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POTENTIAL USE OF 'ENSET' FIBER ASH AS PARTIAL REPLACEMENT OF CONVENTIONAL FILLER MATERIAL IN HOT MIX ASPHALT

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Abstract —The main problems in road construction and maintance work in Ethiopia availability of a large amount of appropriate quality materials in road construction sites, aggregates in different size fractions are not readily obtainable, necessitating their procurement from long distances, thereby causing an exorbitant increase in construction costs. One of the main problems in constructing the asphalt paving mixture is obtaining a sufficient amount of filler material from crushing fine rock material and low percent using ordinary Portland cement (OPC), hydrated lime (HL) and marble dust. To overcome this problem, it is important to come across alternative filler material to address this gap using naturally available material. Currently, renewed attention has been given to the use of 'waste' materials instead of conventional aggregates in pavement construction. This research study investigates the potential use of 'Enset' fiber ash as a partial replacement of conventional filler material in hot mix asphalt supported by experimental laboratory investigation. In order to achieve this study, purposive sampling techniques were adopted to select the sample size and location. The study evaluated the potential of 'Enset' fiber ash as filler for the design of dense-graded hot mix asphalt by referencing traditional filler control mix procedures based on standard specifications, and a crush rock filler was utilized as a conventional filler material as a control for comparison. The Marshal Stability and Rutting Test (RT) was conducted to determine the HMA specimen's performance. Several HMA specimens were prepared using aggregate blend according to ASTM D 1559 with four different percentages of 'Enset' fiber ash (EFA) of 15%, 25%, 35% and 45% filler replacement the total filler weight used in the control mix. Specimens were prepared and tests performed according to EN 12697-22 procedure-B for rutting test. All HMA properties were taken at 4% air void and determined their optimum bitumen content (OBC). Almost the same result with the control mix was observed in the study at 15% and 25% of the 'Enset' fiber ash (EFA) replacement. However, higher Marshall Stability, a lower void filled with asphalt, better flow, a good void in mineral were observed at 25% 'Enset' fiber ash (EFA) replacement. At this rate, the rutting performance is less than that of the control mix but is within the specifications of 2.78mm and 2.9 mm of rutting depth less than 6mm that satisfies the EN 13108 requirement. As a result, Enset fiber ash filler can replace traditional filler material up to 25% of the total filler weight used in this study. It was recommended to use 'Enset' fiber ash (EFA) as a filler material as a partial replacement in a bituminous paving mixture up to the specificed percentage by weight replacement.

***Keywords*:** Aggregates, Enset fiber ash, bituminous paving mixes, Marshall mix design, rutting and crushed stone dust

1.0 INTRODUCTION

In Ethiopian road construction and maintenance work require a huge amount of high-quality materials due to the rapid growth of uncontrolled heavy traffic axle load necessitate a higher quality of paving materials during the construction of pavement [1]. The improvement of construction materials which was locally available material, by using stabilizing techniques to improve the engineering property that satisfies the standard specification to attain the intended purpose for road construction [2-6]. There are currently different Bitumen modification strategies utilized to improve the performance, reducing thermal susceptibility and enhanced rutting and fatigue resistance.; however, the high initial cost of raw polymer materilas limit its application, professional workers, and specialized equipment; this technique is costly when compared. In the other method, common filler materials such as lime, cement and other suitable materials can be substituted in the asphalt mix design production [7].The main constitute of bituminous paving mixes is aggregate in course, fine and filler fraction. In road construction sites there was a scarcity of natural aggregate in varying size fraction, it requires their procurement carrying over a long distance, resulting in an exorbitant rise in construction costs[8]. To be economical in road construction, effective utilization of locally available materials to be adopted based on road authority standards set minimum requirements to be satisfied. These needs it require a detailed investigation or understanding of property of a soil and the aggregate property before construction because it affects pavement stability, and the property of binding materials may be used. Bitumen and tar, asphalt and lime, soil and rock, gravel and slag aggregate are among the most important pavement products. Waste materials have gained renewed attention in recent years as an alternative to the conventional aggregate in the pavement industry to be economical and environmental reasons [9]. This research investigated the suitability of 'Enset' Ensete ventricosum fiber ash as filler in hot mix asphalt. The false banana, Ensete ventricosum, belongs to the order Scitamineae, the family Musaceae and the genus Ensete. It is a close relative of the banana plant (genus Musa) and looks like it, except the false banana plants do not grow as edible fruit. Instead, the pseudostem and corms are used as a food source in Ethiopia, where the plant is grown on over 300 thousand hectares as a staple food [10]. This plant domesticated form is only grown in Ethiopia, where it is a staple food of around 20 million peoples. A typical Enset plant can grow to be 4m to 13m tall, with a pseudostem circumference of 1.5m-3.0m, a pseudostem length of 2m-5m and leaf length and width of 4 to 6 meters and 0.6m-0.9m, respectively [11]. Enset is a valuable local food source, especially in Ethiopia. It contains more calories per unit area than cereals, according to the food and agriculture association; it estimates that 40-60 Enset plant can cover 250-375 square meters will feed a family of five to six peoples[12]. When the inflorescence appears, the Enset plant is usually matured and ready to harvest; the corm is used directly for food production while the lower part of the leaf sheaths from the pseudostem is scraped to obtained a starchy pulp that is used in a variety of popular foods. Fibers are solid agricultural residual byproducts with a fibrous natural formed by this process. These fibers are sundried and used to make sacks, bags, ropes, mats, and sieves in the past, but these use a small portion of the material, leaving a large amount of residuals with little commercial value [10]. As a result, the eco-friendly solution to agricultural waste management is the proper valorization of these agricultural remnants for higher added value items, which removes the need for their disposal. The effect of Enset fiber ash on Marshall Property was explored in this study. Enset fiber ash's feasibility as an alternative filler with the desired proportion to be tested based on experimental analysis by comparing it to control mixture and standard requirement. Filler materials have long been used in asphalt mixtures to fill the voids created by larger aggregate particle during production [13].The explored the effect of different types of fillers on the properties of asphalt concrete mixture as it varies with the particle size, shape, surface area, surface texture and other physical-chemical properties[14]. Fine sand, cement, hydrated lime, crushed stone and marble dust are widely used as filler material in Ethiopia in the bituminous mix design and obtaining a sufficient amount of filler material and raising the initial cost of cement or marble dust as filler materials are two major factors in the construction of asphalt paving mixtures; since the asphalt, institute restricts ordinary Portland cement and hydrated lime, they can only be used up a maximum of 2% in proportion to improve the aggregate adhesion property which is insufficient to meet the grading requirements[15,16]. Marble dust is obtained from the waste byproduct of the marble industry located far away, it takes a long distance to obtained sufficient quantity, and it takes a long time for this dust to dry if it is not placed carefully to avoid moisture absorption. This research investigates the effect of various types of inexpensive and non-traditional fillers on bituminous mixes' behavior. Non-conventional filler Enset fiber ash was used to examine the fundamental marshall properties and its performance test conducted by experimental.

2.0 METHOD AND MATERIAL USED

2.1. Research Design

This research was conduct by using an experimental research design method. After organizing a literature review of different previously published research, the study evaluates the suitability of 'Enset' fiber ash as filler for hot mix asphalt design by referencing a control mix of conventional filler mixed with bitumen 60-70 penetration grade. In this research, conventional filler was used Crushed Rock Fines (CRF) as filler. In particular, AASHTO (T47, T49, T51, T53 and T228-06), ASTM (C13 and C535) and BS (812 part 105(1990), 812 part 3(1995), 812, part 2 (1995)) standard laboratory procedures were performed for all materials properties (bituminous binder, coarse or fine aggregate and fillers. The applicable practice work research findings and other information on the filler material for the asphalt pavement mixture were reviewed to accomplish this research goal.

The Marshal method was used based on Asphalt Institute Manual Series MS-02[17] to determine the suitability of 'Enset' fiber ash as filler. A sample specimen was prepared by compacting 75 blow on both sides based on Standard

Method (ASTMD1559) having five different bitumen content between 4%, 4.5%, 5%, 5.5% and 6% by total weight of aggregate. Control mixes prepared by using 5.5% crushed rock fine as mineral filler. Furthermore, mixes containing 15%, 25%, 35% and 45% of control mix filler were replaced by Enset fiber ash for investigation. Beside with marshal stability test: - Rutting Test (RT) was conducted to determine the designed mix's performance.

The following steps were following for the preparation of test specimens:

a) All of the materials that have been proposed for use satisfy the standard criteria.
b) Mechanical stabilization of different aggregate combinations was satisfy the gradation requirement.
c) The bulk specific gravity of all aggregate in the blend were be used to conduct density and voids tests, and the specific gravity of asphalt cement was be determined.

