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Effects Of Incorporating Shredded Waste Plastic Bottles (PET) As an Additive in A Bituminous Mixture

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Abstract

Asphalt has been in use for decades and its significance as an important engineering material cannot be overstated. In the last few decades, modification of asphalt/bitumen mixtures using polymers has attracted a lot of worldwide interest based on the numerous advantages it possesses. Polymer modified bitumen (PMB) appears to have substantial potential for its effective application in the design of flexible pavements to improve their effective service life. Pavements made with PMB have proven to offer relatively better resistance towards permanent deformation, rainwater, reduction in potholes and stripping as well as stronger roads with greater rigidity and increased Marshall stability. Nonetheless, polymer-modified bituminous mixtures are relatively more costly for a road pavement. A way of cutting on construction expenses is the utilization of less expensive polymers such as waste polymers. Not only is the recycling of waste materials beneficial to the environment, but it also has the potential to enhance the performance of flexible pavements and be cost-effective. It is because of the aforementioned reasons that this research identified the potential for use of waste polymer that is readily available, in form of waste plastic bottles (Polyethylene Terephthalate - PET), in construction of pavements across Kenya. This research's primary purpose is to evaluate the effect of the incorporation of shredded waste plastic bottles (PET) as a modifier on the engineering and volume properties of a bituminous mix. To accomplish this, a reference mix, (containing 0% PET additive) was prepared and the Marshall test was performed on this sample to obtain the optimum bitumen-binder content. Once the optimum bitumen content was obtained, waste Plastic bottles were shredded to small pieces. For ease of incorporation of the shredded waste plastic bottles into the asphalt mix, the research did not conduct sieve analysis of the shredded PET. Shredded PET were incorporated into the mix via the dry process through replacing the optimum bitumen content with 0%, 6%, 10%, 14% and 18% PET per weight of this optimum bitumen content. The samples obtained were then evaluated for their engineering and volume properties. The study involved the analysis of the volume properties as well as Marshall Stability and flow test. The results of the study highlighted that 6% and 10 % PET modified bituminous mix met all the criteria highlighted in Overseas Road Note 19 (ORN 19). Additionally, the aforementioned had higher stability compared to neat samples. Accordingly, it is concluded that PET modification of a bituminous is a viable and can have a positive impact on a bituminous mixture. This paper will form a basis that will not only assist Engineers in better understanding the effects of incorporating shredded waste PET into a bituminous mix on a pavement's engineering properties, but can also assist the Kenyan government with its environmental conservation efforts through providing an alternative for the use of waste plastic bottles.

Keywords: Bituminous Mix, Marshall Test, Polymer modified bitumen (PMB), Waste Plastic Bottles, Polyethylene Terephthalate (PET), Flexible pavement.

INTRODUCTION

The Kenyan Government spends billions of shillings annually on infrastructural projects. A recent article by Angote (2022), highlights that the expenditure on roads construction in Kenya had overshot by more than 5.5 billion shillings by April 2022, two months to the end of the financial year. While the full-year budget for the State Department of

Infrastructure was set at KES. 63.04 billion, the Department had spent KES. 68.6 billion by April 2022. This 10-month expenditure was mostly channelled to roads and bridges. Most of these roads utilize standard unmodified Dense Graded Bitumen (DBM) as their surfacing layer. While DBM is widely acceptable surfacing layer that has proven to have a long service life, it is often very expensive to maintain as it is susceptible to formation of potholes, rutting and stripping (Cheng et al., 2019). Accordingly, any efforts to cut on the construction and maintenance cost of roads within the country would go a long way in ensuring that there is more money available for development projects. One such alternative is the use of "plastic" roads. Many countries including India, Ghana and the United Kingdom have utilized this pavement construction technique to cut down on the maintenance cost of roads (Government of India, 2015; Jamshidi & White, 2019; Appiah, Berko-Boateng & Tagbor, 2017). Pavements made with plastics such as Polyethylene Terephthalate (PET) have proven to offer relatively better resistance towards permanent deformation, rainwater, reduction in potholes and stripping as well as stronger roads with greater rigidity and increased Marshall Stability and flow (Costa, Silva, Oliviera & Fernandes, 2013). It also has the potential of cutting the cost of construction of asphalt pavements given the fact that plastic wastes are cheap and readily available (Al-Hadidy & Yi-qiu, 2009).

There is also an environmental advantage in plastics over bitumen. Plastics are one of the most widely used component in most of the productive sectors of the economy and given the fact that they mostly have a very short useful lifespan, they soon become waste (Clunies-Ross, 2019). This has led plastics to become one of the most prominent pollutants (Chowdhury, 2021). Accordingly, utilization of PET as a modifier in bituminous mix provides an alternative for the use of plastic waste which can in the long-term assist in solving the worldwide pollution crisis. It has also been noted that at the moment, there has been minimum research conducted in Kenya on the utilization of plastic wastes in pavement construction. The former, coupled with the essential need for environmental conservation necessitates investigating the viability of incorporating this kind of waste into pavement construction.

It is for the aforementioned reasons that this study focused on modifying the surfacing layer of a flexible pavement, usually referred to as asphalt paving, hot mix asphalt (HMA), bituminous mix, or bituminous asphalt with waste plastic. Bituminous mix is a composite material utilized for road paving that is composed of roughly 95% aggregates bound together by bitumen, a product of crude oil (Hunter, 2000). The dual essential goals for any road are to satisfy the long-term period engineering requirements design for a singular site and at the same time utilizing materials that are environmentally safe, processed to preserve the ecosystem (AASHTO, 2008).

The expectation of this research was that it could provide a bituminous mix comprising of waste PET that has suitable engineering properties to be utilized in roads within and outside Kenya. It is expected that the modified pavement would offer relatively better resistance towards permanent deformation, rainwater, reduction in pothole formation and stripping, as well as stronger roads with greater rigidity and increased marshal stability compared to an unmodified pavement. This would in turn cut the costs of road maintenance as well as help Kenya fight the pollution crisis that is currently plaguing the country.

In a nutshell, this research primary focus was to study the effects of incorporating shredded waste plastic bottles, made from PET, as a modifier in a bituminous mixture with the expectation of producing an environmentally friendly asphalt mix that has better engineering properties than the typical HMA currently being commonly utilized in Kenyan roads. This would provide valuable literature that can be utilized for further advancement of research on the utilization of plastic wastes in construction in Kenya.

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MATERIALS AND METHODS

Sample Preparations

The bitumen utilized for this study was not subjected to lab test; the sample was assumed to be within the standard specifications of Grade 80/100 penetration grade as it was obtained from a drum of bitumen of 80/100 penetration grade. On the other hand, the aggregates utilized for this study were subjected to mechanical sieve analysis to evaluate the particle size distribution. The aggregates were then blended to obtain the best theoretical combined blending percentages. A reference mix, (containing 0% PET additive) was prepared and the Marshall test was performed on this sample to obtain the optimum bitumen content. Once the optimum bitumen content was obtained, waste Plastic bottles (PET) were shredded to small pieces. For ease of incorporation of the shredded PET into the asphalt mix, this research will not conduct sieve analysis of the shredded PET. Shredded PET was incorporated into the mix via the dry process through replacing the optimum bitumen content with 0%, 6%, 10%, 14% and 18% PET per weight of this optimum bitumen content. The dry process was utilized since it is cheaper since the wet process necessitates the use of specialized high- shearer mixing machine, which is expensive. The samples obtained were then evaluated for their engineering and volume properties via the Marshall stability and flow test.

