails is termed as the flow value. It is a measure of deformation. A higher flow value of bituminous pavement indicates lower rigidity. The range of flow specified in Road Note 19 is 2mm-4mm. Voids in mineral aggregate is the volume of the intergranular void space between the aggregate particles of a compacted paving mixture that includes the air voids and the effective asphalt content. Insufficient VMA results in a lack of capacity to add adequate asphalt binder to coat the individual aggregate particles in the mixture, while excessive, it causes instability. As per the results of the VMA analysis, as shown in Figure 1, the VMA value marginally decreases with increase in WEO percentage from 20.6% for base bitumen to 15.6% for bitumen modified with 8% of WEO. The minimum value of VMA as specified in Road Note 19 is 13%. The percentage of voids filled with bitumen should be limited so as to prevent the possibility of bleeding. The allowable range of values of VFA is 65-75%. There is an increase in voids filled with asphalt from 58.1% to 72.7% for 0% and 8% WEO respectively. The blending of the polymer-modified bituminous mix with WEO caused the value of VFB to fall outside the acceptable range. The percentage of air voids in the mix decreased with increasing concentration of WEO in the mixes in an almost linear relation. The amount of air voids present in the mix is a very important design criterion since there should be sufficient air voids in the pavement mix so that the binder can coat the aggregate properly and, at the same time, it would not create a bleeding problem at elevated temperatures. Road Note 19 specifies an acceptable range of 3%-5%. As indicated in Figure 1, the percentage of air voids in the mix decreased with increasing concentration of WEO 7.8 to 4.3% at 8% WEO content. All samples meets the Nigerian General specification [9] as shown Table .

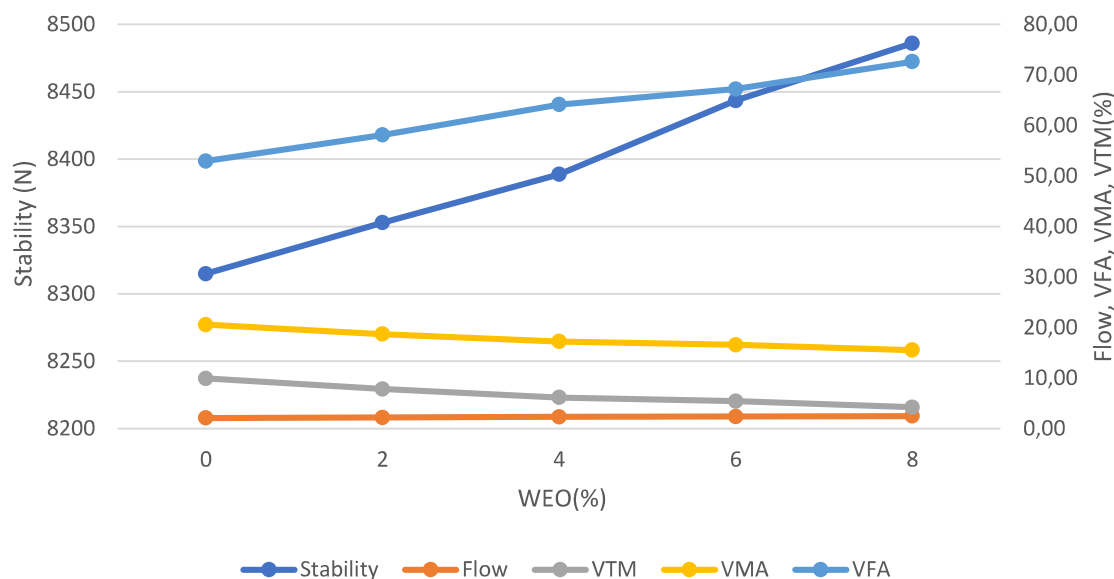


Figure 1. Marshal stability Properties vs WEO %

Table 11. Nigerian Specification for roads and bridges, 2016

NGS(2016)	Stability(N)	Flow(mm)	VTM(%)	VFB(%)
NGS(wearing course)	>3500	4	5	82
NGS(base course)	>3500	6	8	72

#### 4 CONCLUSION

The Properties of bitumen modified with waste engine oil has been investigated. The modified bitumen was used to make dense graded asphalt mixture and Marshal stability and flow properties of the mixture was then evaluated. The addition of WEO to bitumen changes the bitumen with penetration, softening point, flash point, fire point and viscosity changes by 44, -22, -16.8, -15.7, -9% respectively. The modified bitumen becomes softer and this type of bitumen are used in cold climates. From the Marshall Stability tests carried out on the modified mixes, it was found that the stability of the mix increased with increasing waste Engine oil percentage. It varied from 8315N for the neat sample to 8486N for the mix modified with 8% WEO. The relationship between stability of the mix and WEO percentage has a positive coefficient of determination. Similarly, the flow varied from 2.13% for the neat sample to 2.51% for the mix modified with 8% WEO. The relationship between flow of the mix and WEO. The VMA value marginally decreases with increase in WEO percentage from 20.6% for base bitumen to 15.6% for bitumen modified with 8% of WEO. There is an increase in voids filled with asphalt from 58.1% to 72.7% for 0% and 8% WEO respectively. The percentage of air voids in the mix decreased with increasing concentration of WEO from 7.8 to 4.3% at 8% WEO content.

The utilisation of modified bituminous mix in highway construction, the pollution and disposal problems of waste may be partly reduced. The use of innovative technology will not only strengthen road construction but also increase road life as well as will help to improve the environment. Further studies should be done on the use and performance of waste engine oil in the blend of bituminous mixes to develop standard procedures for the application of the practice since only partial replacement of WEO with bitumen was carried out. Also, economic feasibility studies should be done to ensure that an economic benefit is realised once the technique is applied in road construction. The cost of processing the waste engine oil may be of concern. Therefore; the need to carry cost benefit analysis of its use.

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