Evaluation of materials properties was determined before proceeding with the design of hot mix asphalt. Bitumen, aggregates and EFA properties were determined. Then for each stockpile of aggregates, blending was carried out to obtain the binder course gradation specifications, which are used to prepare the asphalt mixture. After that, control mixes and EFA (with various percentages) replacement mixes were prepared to obtain optimum bitumen content by observing and analyzing Marshall Test results. Finally, Marshall Test results were used to evaluate these Enset fiber ash filler properties in the mixtures and the corresponding laboratory test results obtained were analyzed. Then, by taking the best Enset fiber ash replacement results, a rutting test was performed to determine prepared Asphalt performance. Figure 1 shows a flowchart of experimental work for this study.

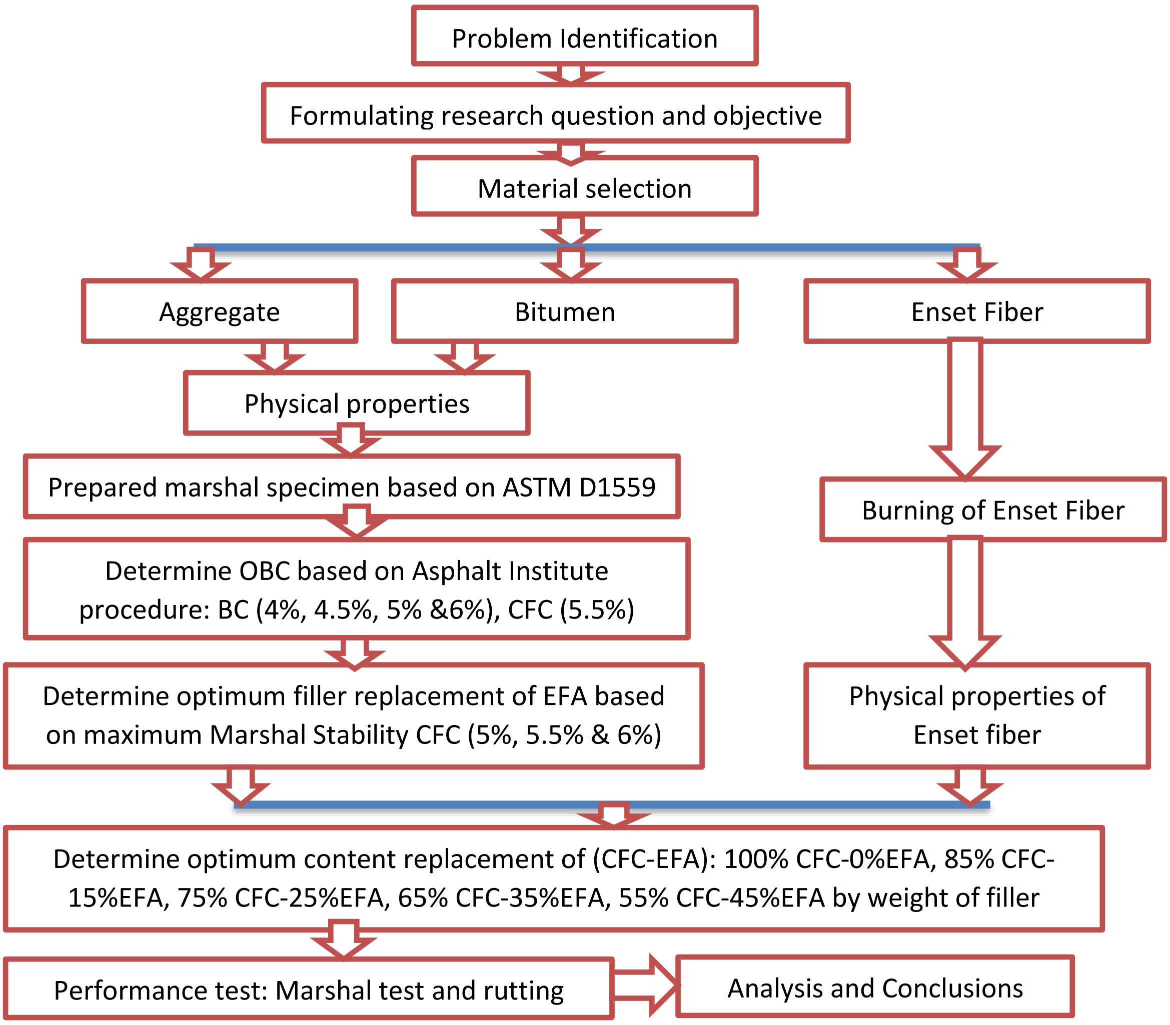

Figure 1 Flow chart of experimental work

2.2. Materials

There are different materials required for producing asphalt specimens. Before designing asphalt mixes, selection, proportioning, and individual material characterization are essential to obtain the finished mix's desired quality and properties. The Row material used in this study, the crushed coarse aggregate and fine aggregate, are taken from Shandong Highway Engineering Construction Group Co. Ltd located at SNNP, Gurage zone in Gunchire site. The asphalt cement of 60-70 penetration grades was obtained from ERA (Jimma branch). Enset fiber is obtained from markets around Wolkite and nearby Woreda, located at Gurage Zone, southwestern Ethiopia.

3.0 RESULT AND DISCUSSIONS

3.1. Aggregate Physical properties

Various test were conducted to determine the physical aggregate properties and the suitability for road construction as shown in Table 1 Surface area factors were multiplied by the percentage passing the various sieve sizes and added together to determine the specific surface area for each aggregate size distribution. As can be seen from the data, the real surface area increases as the filler content in the aggregate proportion increases.

Table 1 Aggregate Physical properties

S/N	Test Description	Test Method	Result	Specification (ERA Manual 2013)
1	Los Angeles Abrasion, %	AASHTO T 96	14.000	< 30.00
2	Aggregate Crushing Value, ACV, %	BS 812 Part 110:1990	17.300	<25.00
3	Aggregate Impact Value, %	BS 812 Part112:1990	14.605	<25.00
4	Flakiness Index	BS 812, Part 105 (1990)	11.500	< 35.00
5	Elongation index in (%)	BS 812, Part 105 (1990)	10.500	< 35.00
6	Coarse Aggregate Specific Gravity (Bulk)(kg/m^3)	AASHTO T 85	2.736	N/A
7	Fine Aggregate Specific Gravity (Bulk)(kg/m^3)	AASHTO T 84	2.705	N/A
8	Coarse Aggregate Specific Gravity (Apparent)(kg/m^3)	AASHTO T 85	2.824	N/A
9	Fine Aggregate Specific Gravity (Apparent)(kg/m^3)	AASHTO T 84	2.831	N/A
10	Water Absorption, %	ASTM C 127	1.370	<2

N/A-Not Available

3.2. Mineral filler (CRF & EFA)

Crushed Rock fine and Enset fiber ash were used as mineral filler in this research. Their physical properties affect the bituminous mixture property, such as bulk specific gravity and plasticity index, which were determined as shown in Table 2.

Table 2 Physical properties of filler material

S/N	Test Description	Test Method	Result	Specification (ERAManual2013)
1	Specific Gravity of Filler(CRF)	AASHTO T-100	2.898	N/A
2	Specific Gravity of Filler (EFA)	AASHTO T-100	2.720	N/A
3	PI, (Plastic Index)	AASTO T 89 or T 90	NP	< 4

NP- Non-Plastic, N/A - Not Available

3.3. Asphalt Binder Test Results

A series of bitumen quality tests were conducted before the start of the mix design. These tests included penetration, specific gravity, softening point, flash point, ductility, and solubility to characterize 60/70 penetration grade binder properties. Table 3 presents the summary of the 60/70 penetration grade binder's various properties, which comply with ERA specifications.

Table 3 Physical properties of bitumen

S/N	Test Description	Unit	Test Method	Test Result	ERA, 2013 Specification Limit
1	Penetration @25ºC25◦ c, 100g, 5sec	1/10mm	AASHTO T 49	64	60 –70
2	Specific gravity @25ºC	kg/cm^3	AASHTO T228-06	1019	1023
3	Ductility @25 ºC	cm	AASHTO T51	100+	100+
4	Loss on heating (%)	%	AASHTO T 47	0.18	Max 0.5

5	Softening Point	^0C	AASHTO T 53	49	46-56
6	Flash Point	^0C	AASHTO T 48	562	Min 232

3.4. Aggregate Gradation of Mix Design

HMA is graded by the percentage of different-size aggregate particles it contains. Table 4 illustrates HMA gradations without blending with Enset fiber ash which is the normal gradation used to control the study. Certain terms are used in referring to aggregate fractions: Course aggregate-G- 1, (13.2-20), Coarse Aggregate-G-2, (7-13.2), Coarse Aggregate-G-3, (3-7), and Fine Aggregate- G-4, (0-3).