Mechanical Sieve Analysis and Gradation of Aggregates

Sieve analysis is an essential basic test conducted to determine the distribution of particles based on their sizes, for a given sample. Sieve analysis was carried out as per AASHTO T 27, sieve analysis of fine and coarse aggregates (AASHTO T 27). In this test an appropriate test sample is first obtained through riffling. The obtained samples are then dried in an oven at temperature of approximately 1050C. The required sample is weighed in a scale and placed on the sieve with the largest mesh, which is positioned on top of a tray. It's important to ensure that the sieves are all dry and particle-free before using them. The sieve is jerked horizontally in all directions until no more than a small sample is passing, while also making sure that all materials passing fall into the tray. All material retained on the sieve is weighed and tabulated. The cumulative weigh of sample passing each sieve is calculated as a proportion of the entire sample to the nearest whole number. Finally, a grading chart is used to draw the grading curve for the sample (AASHTO T 27).

The Marshall Stability and Flow Test

These tests are carried out with the aim of using the results obtained to analyse the engineering and volume properties of the PET modified asphalt mix. The Marshall Stability test was performed using a Marshall press where specimens with different contents of the PET additive were subjected to a loading rate of 50mm/min. This load was applied upon the sample until failure, where the maximum load will be measured. During this test, a dial gauge was utilized to measure the vertical deformation.

Stability of the mix indicates the internal cohesion and friction; where cohesion was an indicator of the asphalt binding strength, while friction was a measure the level of friction and interlocking resistance of aggregates.

The Marshall Flow value was the resultant value obtained at the point of failure of the sample. A high flow value typically shows that permanent deformation such as rutting will occur during traffic, while a low value of flow points to the bitumen mix having higher air voids and insufficient bitumen which might cause cracking during the pavement's service life.

Marshall Test Specimen Preparation and Testing

To create the cores for the Marshall test, the aggregates were first mixed. Then, based on the aggregate weight, 1200g of aggregates that had been mixed were weighed, along with the optimal bitumen percentage. Up till being combined with the bitumen, the aggregates were heated to 150°C. A crater was shaped in the aggregate, and bitumen having a penetration grade of 80/1000 was applied after it was preheated to 150°C. Bitumen together with the aggregates were blended in such a way that all the aggregates were completely covered. The filter was then positioned towards the base of the completely clean mould then heat was applied to it to 150°C; this same mix was poured into the mould and spread round the perimeter, and the collar was extracted with a hot spatula, and the surface of the mixture using a trowel, was flattened to a relatively circular form. Just before compaction, the temperature of the mixture was retained at 140°C. The collar was replaced, and the mould assembly was set on the compaction platform in the mould holder; 50 blows were then delivered to the top of the specimen. The collar and baseplate were extracted, the sample was upturned, and the mould was reconstructed. 50 blows were also delivered to the inverted face. After compaction, the base plate was detached, extraction of the specimen was then done using the sample extractor with the aid of a suitable jack and frame system. To cool to room temperature, the item was placed on a level plane. Similar techniques were used to make the samples of concrete of asphalt that were modified having been substituted with 6%, 10%, 14% and 18% PET based on the bitumen weight (ASTM D6927-06, 2021).

Overall density of each sample was determined by weighing it in air and water that has been demineralized at constant room temperature. The volume was calculated using the difference in weight between the two weights in grams. Stability and flow were also calculated. To do this, samples were immersed in a 60± 1 °C water bath for 40 minutes to get them to the test temperature. The water bath specimen was then mounted in the lower portion of the breaking head. The breaking head's upper section was put on top of the sample, and the complete assembly was mounted on the testing apparatus. The flowmeter was set to 0 prior to the commencement of the assessment. At a loading speed of 50 mm per minute was applied to the sample thereafter the load used began to decrease as the peak load was attained. The peak load was logged and the flowmeter moved away from where it was situated, that is above the guide rod, instantly when the load decreases. In addition, the value of flow was measured then documented.

Concluding Summary

In a nutshell, the methodology section could be summarized into a series of steps highlighted in figure 2 below. First, raw materials needed for sample preparation (bitumen binder, crushed graded aggregate and waste PET) were collected from various sources highlighted in this section. Coarse graded aggregates were then heated to 150℃ after which the shredded waste PET were mixed with the aggregates. Bitumen was also heated to 150℃ and mixed with the PET-coated aggregates. This mixture was poured into moulds and compacted to form samples. The samples were subjected to the Marshall stability and flow test as well as the volumetric properties tests highlighted in this section.

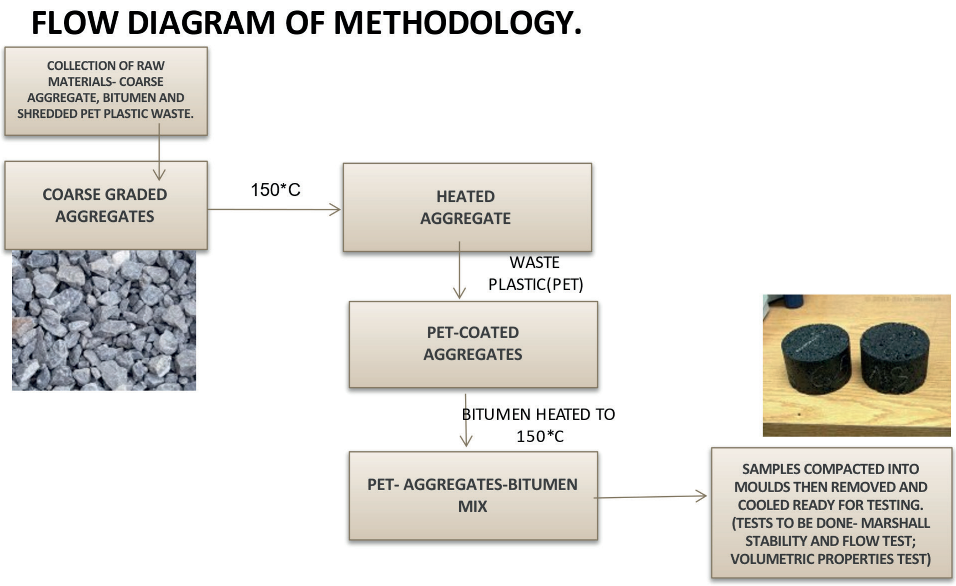

Figure 1: Methodology Flow Chart

RESULTS

Tests on Bitumen

The bitumen utilized for this study was not subjected to lab test; the sample was assumed to be within the standard specifications of Grade 80/100 penetration grade as it was obtained from a drum of bitumen of 80/100 penetration grade.

Tests On Aggregates

Aggregate gradation was used to determine the mechanical and physical properties of the aggregates. Mechanical sieve analysis was conducted to access the particle size distribution. A trial sample was prepared to determine the aggregate's quantity needed for each specimen for the Marshall test. 1.2kg of blended aggregate was determined as the quantity of aggregate at the content of optimum bitumen estimated.

