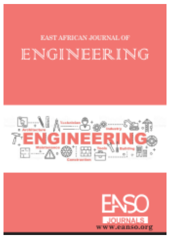

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Original Article

Performance of Plastic Waste and Waste Engine Oil as Partial Replacements of Bituminous Asphalt Concrete in Flexible Pavement

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ABSTRACT

Plastic waste is an emerging issue posing serious pollution problems to the environment. Waste Engine Oil has also become an environmental nuisance causing water pollution and soil degradation. New effective waste management options need to be considered, especially on recycling concepts. In addition to the emerging environmental issues, the sources of bitumen for road construction are continuously being depleted hence the need for innovative ways of sustaining road construction through the use of plastic waste and waste engine oil. This research project reviewed available literature on the concept of using waste plastic and waste engine oil as partial replacements of bitumen in road construction together while also carrying out the Marshall Stability test in both neat and bituminous mixes modified with plastic waste and waste engine oil. The optimum bitumen content was determined as 6% from the neat samples. Samples of the modified mix were then prepared with the percentage plastic content varying as 10%, 20%, 30%, and 40% of the mass of bitumen. The optimum plastic content was determined at 18% with a stability value of 8580N (an increase from 8337.4N for the neat samples). Samples with both plastic waste and waste engine oil replacements were prepared with 18% plastic waste being replaced with 10%, 20%, 30%, and 40% waste engine oil. The optimum replacement was determined at 19% giving the highest stability of 8820N (an increase of 2.8% from the plastic-only modified mix and an increase of 5.8% from the neat sample). With the utilisation of polymer-modified bituminous mix in highway construction, the pollution and disposal problems of waste plastic 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.

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INTRODUCTION

The transportation infrastructure assets are heavily dependent on the functional and structural performance of pavement networks such as ports, airports, and highways for their efficiency and productivity. Construction of new pavement requires advanced technologies and high-quality materials. However, there is a significant burden on non-renewable natural resources such as carbon-based energy carriers (bituminous binder and industrial fuel) and quarried aggregate sources as a result of pavement construction. Year after year, the demands for roads continue to rise (World Highways, 2017). Commercial vehicles with increased axle loads are always increasing in number and the trend is expected to continue in the future. It is, therefore, crucial to increase the use of sustainable materials and construction technologies in road paving. This sustainability would cut down on the environmental impact of pavement design and construction. Highway engineers have been tasked with coming up with alternative solutions to this growing challenge.

All over the globe, there is currently a growing call to conserve or minimise using natural resources such as crude oil, which produces bitumen used in road paving. There are also growing calls by environmentalists to reuse waste materials. Several studies have been conducted to discuss reusing waste materials in road paving to minimise the use of Bitumen (Costa et al., 2013; Anastasiou et al., 2015; Costa et al., 2017). Studies that investigate the performance of new asphalt binders which incorporate wastes are vital in reducing the use of bitumen directly obtained from oil sources, which is essential for the sustainable development of road paving construction. Some of the studies have referred to non-petroleum binders (Metwally & Williams, 2010) and synthetic binders consisting of polymers, resins, and used oils (Fuentes-Auden et al., 2007).

Plastics are an example of waste materials that can be reused as they occur in numerous forms as post-consumer products. Plastics form a large percentage of solid waste in most towns across the world. Due to the rising human population, it is expected the consumption of plastic products will continue to rise globally hence continuing to pose a threat to the environment (Organization for Economic Co-operation and Development, 2022). Various governments have put in place legal frameworks with the aim of controlling the usage of plastic products. For example, in 2017, the Kenyan government banned the importation, use, and manufacture of plastic carrier bags (Kenya Ministry of Environment, 2017). However, people continue to use plastic products hence the need to manage plastic wastes.

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Waste Engine Oil (WEO) is also another waste material that can be reused as a partial replacement for bitumen due to its viscosity. Engine oil is a product of the fractional distillation of crude oil. The demand for oil is also still expected to increase (Deffeyes, 2006). Limited oil resources should, therefore, be carefully utilised. In addition to finding substitutes for oil products, used oil products can be reused.

The current study discusses the performance of bitumen modified with plastic waste and WEO. In incorporating plastic wastes and WEO in asphalt concrete, aggregate is coated with recycled plastic waste before being mixed with Bitumen and WEO and then laying on the road surface. Binder modified with High-Density Polyethylene (HDPE) and Waste Engine Oil (WEO) has been shown to improve characteristics of conventional bitumen with slightly higher penetration and high softening point temperatures. Experimental results have also shown that modified binder improves the mechanical properties of the pavement and provides better binding properties, density, and better in waterproofing. In the long run, using modified asphalt mixes in paving roads reduces the quantity of bitumen used hence cutting down the expenses of road construction. The new binder can be considered a sustainable solution for road paving since it meets both environmental and economic considerations (Moretti et al., 2013; Moretti et al., 2017). Using reduced quantities of bitumen in the mixes, and replacing them with waste materials, would reduce the costs of the asphalt mixes. The key challenge in using asphalt modified with waste materials is identifying the type of plastic and quantity of WEO and plastic for partial replacement, which are most suitable for use in the process.

Due to ongoing environmental concerns and limited resources, there have been increased calls by environmentalists and policymakers to reuse waste materials in road paving. Numerous studies have been conducted to investigate alternatives to Bitumen (Hashmi & Jabary, 2020). Construction industries, specifically road paving industries, use high quantities of limited natural resources such as bitumen and aggregates. Bitumen plants are responsible for environmental pollution due to the high amounts of greenhouse gases they emit. The process of producing bitumen is not eco-friendly. Bitumen is also non-renewable hence the need to use it carefully. The increasing cost of investing in road projects, coupled with the increasing pollution of the environment caused by plastic wastes lying around and poorly disposed of WEO, calls for appropriate solutions to manage such wastes, which will greatly reduce the cost of road construction while at the same time help mitigate the effects of plastics and used oil on the environment. WEO is a waste product from generators in petrol stations and garages. High rates of discharges of WEO have negative impacts on the environment leading to soil degradation and negatively affecting flora and fauna hence a concern for public health and a concern for the country's image across the globe. Kenya produces an estimated 30 million litres of WEO each year (Takouleu, 2019). The disposal of waste engine oil has been poor in Kenya over the years. It has led to contamination. There is no legal framework which has been put in place to ensure the proper disposal of WEO hence addressing the issue of environmental pollution by WEO. Therefore, there is a need to develop sustainable management of WEO and plastic waste. Reusing these waste materials in road paving would reduce environmental pollution while also providing an economical and sustainable solution to challenges facing highway engineers.

The main objective of the study was to investigate the performance of plastic waste and waste engine oil as partial replacements for bituminous asphalt concrete in flexible pavements. The proposed experimental research made use of High-Density Polyethylene (HDPE) grade of plastic and WEO to make the blend of the modified bituminous mix. The study will determine the properties of Ordinary bitumen of grade 60/70 and WEO (Penetration,

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Softening Point, and Specific Gravity). It will also determine the properties of course and fine aggregates (Los Angeles Abrasion, Aggregate Crushing Value, Aggregate Impact Value, and Water Absorption Test). Marshall's Stability test was then performed on both neat samples and modified samples, and their properties were compared to determine the suitability of incorporating waste plastic and WEO into the bituminous mix. All sampling and testing were conducted in the University of Nairobi Highways Laboratory. Data collected from tests were presented graphically, and comparisons were made between the mixes of different replacements.