Table 4 Aggregate Gradation and Blending without Filler material

Suggested combination %	**10.5%**	**36.5%**	**26.0%**	**27.0%**	**100.0%**	**Lower Limit**	**Upper Limit**	**Spec Median**	**FWHA Max Density Curve**
	G-1 13.2-20	**G-2 7-13.2**	**G-3 3-7**	**G-4 0-3**	**Blend**				
Sieve Size (mm)	**% Pass**	**% Pass**	**% Pass**	**% Pass**	**% Pass**	**% Pass**	**% Pass**	**% Pass**	**% Pass**
25.0	100.0	100.0	100.0	100.0	**100.0**	100	100	100	**100.0**
19.0	98.7	100.0	100.0	100.0	**99.9**	90	100	95	**88.4**
9.5	1.1	34.4	99.9	100.0	**65.6**	56	80	68	**64.7**
4.75	0.3	1.6	93.3	100.0	**51.9**	35	65	50	**47.4**
2.36	0.2	0.9	32.4	97.8	**35.2**	23	49	36	**34.6**
0.30	0.1	0.3	1.2	24.1	**6.9**	5	19	12	**13.7**
0.075	0.1	0.3	0.7	10.3	**3.1**	2	8	5	**7.3**

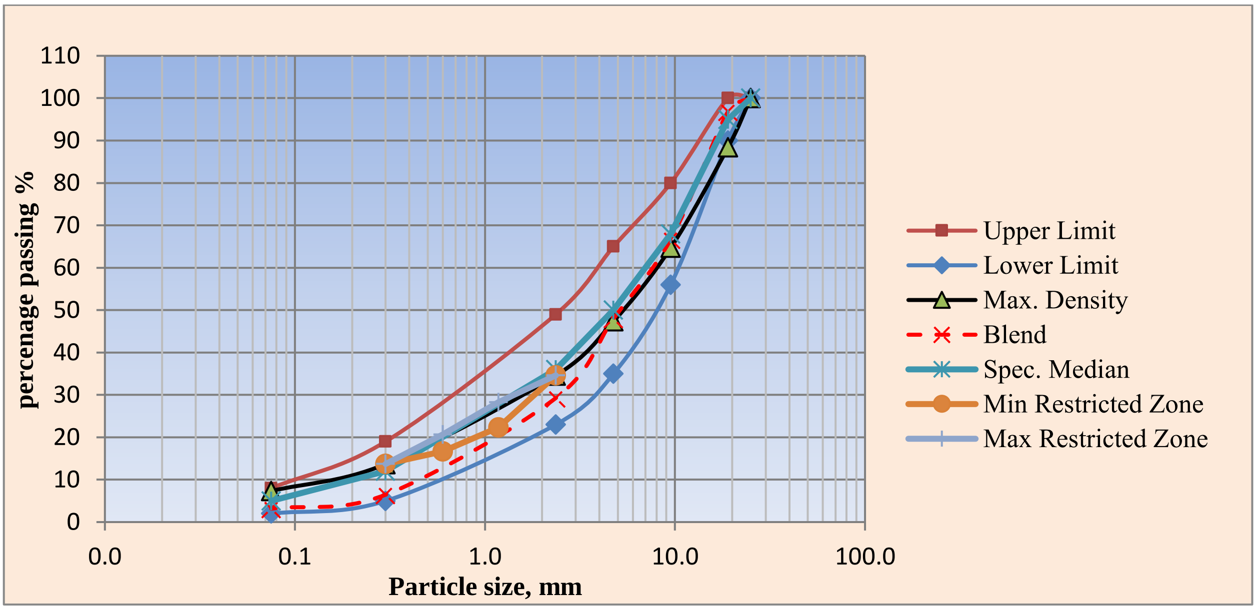

Figure 2 Gradation of Aggregate without Filler Material

Mineral filler such as mineral dust occurs naturally with many aggregates and is produced as a byproduct of crushing many rock types. The above figure shows that the aggregate blend shows additional mineral filler needed to satisfy the gradation requirement for Marshall Mixture preparation, which shows the blend G-1, 10.5%, G-2, 36.5%, G-3, 26%, G-4, 27% meet the requirement but the fillet percent almost touch lower limit which shows there was need of additional filler.

Table 5 Aggregate Gradation Blending with Filler material

Suggested combination %	10.0%	36.0%	25.5%	26.0%	2.5%	100.0%	Lower Limit	Upper Limit	Spec Median	FWHA Max Density Curve
	G-1 13.2-20	G-2 7-13.2	G-3 3-7	G-4 0-3	Filler	Blend				
Sieve Size (mm)	% Pass	% Pass	% Pass	% Pass	% Pass	% Pass	% Pass	% Pass	% Pass	% Pass
25.0	100.0	100.0	100.0	100.0	100.0	100.0	100	100	100	100.0
19.0	98.7	100.0	100.0	100.0	100.0	99.9	90	100	95	88.4
9.5	1.1	34.4	99.9	100.0	100.0	66.5	56	80	68	64.7
4.75	0.3	1.6	93.3	100.0	100.0	52.9	35	65	50	47.4
2.36	0.2	0.9	32.4	97.8	100.0	36.5	23	49	36	34.6
0.30	0.1	0.3	1.2	24.1	100.0	9.2	5	19	12	13.7
0.075	0.1	0.3	0.7	10.3	100.0	5.5	2	8	5	7.3

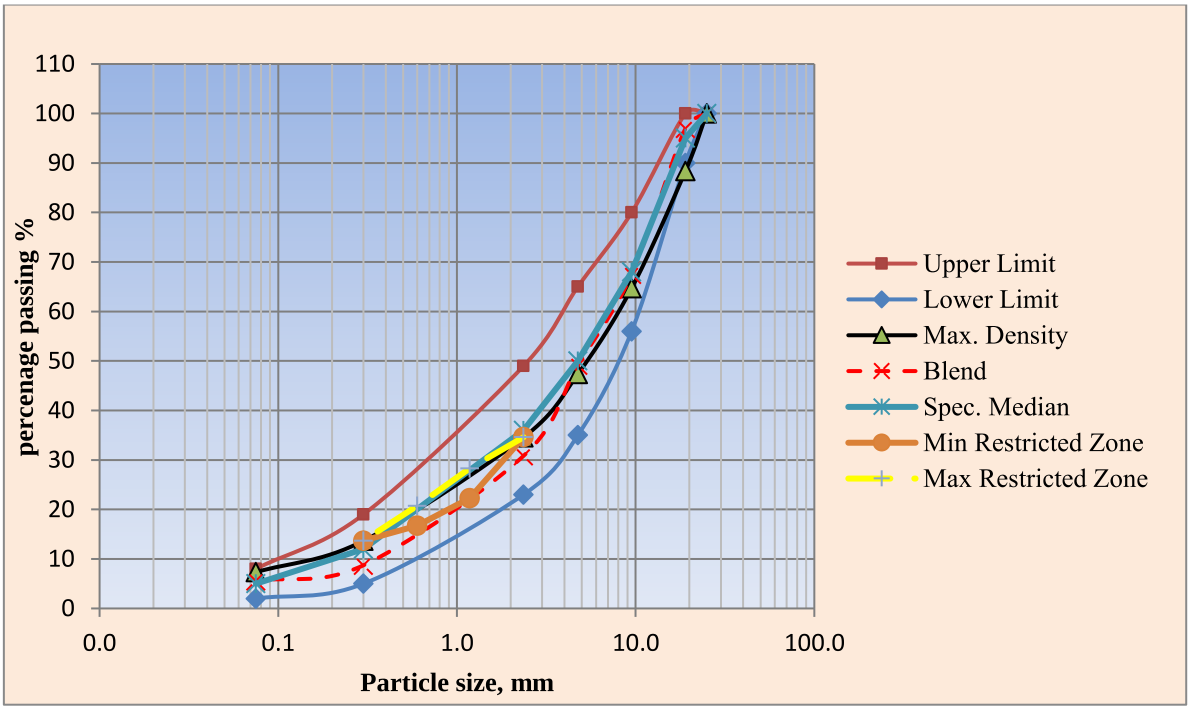

Figure 3 Aggregate Gradation Blending with Filler material

As shown in the above Figure 3, to meet the specification of job mix and to gate smooth job mix curve, there were blended with 2.5% of additional mineral filler with the aggregate of G-1, 10%, G-2 36%, G-3 25.5% and G-4, 26% gives better aggregate blend for the Marshall mix design.

3.5. Marshall Test Results

Marshall Test results of control and 25% EFA replaced mixtures with different binder content are presented in Table 8 and Table 9. The relationships between binder content and the mixture properties such as Stability, Flow, VFB, VMA, VA, Stability, Flow and Bulk Density are presented in Figure 4 – Figure 9. A sets of 75 samples, each weighing 1190.1 gram were prepared using five different bitumen contents (4.0- 6.0%) with 0.5 increments by the total weight to determine the optimum bitumen content as listed in Table 6 and also showed the total batch weight of aggregate hot mix asphalt that used in this study.

Table 6 Bitumen batch weight for Marshal and MTD

Bitumen Batch Weights (gm) for Marshall			Bitumen Batch Weights (gm) for MTD		
Bitumen % by Wt. of Total Mix	Bitumen (gm) = A-1190.1	Total Batch (gm)(A) $\frac{1190.1}{(1-\frac{Bit.Con}{100})}$	Bitumen % by Wt. of Total Mix	Bitumen (gm) = B-1500	Total Batch (gm)(B) $\frac{1500}{(1-\frac{Bit.Con}{100})}$
4.00	49.6	1239.60			
4.50	56.1	1246.09	4.50	70.7	1570.68
5.00	62.6	1252.65	5.00	78.9	1578.95
5.50	69.3	1259.27			
6.00	76.0	1265.97			

The process of measuring the stability values from the standard 63.5mm compacted height. Those with greater compacted thickness were converted to an equivalent 63.5mm value by multiplying the conversion factor. The applied correlation ratio to convert the measured stability values is set in Table 7.