Coarse Aggregate. Crushed gravel passing through 25mm sieve but retained on No.8 sieve was used as coarse aggregate for the study. The quality and gradation of the coarse aggregate determined the characteristics of bituminous mixes. The properties of the coarse aggregate also determine the value of Marshall Stability. Selection of an appropriate coarse aggregate with desired gradation is crucial. The aggregates selected were also durable, tough, clean, and free from vegetable matter, objectionable matter, and soft particle. For the current study,14mm was the maximum size of coarse aggregate utilized in the bituminous mix.

Fine Aggregate. Aggregate passing through sieve No. 8 but retained on sieve No. 200 was used in the test procedure as fine aggregate. The fine aggregate comprised of stone screenings and natural sand. The researcher made sure the fine aggregate was made up of angular, rough surfaced, hard durable particles, clean and free from clay balls, soft particles, vegetable matter, or other inacceptable matter.

Aggregate Gradation

Well-graded aggregates are important in producing durable, dense, and stable mixes. In addition to producing dense mixes, well-graded aggregates require minimum bitumen content. Table 3 and Figure 3 shows the gradation of the fine aggregates for this study to utilized to test both the modified and neat samples. Table 4 and Figure 4 shows the gradation of the coarse aggregates for this research utilized to test both modified and neat samples. Table 5 and Figure 5 shows the combined aggregate gradation for both fine and coarse aggregates. The grading curvature fell within the grading blanket hence the tested aggregates were of the desired quality to produce dense, quality, and durable bituminous mix.

Table 1: Gradation of fine aggregates

Pan mass	(gm)	100			
Initial dry sample mass + pan	(gm)	912			
Initial dry sample mass	(gm)	812	Fine mass	(gm)	124
Washed dry sample mass + pan	(gm)	788	Fine percent	(%)	15.3
Washed dry sample mass	(gm)	688	Acceptance Criteria	(%)	

Sieve size (mm)	Retained mass (gm)	% Retained (%)	Cumulative passed percentage (%)
14	0	0.0	100.0
10	0	0.0	100.0
6.3	5	0.6	99.4
4	67	8.3	91.1
2	246	30.3	60.8
1	153	18.8	42.0
0.425	117	14.4	27.6
0.3	30	3.7	23.9
0.15	41	5.0	18.8
0.075	29	3.6	15.3
	688		

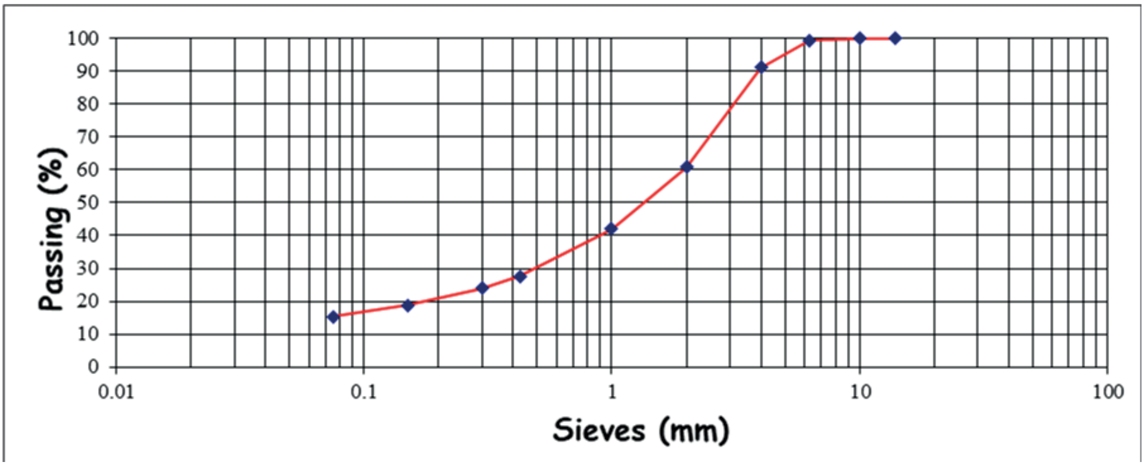

Figure 2: Gradation of the fine aggregates

Table 2: Gradation of coarse aggregates**Figure 3:** Gradation of the coarse aggregates

Washed dry sample mass	(gm)	3477	
Sieve size (mm)	**Retained mass (gm)**	**% Retained (%)**	**Cumulative passed percentage (%)**
28	0	0.0	100.0
20	0	0.0	100.0
14	12	0.3	99.7
10	950	27.3	72.3
6.3	1288	37.0	35.3
4	689	19.8	15.5
2	538	15.5	0.0
	3477		

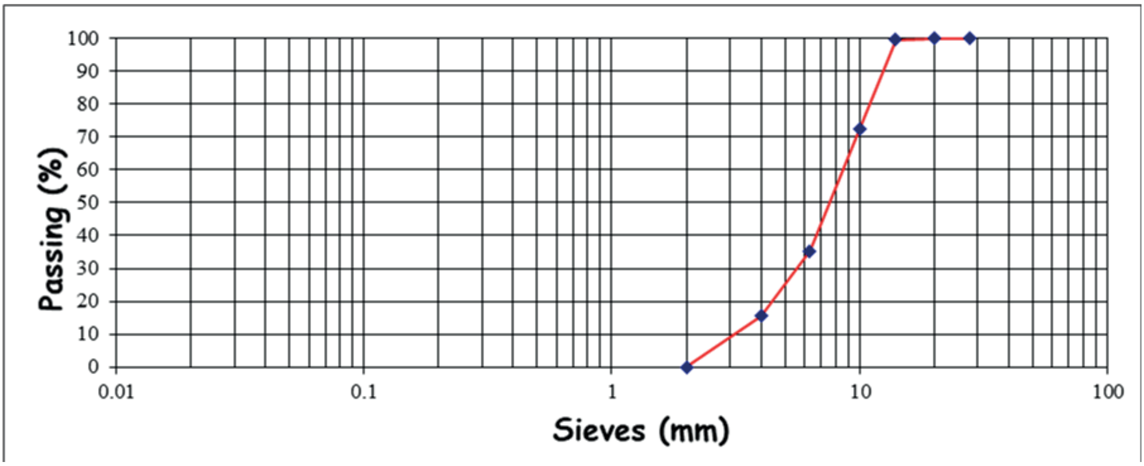

Figure 3: Gradation of the coarse aggregates

Table 3: Combined aggregate gradation for both fine and coarse aggregates

AGGREGATES					
Sample no	**Nominal Size**	**Description and Source**	**TRIAL MIX- MEDIUM BLEND**		
			Total Wt.	**%**	**Wt.**
2	0	Aggregates	0	0	0
3	0	Aggregates	0	0	0
4	6/14	Aggregates	1100	40	440
5	0/6	Crushed rock/quarry dust	1100	60	660

SIEVE ANALYSIS % PASSING

Sample Number	**1**	**2**	**3**	**4**	**5**	**THEO.**	**DESIGN MIX**	
% in Mix 100	0	0	0	40	60	COMBINED	SPEC.	
Sieve Size (mm)						GRADING		
28	100	100	100	100	100	100.0	100	
20	100	100	100	100	100	100	100	
14	100	100	100	100	100	100	90	100
10	100	100	100	72	100	89	70	90
6.3	100	100	100	35	99	73	55	75
4	100	100	100	16	91	61	45	63
2	100	100	100	0	61	37	33	48
1	100	100	100	0	42	25	23	38
0.425	100.0	100	100	0.0	27	16	14	25