MATERIALS AND METHODS

Materials

The materials used in the laboratory investigations were plastic wastes, waste engine oil, bituminous binder, and aggregates. These were sourced from various local suppliers. The materials were prepared and tested as required by various codes.

Ordinary bitumen of grade 60/70 was used in the experimental investigation. The bitumen was sourced from a local provider of Bitumen- Quality Bitumen Limited, Baba Dogo, in Nairobi.

Quality Bitumen Limited's production of bitumen was considered to meet the requirements set out by the American Association of Highway and Transportation Officials (AASHTO) and the guidelines of the Kenya Bureau of Standards. The following tests were conducted on the Bitumen:

- Penetration at 25°C, 100g, 5s *(ASTM D5 Test)*
- Softening Point, ring-and-ball *(*ASTM *D36 Test)*
- Specific gravity at 25°C *(AASHTO Test T228)*

The coarse and fine aggregates were sourced from the Mlolongo quarry along Mombasa Road in Machakos County. Aggregate sizes of 14/6 and 0/6 were used as chippings for the test. Sieve grade analysis was done on a sample of the oven-dried aggregates so as to obtain a batch that lies within the grading envelope. Wet sieve analysis of the quarry dust was also carried out. A sampling of the aggregates was done using the riffle box quartering to ensure a good representation of the aggregates was sampled. The mechanical properties of the aggregate, such as strength, toughness, hardness, water absorption, were investigated to ensure that they were within the specifications as stated by the Kenya Road Design Manual. Aggregates of sufficient strength, hardness, and toughness were used. The following tests were conducted on the aggregates:

- Los Angeles Abrasion (ASTM C131)
- Aggregate Crushing Value (BS812 Part3)
- Aggregate Impact Value (BS812 Part3)
- Water Absorption Test (ASTM C127)

Plastic can be used as a binder, and/or they can be mixed with a binder like bitumen to enhance its binding property. Crushed waste plastic materials were obtained from EcoPost Limited, a plastic waste recycling company located in Baba Dogo, Nairobi. The company is the only known source of quality shredded plastic that has been separated into the different types of plastic available. At EcoPost Limited, plastic waste was segregated into different types of plastics according to the guidelines provided by the Society of Plastic Industry. The plastics were then cleaned before to eliminate impurities being dried off, followed by shredding. HDPE type of plastic was chosen for this test. The plastics were prepared by washing and sun-drying before being sieved.

The low viscosity of engine oil is its most exceptional characteristic hence making it a suitable material for partial replacement with bitumen. Engine oil in asphalt mixes prevents ageing hence lower temperatures in compaction and mixing. Waste engine oil is not totally reusable hence using it as a partial replacement for bitumen is

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environmentally friendly. For this investigation, the waste engine oil was obtained from a lube bay at Shell Petrol Station on Latema road in Nairobi City. The waste engine oil obtained was the multi-grade oil SHELL HELIX HX5 15W-40, whose properties are known. The following tests were conducted on the waste engine oil:

- Penetration at 25°C, 100g, 5s *(ASTM D5 Test)*
- Softening Point, ring-and-ball *(ASTM D36 Test)*
- Specific gravity at 25°C *(AASHTO Test T228)*

Mixes

After the tests were carried out on the specific materials, i.e., bitumen, aggregates, and waste engine oil, the optimum content of bitumen was determined. Marshall stability and flow tests together with volumetric tests, were carried out to determine the Optimum Bitumen Content (OBC) and

Optimum Modifier Content (OMC) of the bituminous concrete mix. The bituminous concrete specimens were prepared with 4%, 5%, 6%, 7%, and 8% of bitumen by weight of aggregates as per the ASTM 1599 test procedure. Two specimens were prepared for each batch, and an average of values was used for analysis.

Partial replacement of bitumen with plastic waste and waste engine oil was done based on the Optimum Bitumen Content. The percentage of replacements (plastic waste and waste engine oil) was a percentage of bitumen weight. Two specimens were prepared for each batch for the Marshall test and an average of values was used for analysis.

Marshall Stability Test

Knowing the optimum bitumen content to use with the specified aggregate gradation, the Marshall, flow, and volumetric tests were performed on specimens whose bitumen content had partially been replaced by plastic waste and waste engine oil. The bitumen content as a percentage of the mass of aggregates was replaced with various combinations of plastic and engine oil to determine the optimum replacement for the combination of both wastes.

A modified dry process of blending waste plastic (to include WEO) in a bituminous mix was used for the experimental procedure. The plastic obtained from EcoPost had already been segregated into different plastics, cleaned, dried, and shredded into 2-4mm sizes. The quantity of aggregate was measured and heated to around 160°C. The shredded plastic chippings were then added to the heated aggregates and mixed thoroughly for 30 – 40 seconds for uniform coating at their surface. The coated aggregate was mixed with hot Bitumen and WEO at a temperature of 165°C in quantities required for each batch. The composite mixture of plastic, WEO, Bitumen, and aggregates was used for experimental investigation at a temperature of 150°C.

Following the ASTM 1599 test procedure, the Marshall stability test was conducted on all specimens made up of different percentages of bitumen, plastic waste, and waste engine oil. The principle of this test is that Marshall Stability is the resistance to the plastic flow of cylindrical specimens of a bituminous mixture loaded on the lateral surface. It is the load-carrying capacity of the mix at 60°C and is measured in kg. The total weight of the mix should be 1200g. Readings for all samples were then recorded and comparisons were made. The data obtained on the various parameters were analysed graphically with the aim of making comparisons for the mixes with different compositions of binders. The data was compared to the standard required of the mixes. The following parameters were determined from the Marshall Stability test:

- Bulk Specific Gravity of Compacted Mix (Gmm)
- Percent Air Voids in Compacted Mix (VIM) (%)

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- Voids in Mineral Aggregate (VMA) (%)
- Percent Voids Filled with Bitumen (VFB) (%)
- Stability (N)
- Flow (mm)

RESULTS AND DISCUSSIONS

Tests on Bitumen

The tests that were done in order to evaluate the properties of the binder included the ring-and-ball softening point and the penetration test. These tests were done in accordance with the AASHTO procedures. The results are presented as shown in *Table 1*.

Table 1: Results of tests on bitumen

Penetration at 25^0C, 100g, 5s (ASTM D5 Test)	64
Softening Point, ring-and-ball (ASTM D36 Test)	55.0^0C
Specific gravity at 25^0C (AASHTO Test T228)	1.01

Based on the results, the bitumen was classified as being of penetration grade 60/70. The 60/70 penetration grade bitumen is generally recommended for use in HMA in a tropical climate such as the one experienced in the majority of parts of Kenya.

Tests on Aggregates

The physical properties, which were determined by the aggregate gradation as well as mechanical properties, which included hardness, toughness and durability of aggregate had a great influence on the mix properties. The amount of aggregate required for each sample for the Marshall test was that which was sufficient to make compacted specimens 63.5 ± 1.27 mm high. This was normally approximately 1.2kg and was confirmed by compacting a trial sample of 1.2kg of blended aggregate mixed at the estimated optimum bitumen content.

Coarse Aggregate

Aggregate passing 25 mm and retained #8 sieve was used as coarse aggregate, which was crushed gravel. The behaviour of bituminous mixes is highly affected by the gradation and quality of coarse aggregate. The value of the Marshall Stability of the mix depends on the characteristics of the coarse aggregate used. Hence, the selection of an appropriate coarse aggregate of the desired gradation is important. Moreover, it was important that the aggregate be clean, tough, durable material free from vegetable matter, soft particles, and other objectionable matter. The maximum size of coarse aggregate that was used in the mix is 14 mm. A specific gravity test was performed using the AASHTO T85 procedure and was found to be 2.55.