3.7. The conversion was made based on either measured thickness or measured volume.

Table 7 Correlation ratio for adjusting the stability values [13]

Volume of Specimen cm^3	Approximate Thickness of Specimen, mm	Correlation Ratio
380 to 392	47.60	1.670
393 to 405	49.20	1.560
406 to 420	50.80	1.470
421 to 431	52.40	1.390
432 to 443	54.00	1.320
444 to 456	55.60	1.250
457 to 470	57.20	1.190
471 to 482	58.70	1.140
483 to 495	60.30	1.090
496 to 508	61.90	1.040
509 to 522	63.50	1.000
523 to 535	64.00	0.960
536 to 546	65.10	0.930
547 to 559	66.70	0.890
560 to 573	68.30	0.860
574 to 585	71.40	0.830
586 to 598	73.00	0.810
599 to 610	74.60	0.780
611 to 625	76.20	0.760

Notes:

1. The measured stability of a specimen multiplied by the ratio for the thickness of the specimen equals the corrected stability for a 63.5-mm (2.5-in.) specimen.
2. Volume-thickness relationship is based on a specimen diameter of 101.6 mm (4 in.)

Table 8 Marshall Test Result for control Mixes or mixes with 0% EFA Filler Content

MARSHALL PROPERTIES OF BITUMINOUS MIXTURES					Control mix 0% EFA Replacement
S.G of Aggregate			**Bitumen**		
Size	Bulk	Apparent	Source	IRAN	
Coarse(4.75 Retain)	2.736	2.831	Grade	60/70	
Fine(4.75 Pass)	2.705	2.824	Specific Gravity	1.019	
Filler	2.898	2.898	Ring Factor		
Combined Sp.Gr	2.73	2.831	Ring Factor	1.17	

Test Method-Asphalt Institute Manual Series MS-02

Trial No.	**Bitumen % by Weight of Total Mix**	**Height of Specimen**	**Weight** In air (A)	**Weight** In water (B)	**Weight** S.S.D in air (C)	**Bulk volume** D=C-B	**Gmb** E=A/D	**Gmm** (G)	**AV**	**VIM** 2.730	**VFA**	**Stability** Dial Reading (mm)	**Stability** Dial R.*RF	**Stability** Adjusted Stability (kN)	**Flow** (mm)
A	4.0	65.30	1233.30	716.00	1236.90	520.90	2.368					14.01	11.97	11.50	1.88
B	4.0	65.80	1229.90	715.70	1234.20	518.50	2.372					12.18	10.41	9.99	1.71
C	4.0	65.50	1230.70	714.40	1234.00	519.60	2.369					14.43	12.33	11.84	1.38
Average		65.53				519.67	2.389	2.580	**2.577**	**7.32**	**16.00**	**54.25**		11.11	1.66
A	4.5	64.90	1240.20	723.30	1241.50	518.20	2.393					14.71	12.57	12.07	1.83
B	4.5	65.60	1241.50	724.50	1244.80	520.30	2.386					12.64	10.80	10.37	2.12
C	4.5	64.90	1243.10	725.30	1245.30	520.00	2.391					13.95	11.92	11.45	1.56
Average		65.25				519.50	2.412	2.560	**2.557**	**5.97**	**15.89**	**62.44**		11.76	1.98
A	5.0	64.80	1245.40	725.80	1245.60	519.80	2.396					14.87	12.71	12.20	1.99
B	5.0	64.90	1253.00	731.60	1253.60	522.00	2.400					13.34	11.40	10.95	2.00
C	5.0	64.40	1249.10	731.80	1249.70	517.90	2.412					16.60	14.19	14.19	2.33
Average		64.80				519.90	2.431	2.543	**2.526**	**4.25**	**15.82**	**73.12**		12.44	2.11
A	5.5	64.00	1250.30	735.60	1250.30	514.70	2.429					15.43	13.19	13.19	1.90
B	5.5	65.50	1267.90	743.20	1268.10	524.90	2.416					14.42	12.32	11.83	1.99
C	5.5	64.90	1254.00	734.10	1254.00	519.90	2.412					15.32	13.09	12.57	2.36
Average		64.80				519.83	2.441	2.516	**2.527**	**3.78**	**15.82**	**76.08**		12.53	2.18
A	6.0	64.40	1257.10	739.90	1257.20	517.30	2.430					14.09	12.04	12.04	3.01
B	6.0	64.50	1256.00	740.40	1256.10	515.70	2.436					13.95	11.92	11.92	2.63
C	6.0	64.60	1259.50	741.30	1259.70	518.40	2.430					12.72	10.87	10.44	2.95
Average		64.50				517.13	2.445	2.500	2.497	**2.08**	**15.78**	**86.85**		11.47	2.86

Where; Gmb= Bulk specific gravity, Gmm= Theoretical maximum specific gravity, Va= Air Void in the total mix, VMA= Voids in the Mineral Aggregate, & VFA% = % Voids Filled with Asphalt

The above table 8 shows the laboratory test results of control mixtures or 0% EFA mixture and the corresponding values of Marshall Properties with different bitumen contents.

Table 9 Marshall Test result mixes with 25% filler content

MARSHALL PROPERTIES OF BITUMINOUS MIXTURES						
S.G of Aggregate			Bitumen			
Size	Bulk Gsb	Apparent Gsa	Source	IRAN	Replacement	25% EFA
Coarse(4.75 Retain)	2.736	2.831	Grade	60/70	Compaction	75 Blows
Fine(4.75 Pass)	2.705	2.824	Specific Gravity	1.019	AC Grade	60/70
Filler	2.898	2.898	Ring Factor			
Combined Bulk & Apparent Sp.Gr	2-Jan-00	2.831	Ring Factor	1.17		

Test Method-Asphalt Institute Manual Series MS-02															
			Weight									Stability			
Trial No.	Bitumen % by Weight of Total Mix	Height of Specimen	In air (A)	In water (B)	S.S.D in air (C)	Bulk volume (m3) D=C-B	Gmb E=A/D	Gmm (G)	AV	VMA 2.730	VFA	Dial Reading (mm)	Dial R.*RF	Adjusted Stability (kN)	Flow (mm)
A	4.0	65.50	1235.20	720.58	1236.00	515.42	2.396					13.50	11.54	11.08	1.95
B	4.0	65.81	1234.80	717.90	1235.90	518.00	2.384					12.90	11.03	10.58	2.30
C	4.0	65.40	1234.50	717.65	1235.26	517.61	2.385					13.56	11.59	11.13	2.12
Average		**65.57**				**517.01**	**2.388**	**2.577**	**7.32**	**16.00**	**54.25**			**10.93**	**2.12**
A	4.5	65.00	1239.00	724.80	1240.60	515.80	2.402					14.00	11.97	11.49	2.31
B	4.5	64.50	1243.50	728.50	1244.60	516.10	2.409					13.56	11.59	11.59	2.25
C	4.5	64.30	1240.20	725.80	1242.36	516.56	2.401					13.54	11.57	11.57	1.56
Average		**64.75**				**516.15**	**2.404**	**2.557**	**5.97**	**15.89**	**62.44**			**11.53**	**2.28**
A	5.0	65.10	1246.25	729.56	1248.00	518.44	2.404					14.45	12.35	11.86	2.32
B	5.0	64.50	1248.90	735.60	1249.80	514.20	2.429					15.00	12.82	12.82	2.20
C	5.0	65.00	1247.30	734.20	1248.87	514.67	2.423					15.32	13.09	12.57	2.58
Average		**65.10**				**515.77**	**2.419**	**2.526**	**4.25**	**15.82**	**73.12**			**12.42**	**2.37**
A	5.5	65.30	1254.50	738.90	1255.90	517.00	2.426					15.23	13.02	12.50	3.20
B	5.5	65.50	1255.00	742.60	1257.10	514.50	2.439					15.10	12.91	12.39	2.51
C	5.5	65.10	1254.36	738.20	1254.60	516.40	2.429					15.12	12.92	12.41	2.42
Average		**65.30**				**515.97**	**2.432**	**2.527**	**3.78**	**15.82**	**76.08**			**12.43**	**2.47**
A	6.0	65.60	1260.30	746.50	1262.00	515.50	2.445					14.96	12.79	12.27	3.25
B	6.0	65.10	1258.70	745.10	1259.60	514.50	2.446					13.50	11.54	11.08	3.12
C	6.0	65.71	1259.30	745.90	1260.80	514.90	2.446					13.21	11.29	10.84	3.50
Average		**65.47**				**514.97**	**2.446**	**2.497**	**2.08**	**15.78**	**86.85**			**11.40**	**3.29**
Where; Gmb= Bulk specific gravity, Gmm= Theoretical maximum specific gravity, Va= Air Void in the total mix, VMA= Voids in the Mineral Aggregate, & VFA% = % Voids Filled with Asphalt															

The above table 9 shows the laboratory test results of mixtures with 25% EFA and the corresponding values of Marshall Properties with different bitumen contents.