Sample Number	1	2	3	4	5	THEO.	DESIGN MIX	
0.3	100.0	100	100	0.0	24	14	12	22
0.15	100.0	100	100	0.0	19	11	8	16
0.075	100.0	100	100	0.0	15	9	5	10

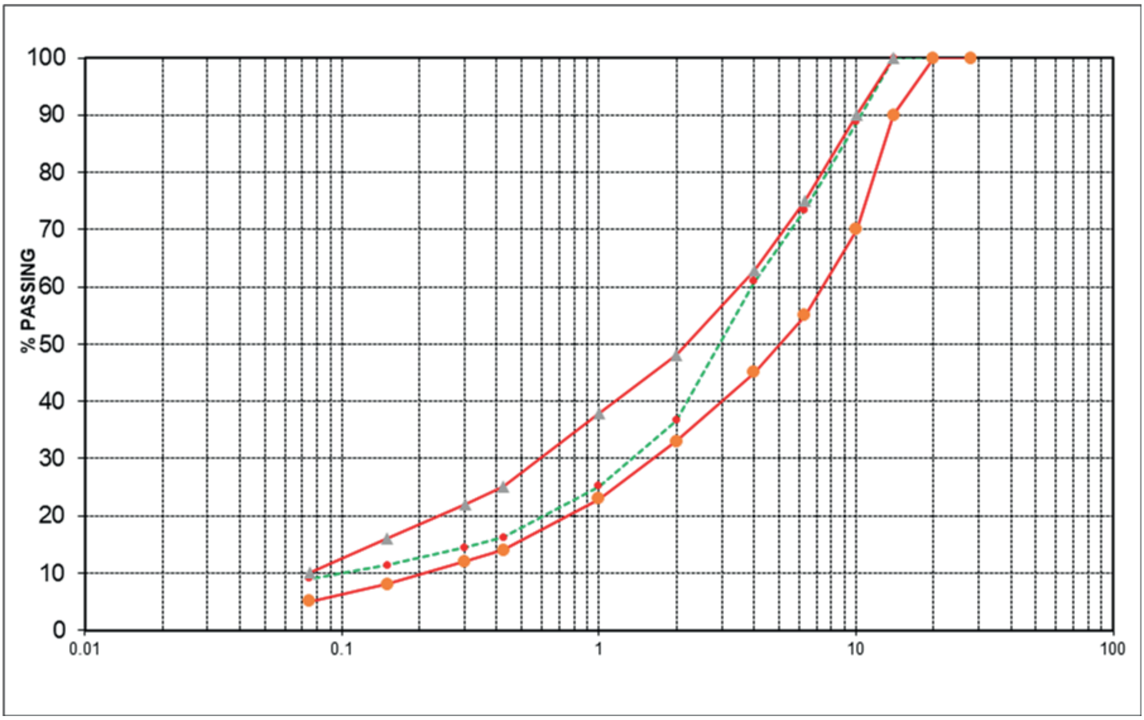

Figure 4: Combined aggregate gradation for both fine and coarse aggregates

Marshall Test

Tests On Neat Samples

The current study also carried out volumetric tests, Marshall Stability, and flow tests on neat samples to elect the Optimum Modifier Content (OMC) and the Optimum Bitumen Content (OBC) of the asphalt mix. The bituminous mix specimens were prepared with 4%, 5%, 6%, and 7% of bitumen by weight of aggregates. For each batch, 2 specimens were prepared, and the average value used in the analysis. Table 6 shows the breakdown of the tests results for the neat sample.

Table 4: Summary of the test results for the neat samples

%Bitumen Content	Bulk Specific gravity of Compacted mix (Gmb)	Maximum Specific gravity of mixed material (Gmm)	Percent air voids in compacted mix (VIM) (%)	Voids in Mineral Aggregate (VMA) (%)	Percent voids filled with Bitumen (VFB) (%)	Stability (N)	Flow (mm)
4	2.294	2.581	11.117	12.648	12.105	4812.02	1.880
5	2.335	2.531	7.762	12.045	35.557	8082.39	2.667
6	2.418	2.511	3.690	9.847	62.524	9126.46	3.683
7	2.458	2.464	0.211	9.331	97.743	6651.35	4.953

Optimum Bitumen Content

The Optimum Bitumen Content (OBC) was determined as 6% as it was the bitumen content that met most of the specifications highlighted in Overseas Road Note 19 (ORN19) for AC wearing course specifications for up to 5 million equivalent standard axles (ESA). From the results, it can be observed that the samples with 6% bitumen content is the only one that met a majority the highlighted specifications in Table 5, hence it was selected.

Table 5: AC wearing course specifications for up to 5 million esa (Source: TRL Limited, 2002).

Mix Properties	6% Bitumen Content	AC wearing course specifications for up to 5million esa.
Stability (N)	9126	5300 min.
Flow (mm)	3.6	2-4
VIM	3.69%	3-5%
VMA	9.87%	13% min.
VFB	62.524%	65-78%

Test Results for Samples Modified With PET

Having the knowledge on the OBC to use with the detailed aggregate gradation, the volumetric and Marshall flow tests were carried out on specimens whose asphalt content had been partly substituted by waste PET plastic. The bitumen content as a percentage of the aggregates' mass was substituted with 6%, 10%, 14% and 18% of plastic to determine optimum plastic percentage. The test results are summarized in Table 8.

Table 6: Summary of the test results for the modified samples

%Bitumen Content	Bulk Specific gravity of Compacted mix (Gmb)	Maximum Specific gravity of mixed material (Gmm)	Percent air voids in compacted mix (VIM) (%)	Voids in Mineral Aggregate (VMA) (%)	Percent voids filled with Bitumen (VFB) (%)	Stability (N)	Flow (mm)
4	2.294	2.581	11.117	12.648	12.105	4812.02	1.880
5	2.335	2.531	7.762	12.045	35.557	8082.39	2.667
6	2.418	2.511	3.690	9.847	62.524	9126.46	3.683
7	2.458	2.464	0.211	9.331	97.743	6651.35	4.953

PET Modified Bituminous Mix Bulk Density

Bulk density is determined by dividing the sample's dry weight by its volume and is normally expressed in g/cm3. The volume of the sample used in determining the bulk density consists that of the pores and particles in the sample. The value of the bulk density is used to determine properties of the mix such as voids filled with bitumen, voids in mineral aggregate, and voids in mix. According to Figure 12, as the quantity of plastic waste increased, there was a decrease in the density of the compacted mixes. The reduction in density of the compacted mixes can be attributed to the fact that the bitumen's SG blended with plastic waste is slightly lower than that of pure asphalt.