Fine Aggregate

Aggregate passing sieve #8 and retained #200 was the fine aggregate used in the test procedure. It consisted of natural sand and stone screenings. It was ensured that the fine aggregate was composed of clean, hard, durable particles, rough-surfaced and angular, free from vegetable matter, soft particles, clay balls or other objectionable matter. The specific gravity of the fine aggregate, as determined using the AASHTO T84 was found to be 2.60.

Mineral Filler

The properties of bituminous materials depend not only upon the quality of the binder and aggregates but also upon the properties of the filler. The mineral filler used for this test was Portland cement which passes the #200 sieve. It was ensured that the

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filler was non-plastic and free from foreign and other objectionable materials. Bituminous materials are influenced by such factors as the amount and mineral composition, the grading and shape of the grains, micro-coarseness, and the specific activity of the filler. The specific gravity of mineral filler, as determined using the AASHTO T100 procedure was found to be 3.12.

Mechanical Properties

The mechanical properties of the aggregate such as strength, toughness, hardness, water absorption, were investigated to ensure that they were within the specifications as stated by the Kenya Road Design Manual Part III. The results were found to be within the allowable limits of the bituminous concrete mix.

Table 2: Results of tests on aggregate

Type of Test	Result	Specification (Maximum allowable %)
Los Angeles Abrasion *(ASTM C131)*	17.2%	35%
Aggregate Crushing Value *(BS812 Part3)*	17.98%	28%
Aggregate Impact Value *(BS812 Part3)*	6.95%	30%
Water Absorption Test *(ASTM C127)*	1.87%	2%

Aggregate Gradation

Well-graded materials produce the densest and therefore, the most stable and durable mixes requiring the minimum bitumen content for satisfactory results. The aggregate gradation used for this research for testing both neat and modified samples was as shown in *Table 3*. *Figure 1* shows the grading curve fell within the grading envelope.

Table 3: Aggregate Gradation

Sample no	Nominal Size	AGGREGATES Description and Source	TRIAL MIX		
			Total Wt.	%	Wt.
2	0	Aggregates	0	0	0
3	0	Aggregates	0	0	0
4	6/14	Aggregates	1100	53	583
5	0/6	Crushed rock	1100	47	517

SIEVE ANALYSIS % PASSING									
Sample Number		1	2	3	4	5	THEO. COMBINED GRADING	DESIGN MIX SPEC.	
% In Mix	100	0	0	0	53	47			
Sieve Size (mm)									
28		100	100	100	100	100	100.0	100	
20		100	100	100	100	100	100	100	
14		100	100	100	96	100	98	90	100
10		100	100	100	57	100	77	70	90
6.3		100	100	100	23	96	57	55	75
4		100	100	100	9	90	47	45	63
2		100	100	100	0	70	33	33	48
1		100	100	100	0	54	25	23	38
0.425		100.0	100	100	0.0	38	18	14	25
0.3		100.0	100	100	0.0	34	16	12	22
0.15		100.0	100	100	0.0	27	13	8	16
0.075		100.0	100	100	0.0	22	10	5	10

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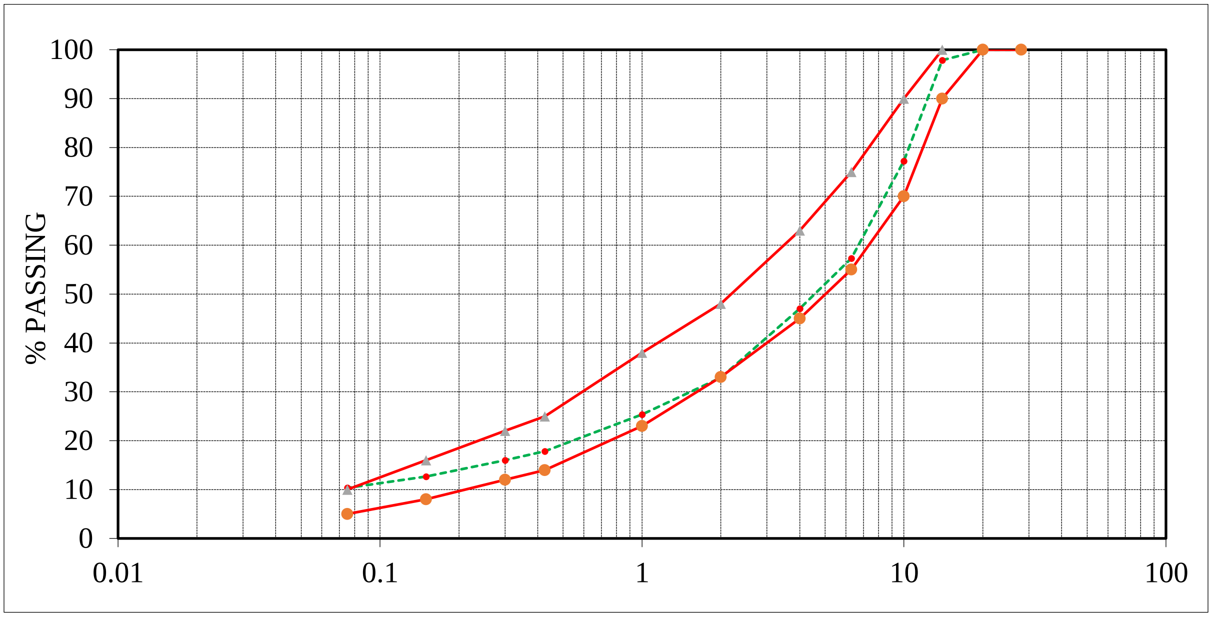
Figure 1: Aggregate grading used in the mix design and design specifications



Marshall Test

Marshall stability and flow tests together with volumetric tests were carried out to determine the optimum bitumen content (OBC) and optimum modifier content (OMC) of the bituminous concrete mix. The bituminous concrete specimens were prepared with 4%, 5%, 6%, 7%, and 8% of bitumen by weight of aggregates as per the ASTM 1599 test procedure. Two specimens were prepared for each batch and an average of values was used for analysis.

Knowing the optimum bitumen content to use with the specified aggregate gradation, the Marshall, flow, and volumetric tests were performed on specimens whose bitumen content had partially been replaced by plastic. The bitumen content as a percentage of the mass of aggregates was replaced with 10%, 20%, 30%, and 40% of plastic so as to determine the optimum plastic percentage.

Knowing the optimum bitumen and plastic contents to use with the specified aggregate gradation, the Marshall, flow, and volumetric tests were performed on specimens whose bitumen and plastic contents had partially been replaced by the waste engine oil. The bitumen and plastic content as a percentage of the mass of aggregates was replaced with 10%, 20%, 30%, and 40% of waste engine oil so as to determine the optimum WEO percentage. The test results are summarised below:

Analysis of Neat Samples

Stability

Figure 2 shows the values of stability against the percentage bitumen content. The value of stability reached a maximum of 9500N at 5%, which is then used to determine the optimum bitumen content.