3.5.1 Marshall Stability

Stability is generally a measure of the aggregate-asphalt cement mixture's mass viscosity and is affected significantly by the angle of internal friction of the aggregate and the asphalt cement's viscosity. As we see in Table 10 and Figure 4, the addition of EFA as filler in the hot asphalt mix result decrees the stability performance comparing with the control mix. However, there is stability fluctuation when we observed 15% and 25% EFA replacement. 25% EFA replacement better stability result than 15% replacement but Increasing percent of EFA content decreased the mix's stability performance.

Table 10 Stability Value of different percent of EFA replacement

Stability value					
	0% EFA	15%EFA	25% EFA	35% EFA	45% EFA
4	11.1	10.9	10.9	9.4	9.6
4.5	11.8	11.5	11.5	11.0	10.4
5	12.4	12.3	12.4	11.8	10.8
5.5	12.5	12.4	12.4	11.6	10.6
6	11.5	11.3	11.4	10.4	10.2

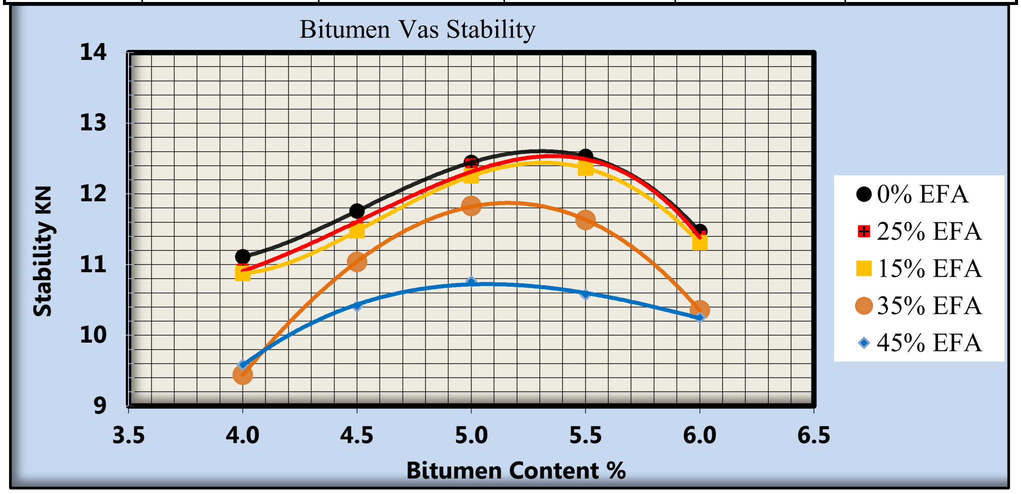

Figure 4 Stability vs. Bitumen Content

3.5.2 Flow

Flow is the total amount of deformation which occurs at maximum load. From Figure 5 below shows that the asphalt mix's maximum flow was at 6% bitumen content, which shows flow was increased with increasing bitumen content. High flow values indicated a plastic mix that will be caused permanent deformation under traffic, whereas low flow values may indicate a mix with higher air void in the mix than acceptable voids and insufficient asphalt and may experience premature cracking due to mixture brittleness during the life of the pavement. Figure 5 shows bitumen flow results with different bitumen contents. The flow value has a consistent increase with increasing asphalt content were within the range of (1.6 – 2.86mm) for 0%, (2-3.06mm) for 15%, (2.1-3.29mm) for 25% (2.04-3.55mm) for 35% and (2.6-4.14mm) for 45% EFA replacement. The result shows flow, bitumen and EFA direct relationship, which means that flow increased with increasing bitumen and EFA content.

Table 11 Flow Value of different percent of EFA replacement

Flow in (mm)					
%Bit.	0% EFA	15%EFA	25% EFA	35% EFA	45% EFA
4	1.66	2.09	2.12	2.04	2.60
4.5	1.98	2.23	2.28	2.18	3.10
5	2.11	2.43	2.37	2.43	4.00
5.5	2.18	2.55	2.47	2.90	4.12
6	2.86	3.06	3.29	3.55	4.14

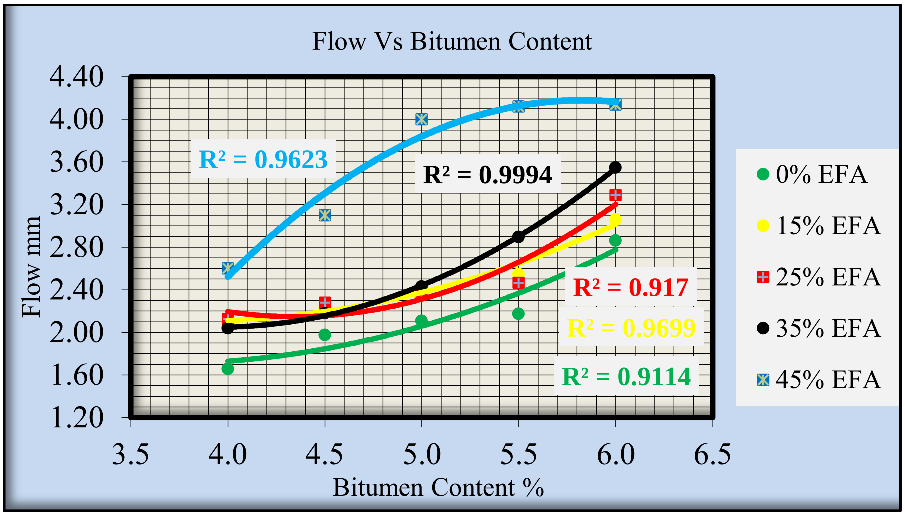

Figure 5 Flow vs. Bitumen Content

3.5.3 Unit Weight (Density)

The mixture's unit weight is the density of the compacted mix and the density of the finished product is important for long-term pavement efficacy. Mix property must be calculated in volumetric as well as weight terms. The addition of EFA has improved the compacted mixture unit weight, as shown in Figure 6, and its density increases as the percentage of EFA increases; however, the higher content of mix becomes stiffer and needs a greater compaction effort than the lower dense mixtures.

Table 12 Unit weight value of compacted mixture for different percent of EFA replacement

	Unit Weight (Density)				
%Bit.	0% EFA	15%EFA	25% EFA	35% EFA	45% EFA
4	2.389	2.372	2.388	2.384	2.385
4.5	2.412	2.392	2.404	2.401	2.406
5	2.431	2.405	2.419	2.420	2.420
5.5	2.441	2.420	2.433	2.446	2.453
6	2.445	2.433	2.446	2.461	2.466

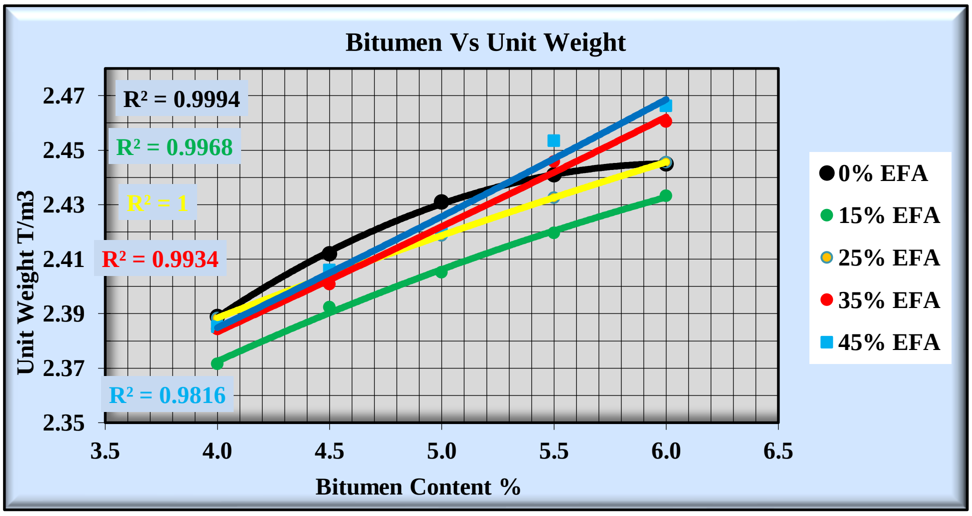

Figure 6 Unit Weight vs. Bitumen Content

3.5.4 Air Voids Content (Va)

The total volume of small air pockets between coated aggregate particles in a compacted paving mixture is known as the air void (Va). It is measured as a percentage of the compacted paving mixtures of bulk volume. Figure 7 below shows that air-void content gradually decreases with increasing the bitumen content and EFA addition. Due to the increased VFA in the asphalt mix, the EFA was finer than CRF, or FFA may have a higher absorption capacity than CRF. Figure 7 shows the result of air voids content with different bitumen content.