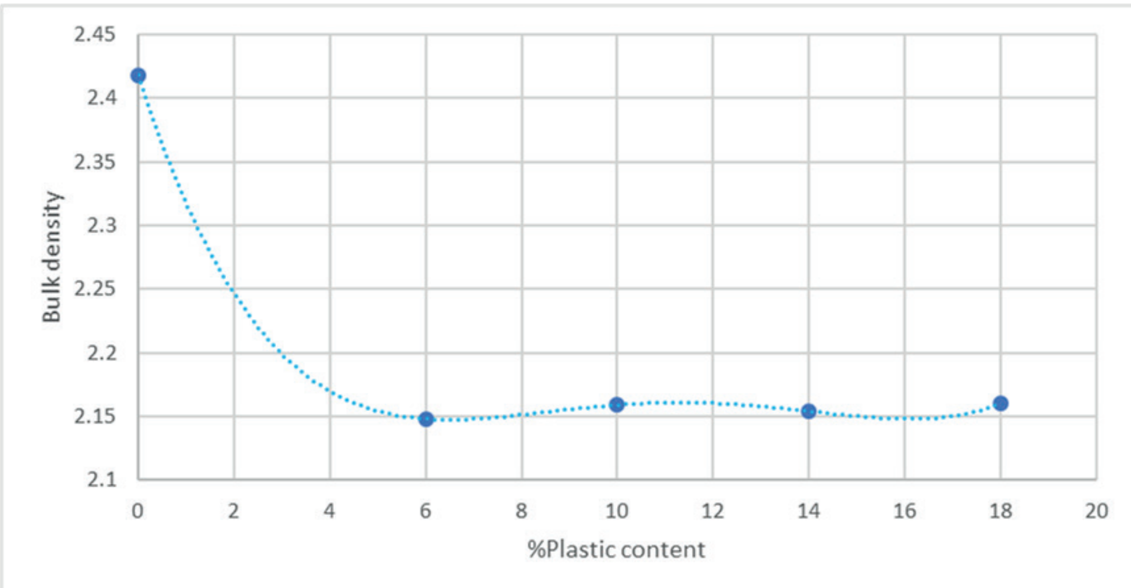

Figure 5: Bulk density against % plastic content

PET Modified Bituminous Mix Voids in Mineral Aggregates

According to Figure 13, the value of VMA increases with an increase in the plastic content. Road Note 19 specifies a minimum value of VMA as 13%. This minimum value was achieved at around 1.7% plastic content.

Table 6: Summary of the test results for the modified samples

%PET Per Weight of Bitumen Content	Bulk Specific gravity of Compacted mix (Gmb)	Maximum Specific gravity of mixed material (Gmm)	Percent air voids in compacted mix (VIM) (%)	Voids in Mineral Aggregate (VMA) (%)	Percent voids filled with Bitumen (VFB) (%)	Stability (N)	Flow (mm)
0	2.418	2.511	3.690	9.87	62.524	9126.46	3.683
6	2.148	2.420	3.263	19.915	76.891	9248.85	3.429
10	2.159	2.531	3.154	22.931	76.897	9384.62	3.937
14	2.154	2.511	2.956	26.551	77.961	8990.92	3.429
18	2.160	2.321	2.808	29.769	78.556	8875.05	4.233
AC wearing course specifications for up to 5million esa (ORN 19).	-	-	3-5	13% min	65-78%	5300 min	2-4

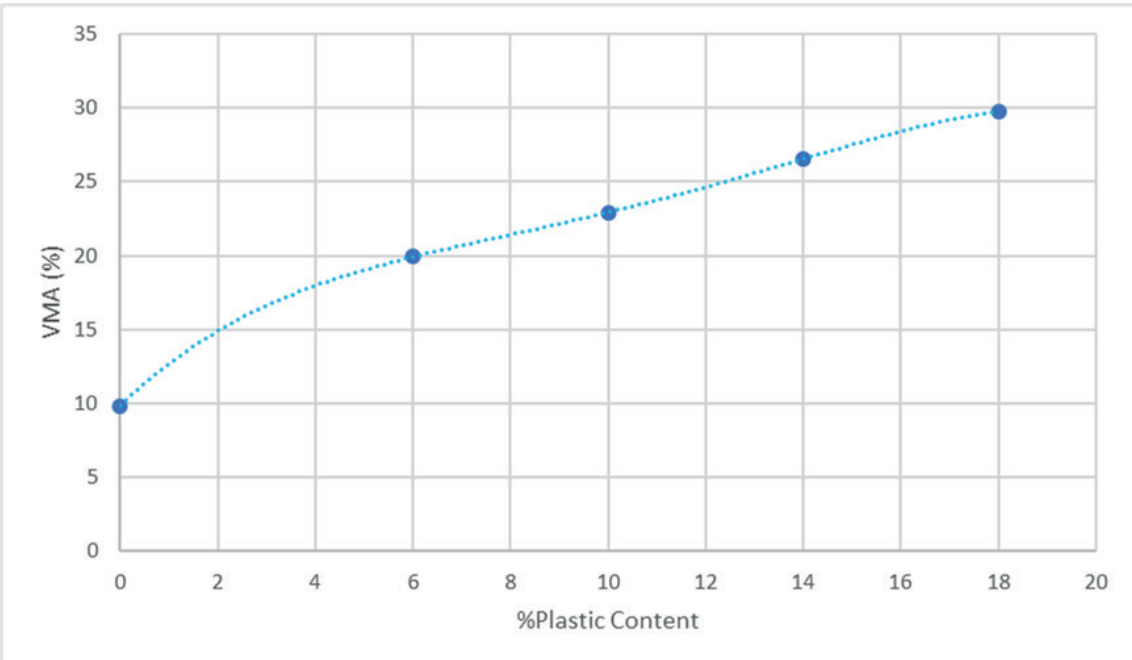

Figure 6: Voids mineral aggregates against % plastic content

PET Modified Bituminous Mix Voids Filled with Bitumen-

From Figure 14, adding the plastic waste increases the voids filled with bitumen. The aim of the voids filled with

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bitumen (VFB) analysis was to maximize the binder's content through limiting the maximum levels of VMA. VFB also limits the admissible content of air voids compacted mixtures. Nevertheless, the percentage of VFB should be limited to prevent the likelihood of bleeding. The tolerable range of values of VFB is 65-78%. At 6% plastic content, the VFB was 76.891% while that of the control sample was 62%. Blending of the bituminous mixture with shredded PET bottles prompted the VFB value to fall within the permissible range.