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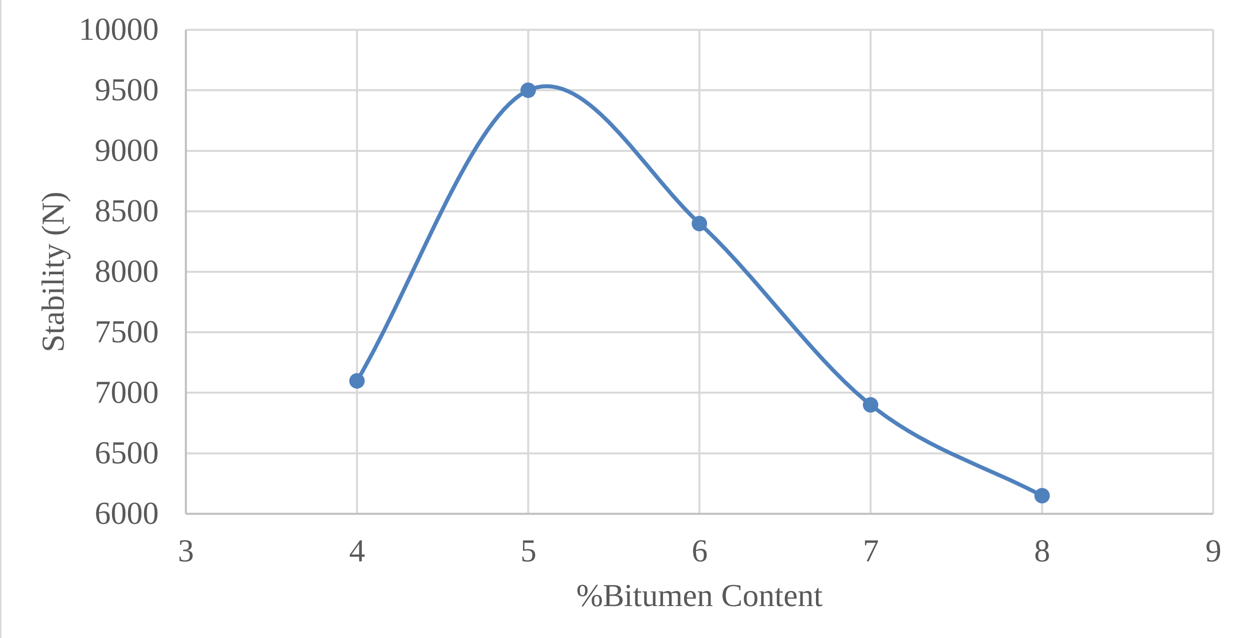
Figure 2: Stability against %Bitumen content



Optimum Bitumen Content

The optimum bitumen content was obtained as an average of the percentage of bitumen content from the respective plots displaying the following characteristics:

- Maximum unit weight- 6%
- Maximum stability- 5%
- Percent air voids in compacted mixture using the mean of limits (4%) - 6%

The optimum bitumen content was determined as 6%. This is the bitumen content that was then used in preparing the polymer-modified bituminous mix. The properties of the paving mixture containing the optimum bitumen content in comparison with the requirements as set out by AASHTO were as shown in *Table 4*.

Table 4: Test Aggregate Properties and Specifications

Mix Properties	6% Bitumen Content	Mix criteria
VIM	4.14%	3-5%
VMA	16.1%	13% min.
VFB	69.71%	65-78%
Stability (N)	8337.4	7000 min.
Flow (mm)	2.87	2-4

Analysis of Modified Bituminous Mix Samples

Bulk Density

Bulk density is calculated as the dry weight of the sample divided by its volume expressed in g/cm3. The volume includes that of particles and pores in the sample. Properties of the samples such as voids in mineral aggregate, voids in the mix, and voids filled with bitumen are calculated through the value of bulk density. The density of compacted mixes decreased with the increase of plastic waste content in bitumen. This may have happened due to the fact that the specific gravity of waste plastic blended bitumen is slightly less than that of pure bitumen.

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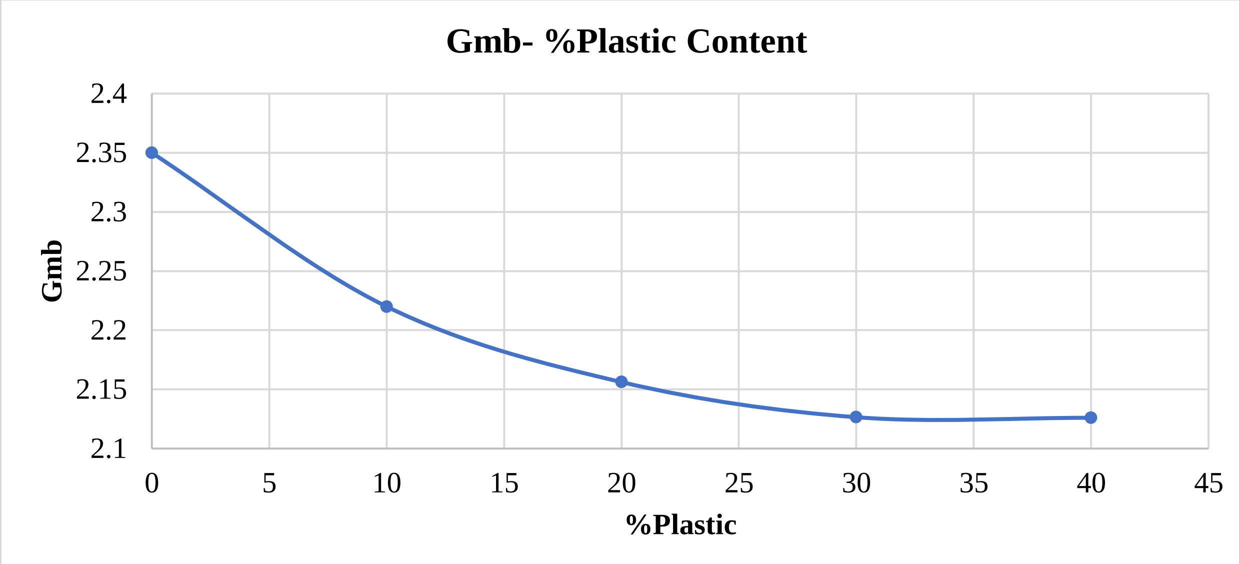
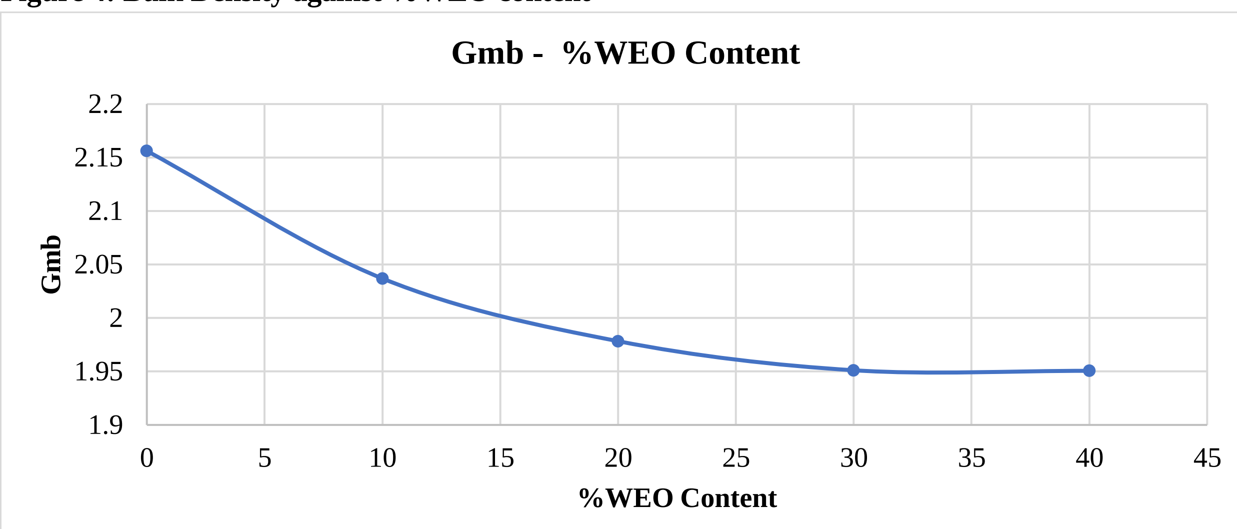
Figure 3 shows the bulk density of the mixes against plastic content.