Table 13 Air void value for different percent of EFA replacement.

Air Voids Content AV in %					
%Bit.	0% EFA	15%EFA	25% EFA	35% EFA	45% EFA
4	7.4	7.6	7.3	7.2	6.9
4.5	6.1	6.1	6.0	5.8	5.3
5	4.9	4.3	4.3	4.1	3.1
5.5	3.4	4.0	3.7	2.7	2.9
6	2.2	2.2	2.1	1.2	0.7

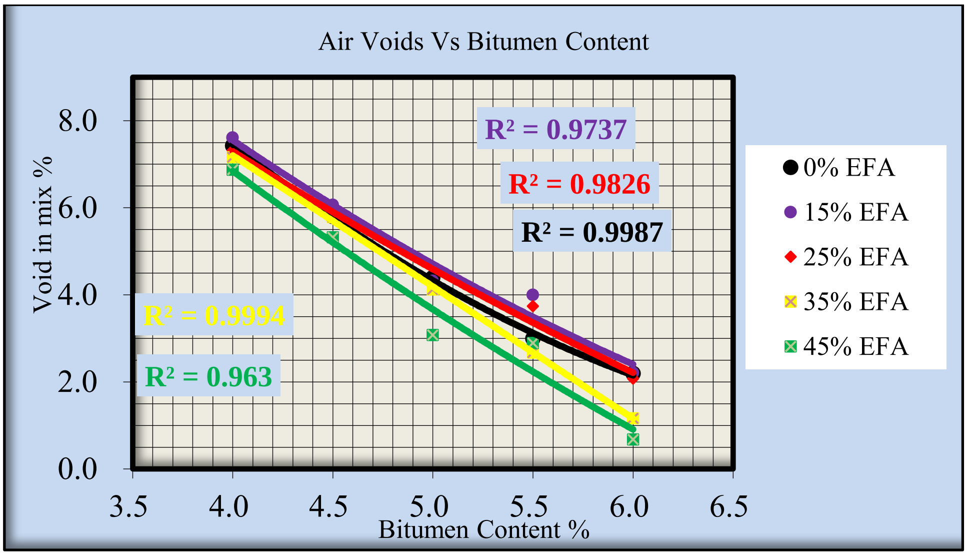

Figure 7 Air Void vs. Bitumen Content

3.5.5 Voids in Mineral Aggregate (VMA)

The intergranular void space between the aggregate particles in a compacted paving mixture includes the air void, and the effective material, expressed as the percentage of the total, is known as a void in the mineral aggregate(VMA). This value decreases as the EFA and bitumen content increases, as shown in Figure 8; however, the void in mineral aggregate decreases until it reaches a minimum value and increases as a filler content in the mix increases. Figure 8 shows the result of VMA with different bitumen content and EFA content.

Table 14 Void in mineral aggregate for different percent of EFA replacement.

Voids in Mineral Aggregate (VMA)%					
%Bit.	0% EFA	15%EFA	25% EFA	35% EFA	45% EFA
4	16.0	16.6	16.0	16.1	16.1
4.5	15.6	16.3	15.9	16.0	15.8
5	15.4	16.3	15.8	15.8	15.8
5.5	15.5	16.2	15.8	15.3	15.1
6	15.8	16.2	15.8	15.3	15.1

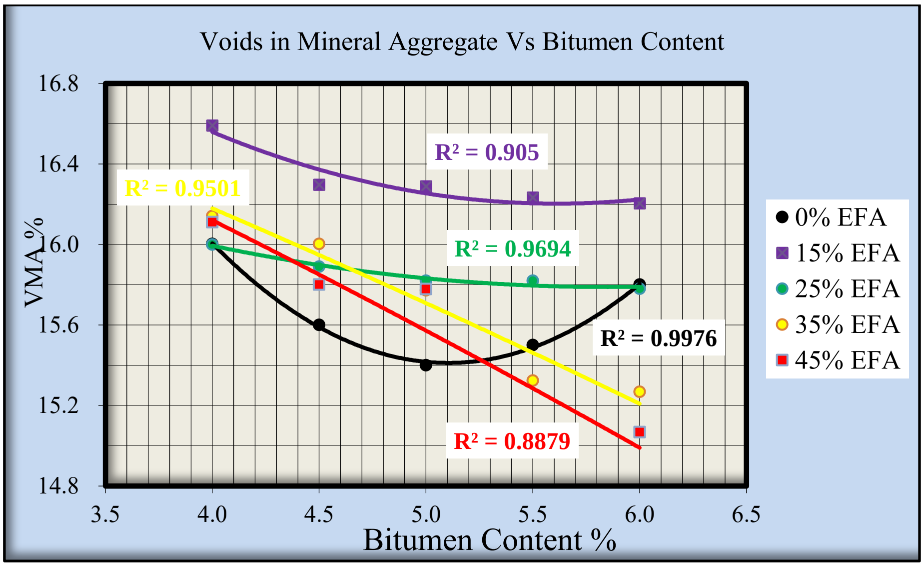

Figure 8 VMA Vs Bitumen Content

3.5.6 Voids Filled with Asphalt (VFA)

The percentage of intergranular void space between aggregate particles is expressed by the void filled with asphalt (VFA). The VFA percentage increases steadily as the bitumen and EFA content increase due to a rise in the percentage of void filled with bitumen in the asphalt mix, as shown in Figure 9. It is inversely proportional to the number of air voids; thus, as the air voids decrease, its VFA value grows.

Table 15 Void filled with asphalt for different percent of EFA replacement

Voids Filled with Asphalt (VFA) in %					
%Bit.	0% EFA	15%EFA	25% EFA	35% EFA	45% EFA
4	53.6	54.1	54.3	55.6	57.3
4.5	61.8	62.8	62.4	63.8	66.3
5	69.1	73.4	73.1	73.9	80.5
5.5	78.7	75.4	76.3	82.6	80.8
6	86.0	86.3	86.8	92.3	95.5

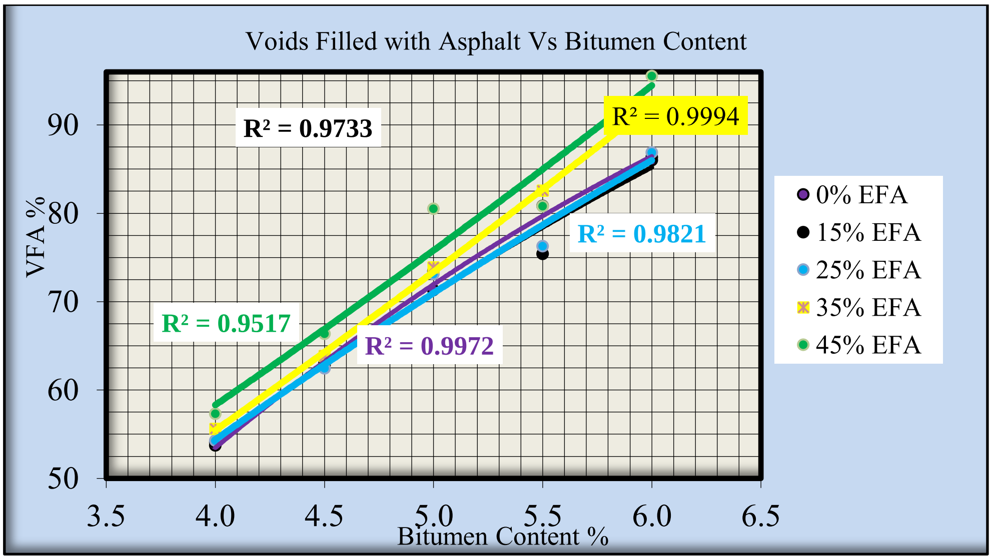

Figure 9 VFA Vs Bitumen Content

3.5.7 Optimum Asphalt Content Determination

The output of the mixture is expressed to be determined by the effective asphalt material. The successful asphalt material that forms the asphalt film around the aggregate particles is expressed this way. The bituminous mixture can achieve various desirable characteristics such as better longevity, fatigue resistance, and higher resistance to moisture-induced damage if the aggregate particles' asphalt film thickness is thick enough. However, there should be a limit above as the temperature and loading rise; as the asphalt content in the mix increases, it becomes bleeding on the paved road surface. The successful asphalt content of mixes blended with 0%EFA filler is plotted in Figure 10; as the amount of effective asphalt in the mix decreases, the amount of filler in the mix becomes increases. As the filler content in the mix increases, more void are filled with mineral fillers, resulting in increased asphalt content and increases in effective asphalt content. Furthermore, fine aggregate is absorbed more asphalt due to a higher proportion of fines in the mixture as the filler content increases. Tables 8 and 9 demonstrate the properties of the mix design binder material using Marshall Criteria.