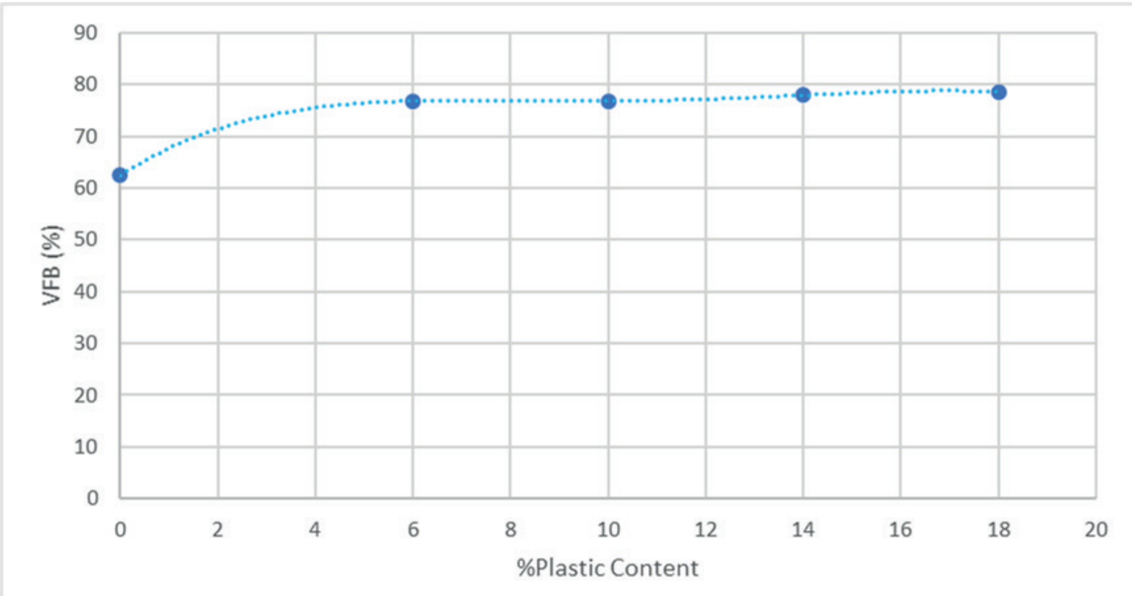

Figure 7: Voids Filled Bitumen against % plastic content

PET Modified Bituminous Mix Percent Air Voids in Compacted Mix (VIM)

Increasing concentration of PET in the mixtures resulted to decreasing of the air voids percentage of the mix in an almost linear relation. The percentage of air voids in the bituminous mix is crucial in the design criteria of the mix. The mix requires adequate air voids so that the binder can properly coat the aggregate while at the same time also ensuring the percentage of air voids is not too high to result in bleeding when the pavement mix is exposed to high temperatures. Overseas Road Note 19 (ORN19) specifies an permissible range of 3% to 5%. Figure 15 highlights VIM versus the percentage plastic content.

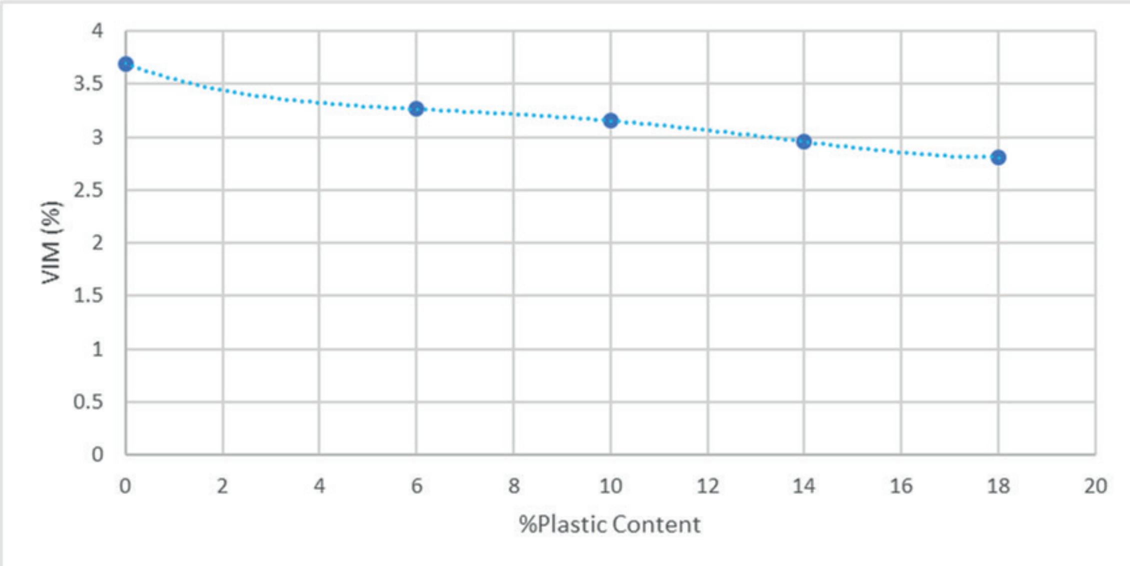

Figure 8: Percentage Air Voids in Compacted Mix against % plastic content

PET Modified Bituminous Mix Flow

As shown in Figure 16 , the value of flow reduced, increased, then reduced, and increased with increasing plastic content. Road Note 19 specifies a flow range of between 2mm- 4mm.

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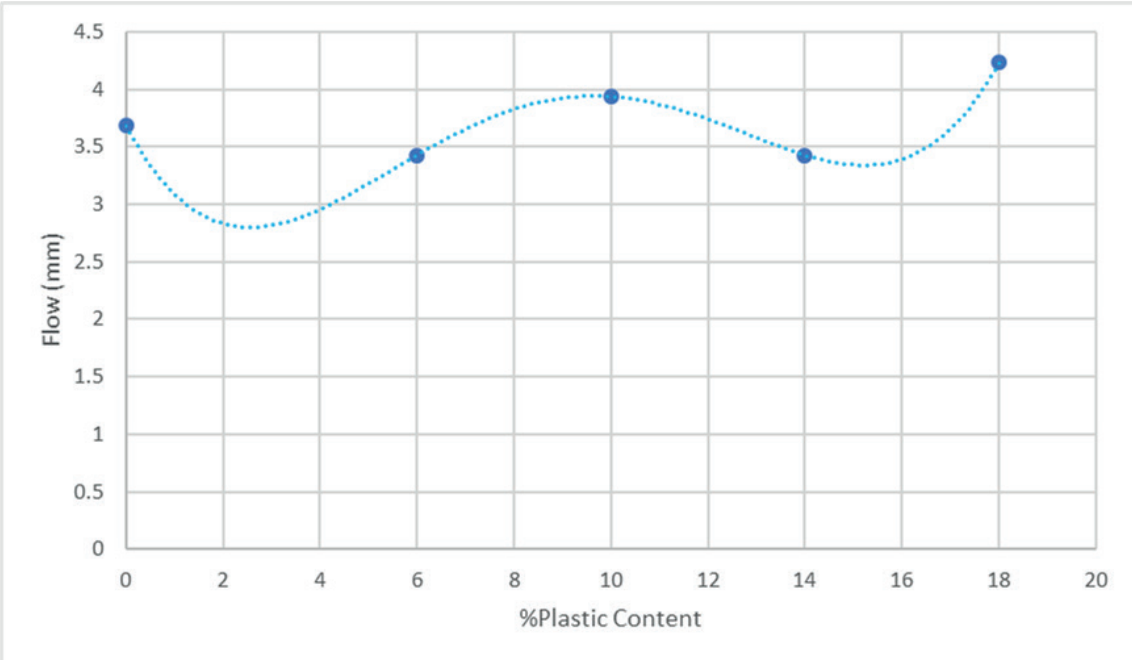

Figure 9: Flow against % plastic content

PET Modified Marshall Stability

Figure 17 indicates an increase in stability with an increase in plastic content until an optimum percent of plastic content. Further addition in plastic content beyond this point leads to reducing in stability value of the mixture. A 9% plastic content provides the highest value of stability of 9400N which was above the minimum requirement of 7000N. The addition of PET, a polymer, improves the adhesion between the various materials in the mix hence the stability of the mix improves. When further PET is added to the mix, the stability of the mix reduces under compressive stress. The addition of the polymer results in a rise in the viscosity of the bituminous mix hence an increase and decrease in the stability. It is evident that the addition of waste PET bottles improved the adhesion between the asphalt binder and aggregate particles.