Figure 3: Bulk Density against %Plastic content



As indicated in *Figure 4*, the density of compacted mixes decreased with the increase of waste engine oil in polymer-modified bitumen. This may happen due to the fact that the specific gravity of WEO blended with polymer-modified bitumen is slightly less than that of pure bitumen and plastic.

Figure 4: Bulk Density against %WEO content



Voids in Mineral Aggregates (VMA)

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 in *Figure 5* of the VMA analysis, the VMA value

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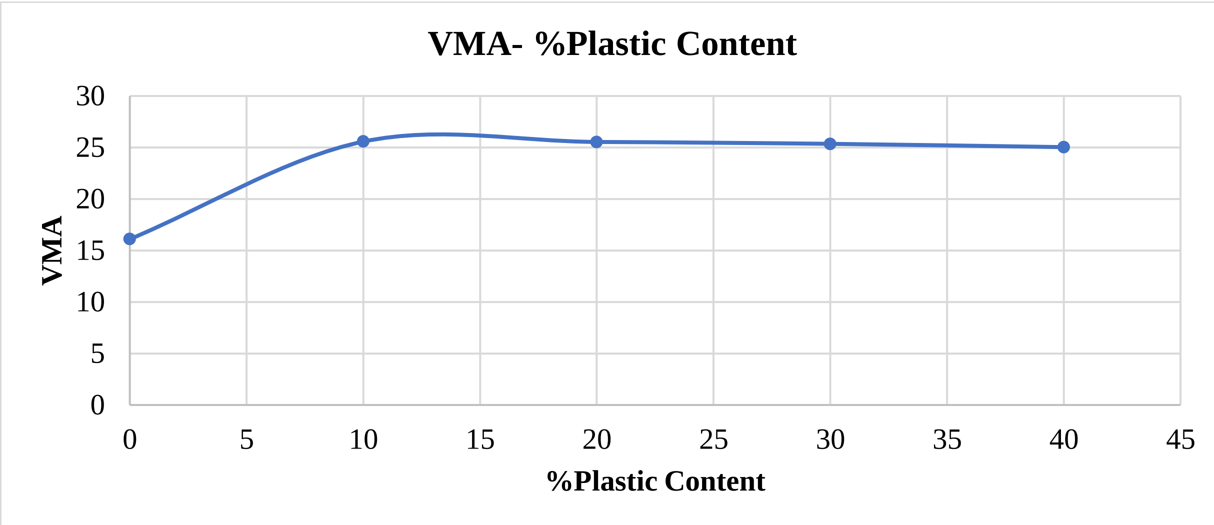
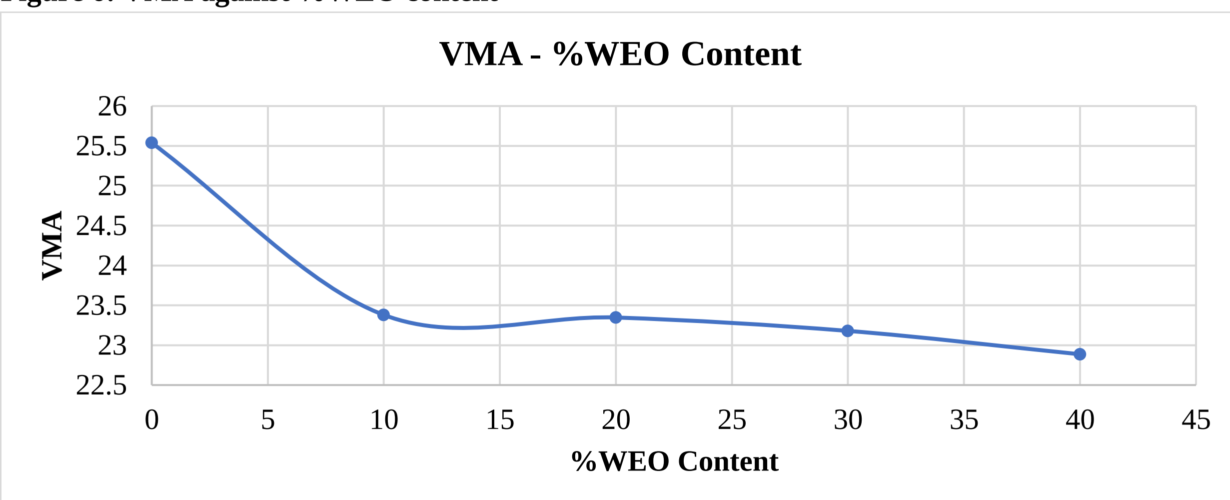
increased with the inclusion of waste plastic content. The minimum value of VMA as specified in Road Note 19, is 13%, while that which was achieved at 5.5% plastic content was 23%, an increase from 13% for the neat sample.

Figure 5: VMA against %Plastic content



As per the results of the VMA analysis, as shown in *Figure 6*, the VMA value decreased slightly with the inclusion of WEO. The minimum value of VMA as specified in Road Note 19 is 13%, while that which was achieved at 6% WEO content was 23.4%, an increase from 16% for the neat sample.

Figure 6: VMA against %WEO content



Voids Filled with Bitumen (VFB)

The voids filled with bitumen increased with the addition of waste plastic. The objective of the VFB analysis was to limit maximum levels of VMA and substantially maximise the levels of binder content. VFB also restricts the allowable air void content in compacted mixes. However, the percentage of voids filled with bitumen should be limited so as to prevent the possibility of bleeding. The allowable range of values of VFB is 65-75%. As shown in *Figure 7*, at 4.6% plastic content, the voids filled with bitumen was 76%, while that of the neat