Table 16 Properties summary for control mix design

% of asphalt	Unit Weight	Air Void	Stability	Flow	VMA	VFA
4.00	2.389	7.4	11.1	1.66	16.0	53.7
4.50	2.412	5.8	11.8	1.98	15.6	63.0
5.00	2.431	4.4	12.4	2.11	15.4	71.3
5.50	2.441	3.0	12.5	2.18	15.5	80.8
6.00	2.445	2.2	11.5	2.86	15.8	86.0

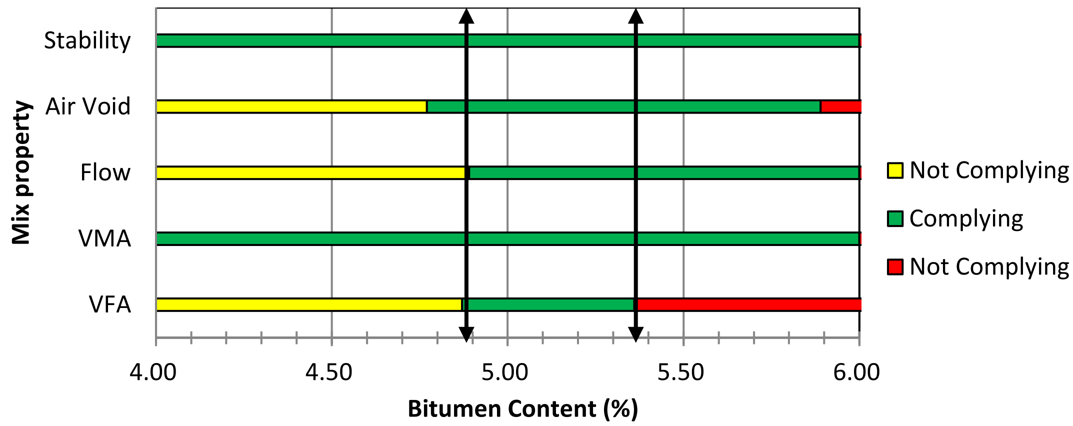

Figure 10 Acceptable Bitumen range complying with design criteria

Therefore the target AC is 5.1%, and the Acceptable Asphalt Limit can be Min. 4.89 and Max. 5.36

Table 17 Mechanical Properties of Asphalt Mixes with EFA at 5.1% Bitumen Content

Specification Requirement as per ERA 2013 &MS-2		Test result for different % of EFA replacement				
		0%	15%	25%	35%	45%
Bitumen Content (%)	4.89-5.36	5.1	5.2	5.15	5.05	4.85
Stability(KN)	Min. 8	12.5	12.4	12.52	11.81	10.7
Flow(mm)	2-3.5	2.1	2.41	2.4	2.43	3.6
AV (%)	4	4	4	4	4	4
VMA (%)	Min.13	15.4	16.22	15.81	15.65	15.63
VFA (%)	65-75	73.33	73.5	73.2	75.1	73
Bulk Density(g/cm^3)	-	2.433	2.411	2.423	2.424	2.429

Table 17 above shows the asphalt mixtures laboratory test results with different EFA filler content replacement and the corresponding values of Marshall Properties at 5.1% bitumen contents at 15%, and 25% satisfied all standard specification requirements with the control mix. From those two results, 25% EFA replacement had a better stability result than 15% EFA.

3.6. The relationship of Marshall Properties with EFA Filler Material

3.6.1 Marshall Stability – EFA Filler Content Relationship

All values of stability with different percentages of EFA replacement as a filler content meet the standard requirement, as shown in Figure 11. The EFA-based mixes' stability has decreased as the replaced filler content has it becomes increased except at 25%EFA replacement, which had a better stability result than 15% replacement.

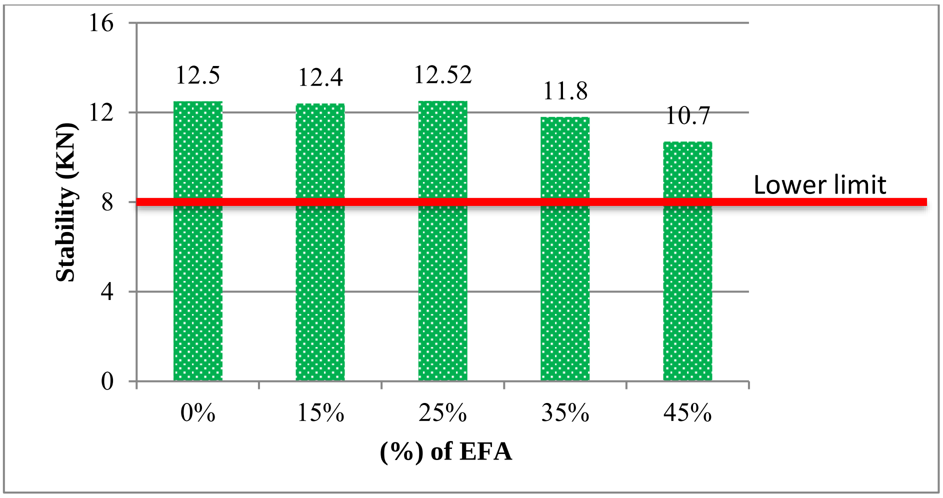

Figure 11 Relationship between Stability and replacement rate of EFA fillers at 5.1% bitumen content

3.6.2 Flow – EFA Filler Content Relationship

The flow of mixes with 45% EFA filler replacement had a value more than the maximum limit, but all other results within the specifications range. Figure 12 shows flow value results of HMA at different replacement percent of filler content.

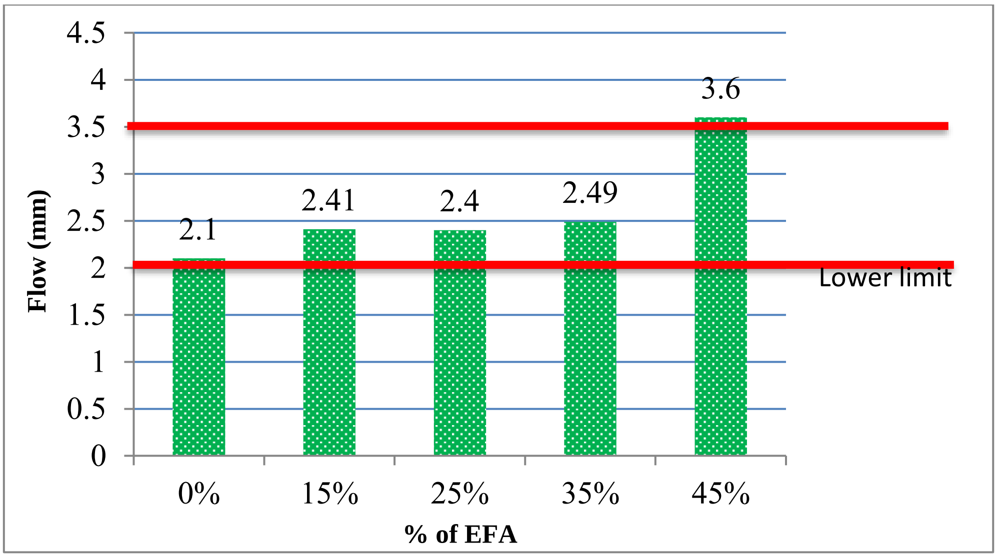

Figure 12 Relationship between flow and replacement rate of EFA fillers at 5.1% bitumen content

3.6.3 Bulk Density – EFA Filler Content Relationship

The bulk density of HMA mixes with various EFA filler replacement percentages meet the specification requirement. The bulk density increases as the EFA filler content increases. Figure 13 shows the bulk density of asphalt mixes with different filler content.

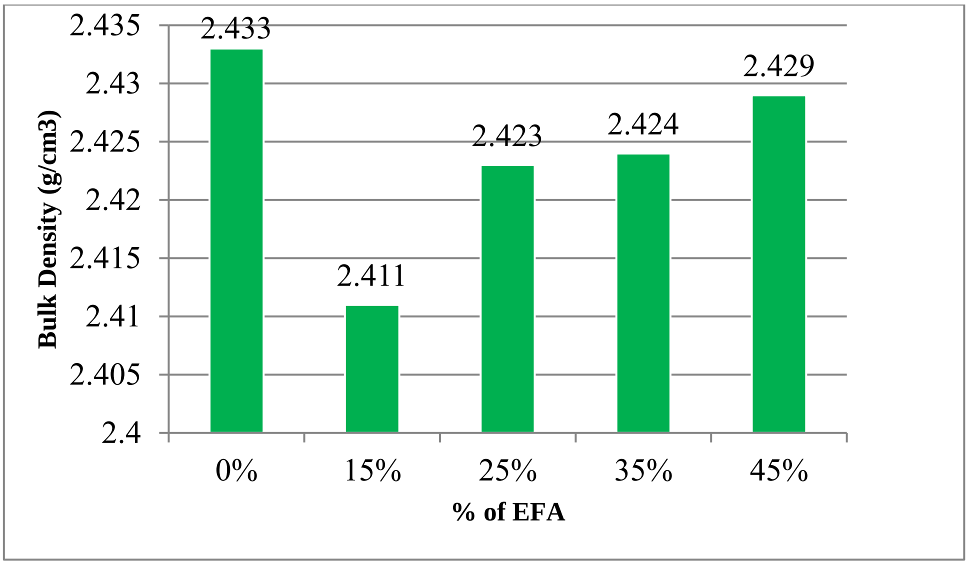

Figure 13 Relationship between bulk density and replacement rate of EFA fillers at 5.1% bitumen content

3.6.4 Air Voids (Va) – EFA Filler Content Relationship

As the EFA filler content increased, the air voids value of the mixes decreased gradually. Figure 14 below showed that at 25% filler content the bitumen content percentage was 5.15% which was more approached to OBC at 4% air void than others, but all results were at the specification range. Figure 14 represents the air voids values of asphalt mixes at different EFA filler content.