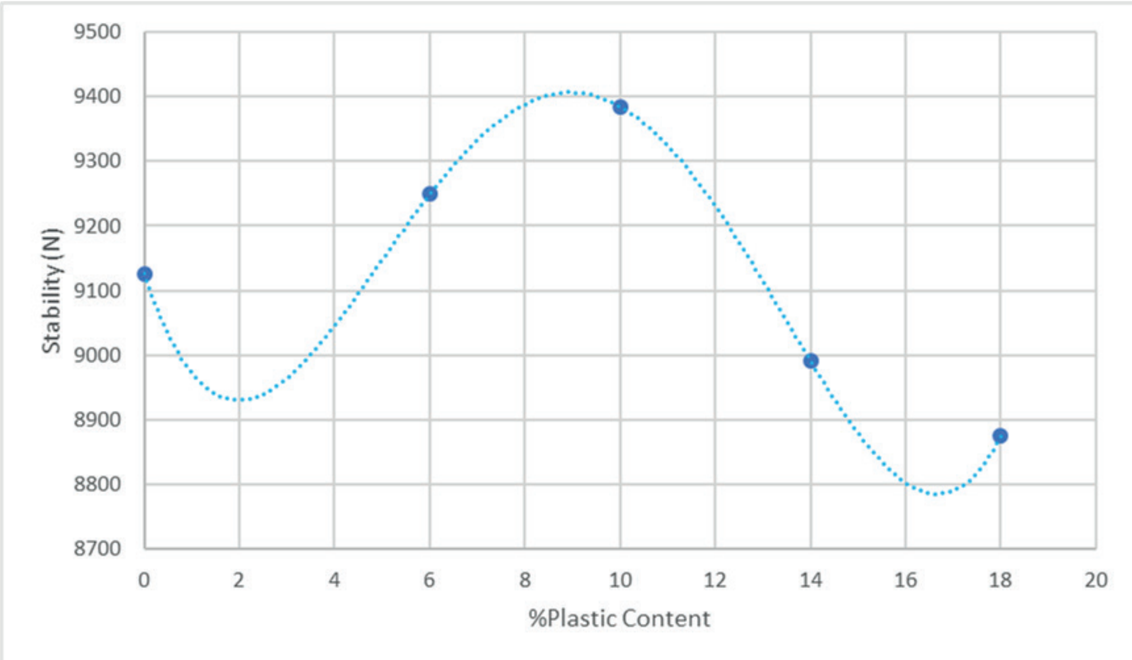

Figure 10: Stability against % bitumen

Optimum Plastic Content

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

- Point of maximum stability- 9%
- Point of 75% voids filled with bitumen- 4.5%

Based on the value of stability alone, an optimum plastic content of 9% was chosen.

DISCUSSIONS

Bulk Specific gravity of Compacted mix (Gmb)

From observation of the trend of the effect of incorporation PET into the bituminous mix, it can be seen that there was a substantial decrease in specific gravity (SG) of the PET blended mixture samples vis-à-vis a neat sample. Regardless of the content of PET, the bulk SG of the mix was lower than that of the virgin mixture. This decrease is due to that fact that the SG of PET is lower that than of the bitumen its replacing.

Marshall Stability

Based on the study results, the stability of the PET modified mixture increases up to a peak stability of approximately 9400kN at 9% plastic content per weight of bitumen content. At this point, with increase of plastic content, the stability of the mixture reduces. This goes to show that the introduction of PET waste into a bituminous mixture improves the stability of the mix to a certain limit. An improvement in stability means that the mixture is less susceptible to rutting and has a positive impact on resistance (Dalhat & Al-Abdul, 2015). Rutting develops as a result of weak shear strength required to resist continuous heavy load and it affects the performance of the surface course of a pavement. This results in accumulation of the mix, forming a rut which is characterized by a lateral and downward movement of the pavement (Bale, 2011). Accordingly, it is observed that modification of a bituminous mixture with PET results in an increase in stability and shear strength, which in turn has a positive impact on rutting (Wu & Montalvo, 2021).

Karmakar & Roy, 2016, conducted a study and concluded that adding waste plastic directly into hot aggregate increases the stability of the bituminous mix. Vasudevan et al., 2006 also highlighted that incorporating waste PET into a bituminous mix using the dry process produced a more stable mix compared to incorporation of PET using the wet process.

PET Modified Bituminous Mix Flow

The results of the flow test highlights that the flow fluctuated with the introduction of PET waste into the bituminous mix. At 6%, the flow decreased to 3.429 vis a vis the neat sample's flow. It then increased to 3.937 at 10%, then reduced to 3.429 at 14% PET content and increased to 4.233 at 18% PET content. ORN specifies a permissible flow value of between 2-4mm (TRL limited, 2002). Accordingly, it is deduced from the test results that the flow for all test samples were within range expect the one of 18% PET per weight of bitumen content, whose flow was 4.233.

PET Modified Bituminous Mix Percent Air Voids in Compacted Mix (VIM)

From the results, it can be observed that modification of a bituminous mixture with PET results in a reduction of the VIM of the mixture. ORN 19 specifies that the permissible range of VIM should be between 3%-5%. The results indicate that samples with 0%,6% and 10% PET modification per weight of bitumen content met the aforementioned criteria. However, samples with 14% and 18% PET per weight of bitumen content did not meet the specified criteria as they both had VIM values < 3%. A VIM % greater than 5 % leads to increased permeability to air and proneness to oxidation of the bituminous mix which will result in stripping, premature cracking and brittleness (TRL Limited, 2002). On the other hand, VIM values below 3% leads to a mixture that is susceptible to plastic deformation under heavy loading (TRL Limited, 2002)

PET Modified Bituminous Mix Voids in Mineral Aggregates (VMA)

In many instances, VMA is one of the most difficult mix design properties to achieve (TRL Limited, 2002). The aim is to provide enough space for the binder to provide sufficient adhesion to bind the aggregates without the mix bleeding when there is a temperature increase and the bitumen expands.

From the result, it can be observed that value of VMA increases with an increase in the plastic content. Road Note 19 specifies a minimum value of VMA as 13% for a sample with nominal maximum stone size of 19mm. This minimum value was achieved at around 1.7% plastic content. Accordingly, it can be noted that introduction of PET into a bituminous mix, has a positive impact on a mix achieving the minimum 13% VMA as this value significantly rises compared to that of an un-modified mix. The unmodified bituminous mix had a VMA of 9.85%; with the introduction of 6% waste PET, this value shot to 19.915%, a significant positive increase. Inadequate VMA results in reduced capacity of adding sufficient asphalt binder to coat each of the aggregate particles in the mixture. On the other hand, too much VMA results in instability.