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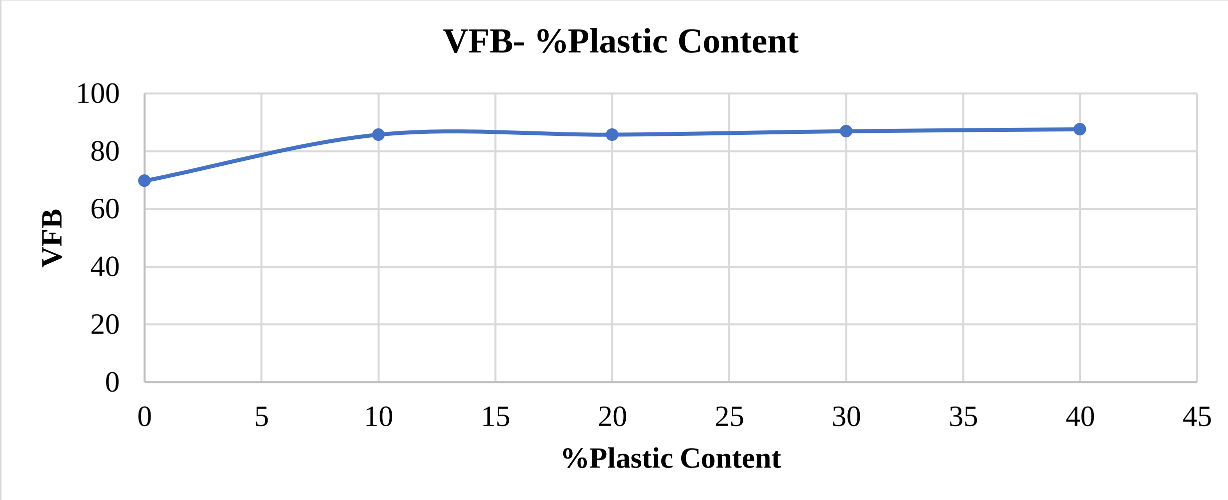
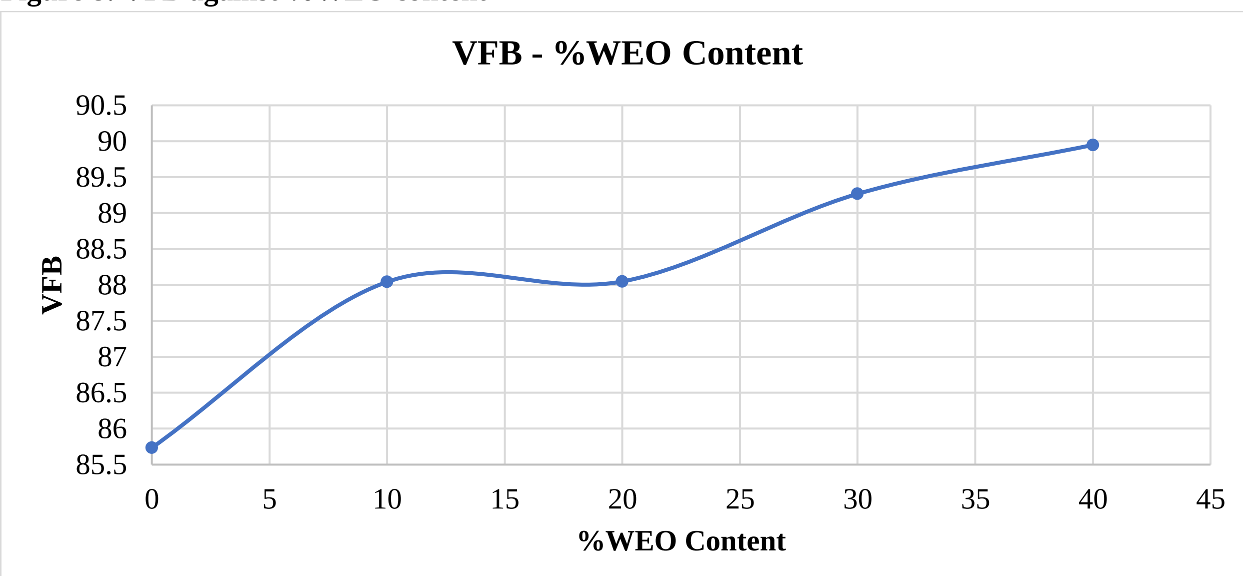
sample was 70%. Blending with plastic caused the value of VFB to fell outside the acceptable range.

Figure 7: VFB against %Plastic content



At 6% WEO content, as shown in *Figure 8*, the voids filled with bitumen was 87.5%, while that of the neat sample was 70%. The blending of the polymer-modified bituminous mix with WEO caused the value of VFB to fall outside the acceptable range.

Figure 8: VFB against %WEO content



Percent Air Voids in Compacted Mix (VIM)

The percentage of air voids in the mix decreased with increasing concentration of polymer 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

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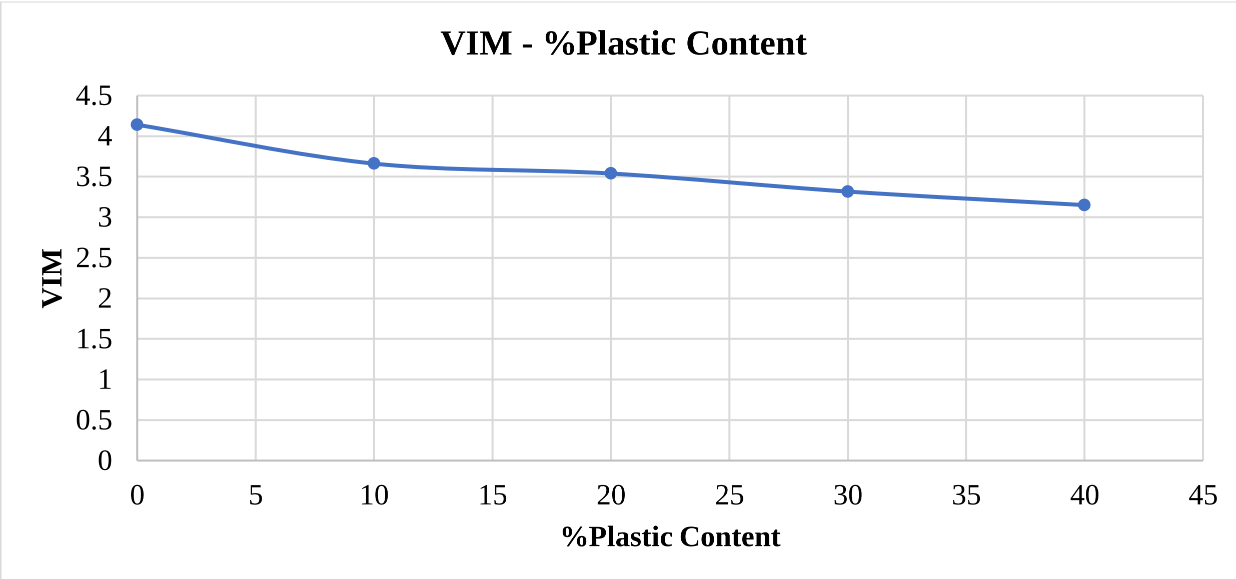
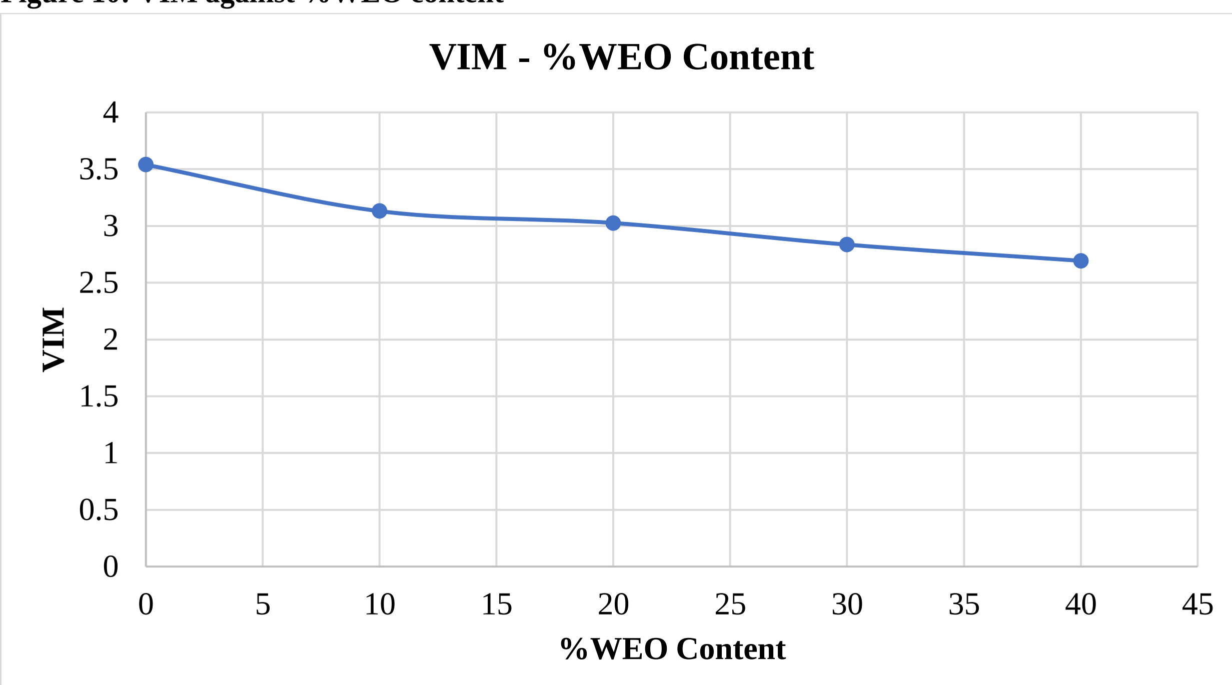
range of 3%-5%. *Figure 9* highlights VIM against the percentage of plastic content.

Figure 9: VIM against %Plastic content



As indicated in *Figure 10*, 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 bleeding problems at elevated temperatures. Road Note 19 specifies an acceptable range of 3%-5%.

Figure 10: VIM against %WEO content



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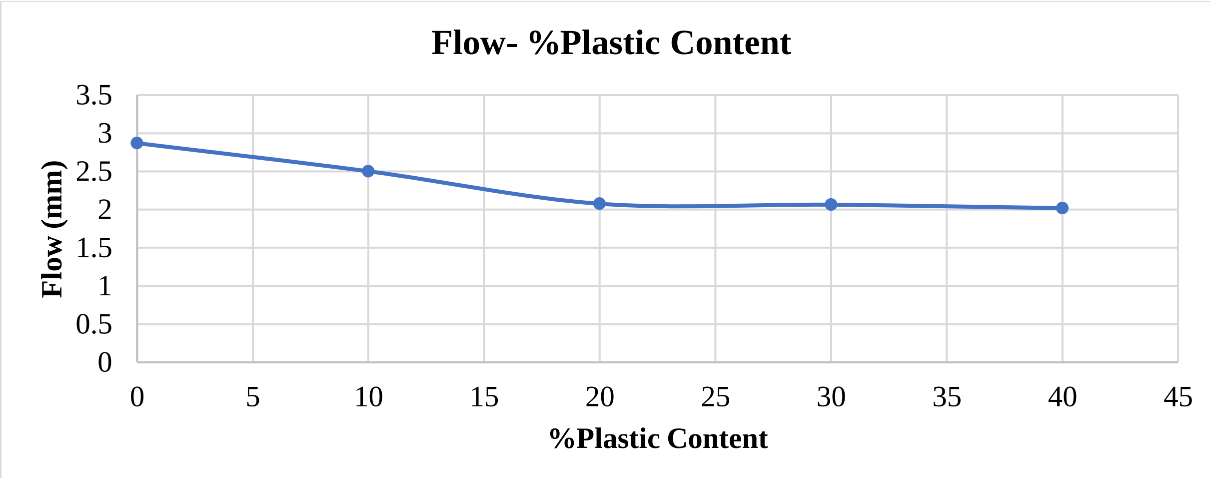
Flow

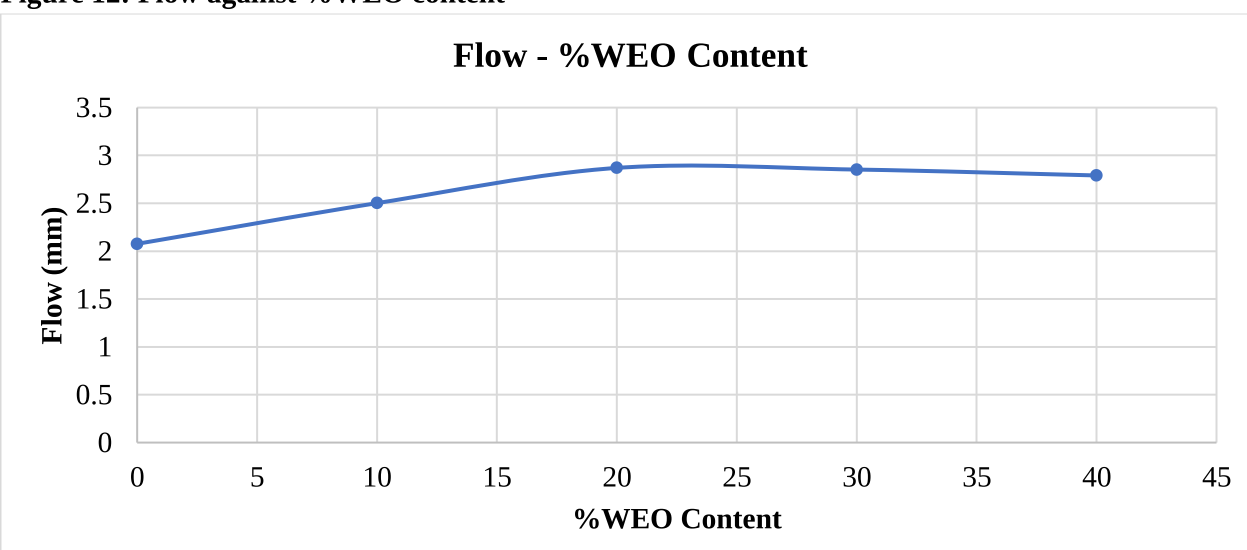
From the results obtained, as shown in *Figure 11*, the flow value reduced with increasing plastic content. The maximum deformation at which a Marshall specimen fails is termed the flow value. It is a measure of deformation. A higher flow value of bituminous pavement indicates lower rigidity. The range of flow specified in Road Note 19 is 2 mm - 4 mm.

Figure 11: Flow against %Plastic content



From the results obtained, shown in *Figure 12*, 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.