PET Modified Bituminous Mix Voids Filled with Bitumen (VFB)

From the test results, it can be observed that the VFB increased with an increase with bitumen content. At 6%, 10%, and 14%, the VFB was within the permissible range of VFB of between 65-78%. Nonetheless, at 18% PET content, the VFB was at 78% which was out of the permissible range. This indicates that PET modified bituminous mix can be a viable alternative to an unmodified mix.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Investigation on using shredded waste PET bottles as a partial replacement of bitumen in producing the bituminous mix is the main aim of the research. Performance and analysis of the tests carried out formed the basis of the conclusions drawn below:

a. 6% was established to be the Optimum Bitumen Content for the mix according to the tests carried out on the Marshall stability of the samples that were neat. This percentage gave guidance on how much or the extent of binder replacement to be carried out.
b. Based on the study results, the stability of the PET modified mixture increased from 9126kN the neat sample, to a peak stability of approximately 9400kN at 9% plastic content per weight of bitumen content. All test samples met the minimum threshold of 5300kN highlighted in the ORN 19.
c. Flow for 6%, 10%, 14% PET modified bitumen mix were all within the permissible range provided in the ORN 19.
d. VIM for 6%,10% PET modified bitumen samples were within the VIM permissible range provided in the ORN 19.
e. VMA for all PET modified bitumen were all within the permissible range highlighted in the ORN 19% (>13%).
f. 6%, 10%, and 14%, the VFB was within the permissible range of VFB highlighted in the ORN 19 (65%-78%).
g. 6% and 10 % PET modified bituminous mix met all the criteria highlighted in ORN 19. Additionally, the aforementioned had higher stability compared to neat samples. Accordingly, it is concluded that PET modification of a bituminous is a viable and can have a positive impact on a bituminous mixture.

Recommendations

The study shows that in road construction, shredded waste plastic bottles (PET) can be utilized as partial substitutes of bitumen, the recommendations below are made to encourage promotion of this technology in Kenya:

a. Further investigations should be carried out on the performance and usage of shredded waste plastic bottles (PET) in the blend of bituminous mixes to establish procedures that are standard for the practice application. Moreover, economic attainability research should be carried out to ensure that there is realization of economic benefit once there is application of the technique in construction of roads.
b. According to the test results, Marshall Test is fitting for testing of polymer-modified bituminous mixes hence Government agencies engaged with construction of roads in the country such as Kenya Rural Roads Authority (KeRRA), Kenya Urban Roads Authority (KURA) and Kenya National Highways Authority (KeNHA) should establish field trials of determining the validity of blending shredded waste plastic bottles with bituminous mix. Based on the findings of the investigation, for foot paths, rural roads, cycle tracks, and low volume roads whose capacity of carrying loads can be compromised then the partial replacement of bitumen with plastic waste

will be useful.

c. The government should team up with non-governmental organizations and organizations in the private sector in order to construct an efficient model of management and waste plastic collection throughout the country which could be put into more profitable use in construction of roads.

d. For the waste plastic to be successfully incorporated into the bituminous mix, it was found that 1650C was the necessary mixing temperature for blending effectively. Manual blending was feasible for the purpose of the study however, for production of the polymer modified bituminous mix in large-scale, mechanical blending would be necessary. The temperature for mixing was also sufficiently low to make sure no toxic gases were produced from heating the waste plastic.

REFERENCES

AASHTO T 27 . (n.d.). Sieve analysis of fine and coarse aggregates ... https://www.in.gov/indot/div/mt/aashto/testmethods/aashto_t27.pdf

AASHTO. (2008). Mechanistic-Empirical Pavement Design Guide. American Association of State Highway and Transportation Officials; Washington, DC, USA.

Al-Hadidy, A. I., & Yi-qiu, T. (2009). Mechanistic approach for polypropylene-modified flexible pavements. Materials & Design, 30(4), 1133–1140. https://doi.org/10.1016/j.matdes.2008.06.021

Angote, J. (2022). Road's spending exceeds budget by Sh5.5 billion. Retrieved 21 July 2022, from https://www.businessdailyafrica.com/bd/economy/roads-spending-exceeds-budget-by-sh5-5-billion-3817658.

Appiah, J. K., Berko-Boateng, V. N., & Tagbor, T. A. (2017). Use of waste plastic materials for road construction in Ghana. Case Studies in Construction Materials, 6, 1–7. https://doi.org/10.1016/j.cscm.2016.11.001

ASTM D6927-06. (2021). ASTM D6927 - 06 Standard Test Method for Marshall Stability and Flow of Bituminous Mixtures. Astm.org. Retrieved 12 May 2021, from https://www.astm.org/DATABASE.CART/HISTORICAL/D6927-06.htm.

Bale, A.S. (2011). "Potential reuse of plastic waste in road construction: a review." International Journal of Advances in Engineering & Technology (IJAET) 2: 233-236.

Cheng, Y., Fu, Q., Fang, C., Zhang, Q., & Lu, C. (2019). Preparation, structure, and properties of modified asphalt with waste packaging polypropylene and organic rectorite. Advances in Materials Science and Engineering, 2019, 1–9. https://doi.org/10.1155/2019/5362795

Chowdhury, G. W., Koldewey, H. J., Duncan, E., Napper, I. E., Niloy, Md. N., Nelms, S. E., Sarker, S., Bhola, S., & Nishat, B. (2021). Plastic pollution in Aquatic Systems in Bangladesh: A review of current knowledge. Science of The Total Environment, 761, 143285. https://doi.org/10.1016/j.scitotenv.2020.143285

Clunies-Ross, P. (2019). Plastics in the Environment. Retrieved 22 April 2021, from https://www.researchgate.net/publication/335338250_Plastics_in_the_Environment.

Costa L.M.B., Silva H.M.R.D., Oliveira J.R.M., Fernandes S.R.M. (2013). Incorporation of Waste Plastic in Asphalt Binders to Improve their Performance in the Pavement. Int. J. Pavement Res. Technol. 2013; 6:457–464.

Dalhat, M. A., & Al-Abdul Wahhab, H. I. (2015). Performance of recycled plastic waste modified asphalt binder in

Saudi Arabia. International Journal of Pavement Engineering, 18(4), 349–357. https://doi.org/10.1080/10298436.2015.1088150

Government of India (2015). Use of plastic waste in bituminous mixes in construction of National Highways. M.o.R.T. Highway, Ministry of Road Transport & Highway.

Hunter, R. (2000). Asphalts in Road Construction. Thomas Telford Pub.

Jamshidi A., White G. (2019). Use of Recyclable Materials in Pavement Construction for Environmental Sustainability, Proceedings of the Eighteenth Annual International Conference on Pavement Engineering, Liverpool, UK, 27–28 February 2019. Asphalt Reinforcement Services; Liverpool, UK: 2019.

Karmakar, S., & Roy, T. K. (2016). Effect of waste plastic and waste tires ash on mechanical behavior of bitumen. Journal of Materials in Civil Engineering, 28(6). https://doi.org/10.1061/(asce)mt.1943-5533.0001484

TRL Limited. (2002). Oversees Road Note 19. A guide to the design of hot mix asphalt in tropical and sub-tropical countries. TRL.

Vasudevan, R., and S. Rajasekaran (2006). Study on the construction of flexible road using plastic coated aggregate. Global Plastics Environmental Conference (GPEC), Atlanta, USA.

Wu, S., & Montalvo, L. (2021). Repurposing waste plastics into cleaner asphalt pavement materials: A critical literature review. Journal of Cleaner Production, 280, 124355. https://doi.org/10.1016/j.jclepro.2020.124355