Figure 12: Flow against %WEO content



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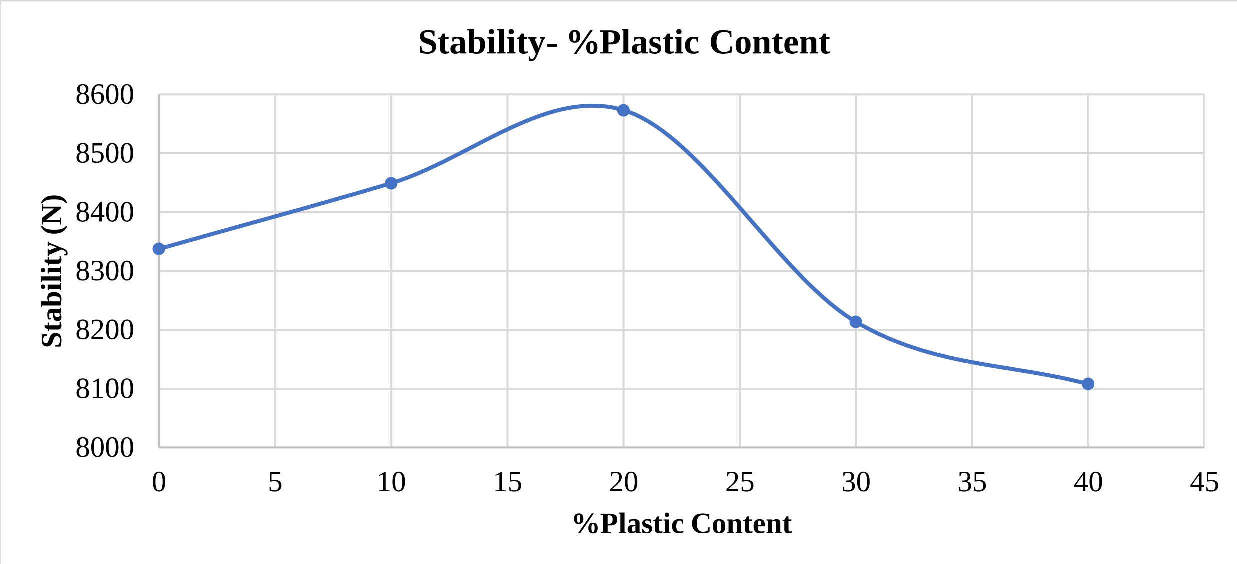
Marshall Stability

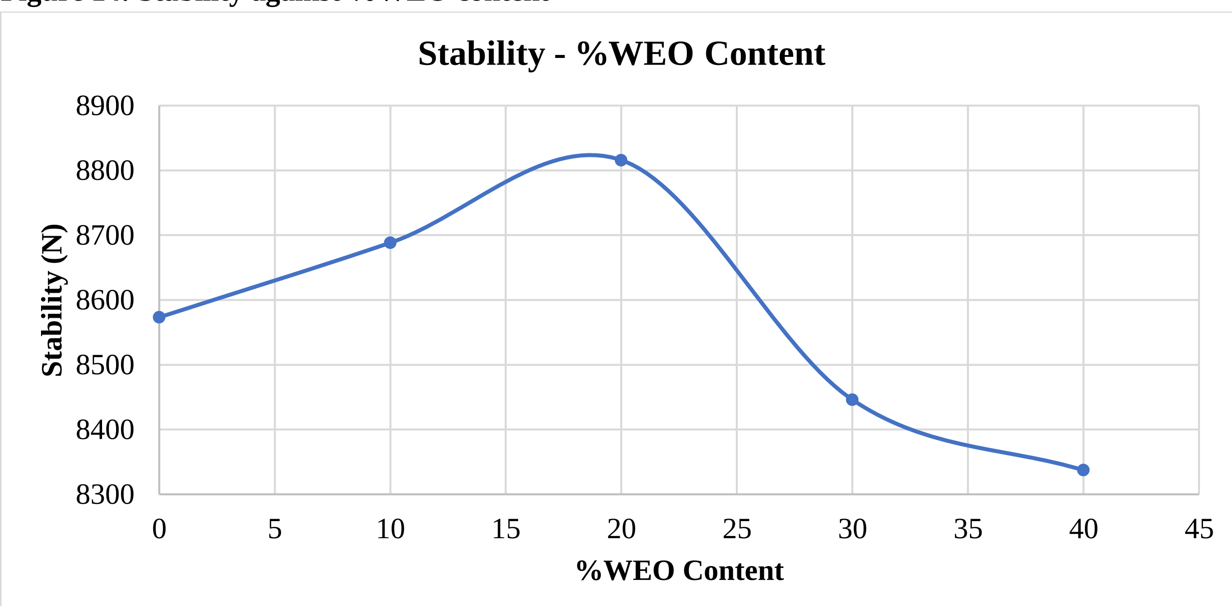
It is seen from the graph in *Figure 13* that the stability for all mixes increases up to an optimum percent of plastic content from which further increase in the plastic content causes a reduction in the stability value of the mix. The plastic content of 18% gives the highest stability value.

Figure 13: Stability against %Plastic content



It is seen from the graph, shown in *Figure 14*, 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 19% gives the highest stability value.

Figure 14: Stability against %WEO content



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Optimum Plastic Content

The optimum plastic content was to be determined from the average of:

- Point of maximum stability- 18%
- Point of 80% voids filled with bitumen- 6%
- Point of 4% air voids in the total mix- 3%

Based on the value of stability alone, an optimum plastic content of 18% was selected for use.

Optimum WEO Content

The optimum plastic content was to be determined from the average of:

- Point of maximum stability- 19%

Based on the value of stability alone, an optimum WEO content of 19% can be selected for use.

CONCLUSIONS

The main objective of the research was to investigate the use of plastic waste and waste engine oil as partial replacements of bitumen in the making of asphalt concrete. Based on the tests performed and their analysis, the following conclusions were reached:

- From the Marshall Stability tests of the neat samples, it was determined that the Optimum Bitumen Content for the mix was 6%. This percentage provided a guide to how much binder replacement should be done.
- From the Marshall Stability tests carried out on the modified mixes, it was found that the stability of the mix increased with increasing plastic content up to a plastic content of 18% as the mass of bitumen used from where the stability started decreasing. 18% plastic content could be taken as the optimum plastic content for use in the making of the modified mix based on stability alone. The optimum replacement of Waste Engine Oil was determined at 19%, also with increased stability of the mix. The increase in stability is an added advantage together with reducing the amount of bitumen used in road construction.
- The properties of asphalt mixes of modified and neat bitumen varied. The VMA varied from 6% for the neat sample, to 26% for the mix modified with plastic, and to 23.4% for the mix modified with both plastic and WEO. The VFB varied from 70% for the neat sample to 88% for the mix modified with plastic and to 88% for the mix modified with both plastic and WEO. The VIM varied from 3% for the neat sample, to 3.5% for the mix modified with plastic, and to 3% for the mix modified with both plastic and WEO. The flow varied from 2.2% for the neat sample to 2.1% for the mix modified with plastic and 2.8% for the mix modified with both plastic and WEO. The Marshall Stability varied from 9500N for the neat sample, to 8580N for the mix modified with plastic, and to 8830N for the mix modified with both plastic and WEO.

Recommendations

With the **research** showing that plastic waste and waste engine oil could be used as partial replacements of bitumen in road construction, the following recommendations are made so as to promote the technology in Kenya:

- Further studies should be done on the use and performance of plastic waste and waste engine oil in the blend of bituminous mixes to develop standard procedures for the application of the practice. Also, economic feasibility studies should be done to ensure that an economic benefit is realised once the technique is applied in road construction.
- Based on the test results, the Marshall test is suitable for testing polymer-modified bituminous mixes, therefore, Government

agencies involved with road construction in the country such as; KeNHA, KeRRA and KURA should develop field trials to determine the suitability of blending waste plastic with bituminous mix. The analysis of test results indicates that if we have provision to compromise on load carrying capacity of roads, e.g., Low Volume Roads, Rural Roads, Footpaths, and Cycle tracks, then partial replacement of Bitumen by WEO and WCO will be beneficial.

- The government should team up with organisations in the private sector and also non-governmental organisations so as to create an efficient model of waste plastic and waste engine oil management and collection throughout the country, which could be put to more beneficial use in road construction.
- For the successful incorporation of waste plastic into the bituminous mix, it was found that a mixing temperature of 165^0C was necessary for effective blending. Manual blending was possible for the purpose of the research; however, mechanical blending would be necessary for large-scale production of the polymer modified bituminous mix. The mixing temperature was also low enough to ensure no toxic gases were produced from the heating of the waste plastic.

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