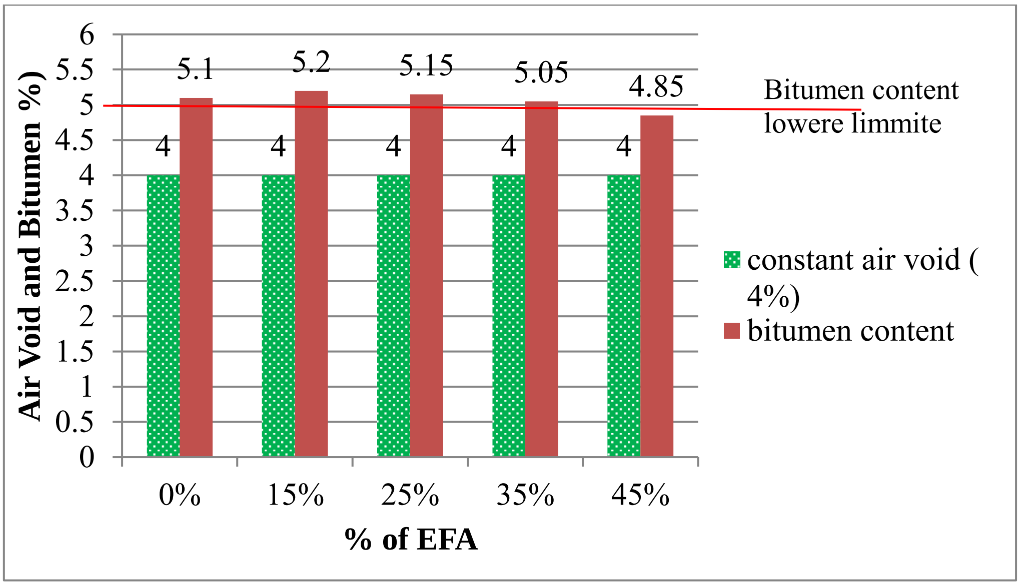

Figure 14 Relationship between Air voids and replacement rate of EFA fillers at 5.1% bitumen content

3.6.5 Voids in mineral aggregates (VMA) – EFA filler content relationship

Figure 15 showed voids in mineral aggregates decrease with increases in EFA content up to a minimum value. The minimum VMA value is 15.75% of asphalt samples prepared with 65% CRF and 35% EFA. The voids in mineral aggregates value are within the permissible limits specified in the ERA Pavement Design Manual (2013).

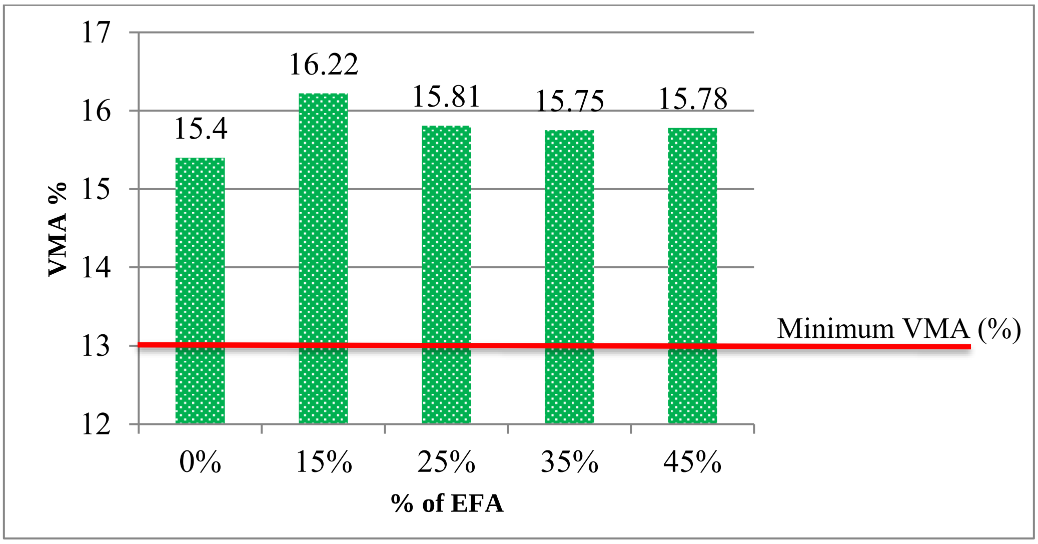

Figure 15 Relationship between VMA and replacement rate of EFA fillers at 5.1% bitumen content

3.6.6 Percent Voids filled with Asphalt (VFA)–EFA content relationship

Voids filled with asphalt value increase with increase replacement percent of EFA. Figure 16 showed that VFA for replaced mixes with 0%, 15%, 25% and 45% EFA was within the range of 65% - 75% specified by (ERA, Pavement Design Manual, 2013). But at 35% a replacement was laid outside the specifications. At 45% replacement of EFA filler content the VFA in the mix is approached to the median value of VFA in the specifications. The VFA for the control mix is higher than the 25% and 45% of the replaced mix. This was due to the fact that more effective bitumen content was present in the mix to filled available voids between the inter-granular spaces. But when VFA increase it was Couse by the failure of HMA.

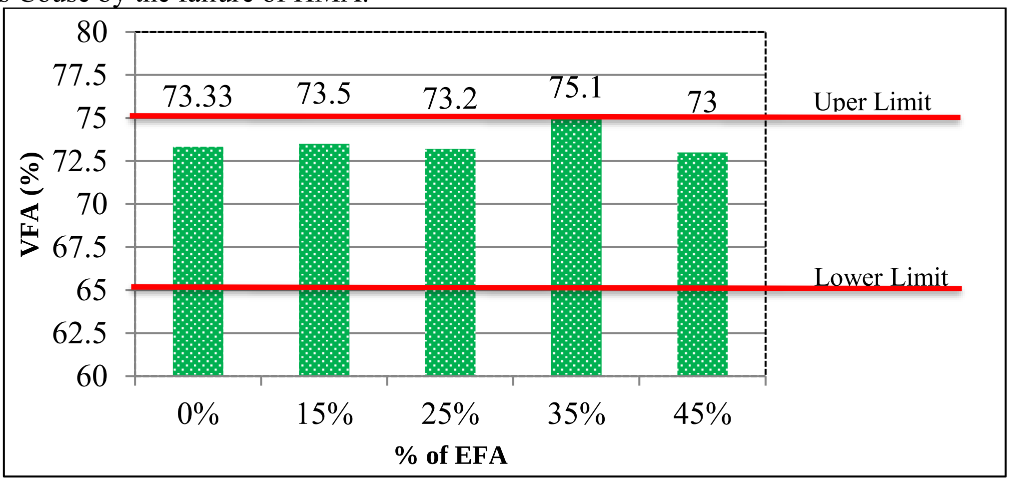

Figure 16 Relationship between VFA and replacement rate of EFA fillers at 5.1% bitumen content

3.6.7 Summary of HMA Properties

The Table 18 indicated below summarizes the properties of HMA with different filler content.

Table 18 Summary of Marshall Test Result of the Study

Specification Requirement		Test result for different % of EFA replacement				
		0%	15%	**25%**	35%	45%
Bitumen Content (%)	4.89-5.36	5.1	5.2	5.15	5.05	4.85
Stability(KN)	Min. 8	12.5	12.4	12.52	11.8	10.6
Flow(mm)	2-3.5	2.1	2.4	2.4	2.43	3.6
AV (%)	4	4	4	4	4	4
VMA (%)	Min.13	15.4	16.22	15.81	15.65	15.63
VFA (%)	65-75	73.1	74	73	75.1	73.3
Bulk Density(g/cm^3)	-	2.433	2.49	2.423	2.43	2.412

Table 18 above shows the asphalt mixtures laboratory test results with different EFA filler content replacement and the corresponding values of Marshall Properties at 4% air void. From the table at 15% and 25% satisfied all requirements of standard specification and comparing with control mix. From those two results, 25% EFA replacement had a better stability result than 15%EFA.

3.7. Optimum Filler Content

From Table 18, it is noticed that all values of 15% and 25% replacement satisfied all specifications requirements, which is 8KN minimum. But the result for 25% replacement of EFA better in Marshall Stability with 12.52KN. Figure 14 represents the bitumen percentage with 4% air void at different filler content and at 25% filler content, the corresponding bitumen content value was 5.15% which is very close to the median bitumen content in the specifications. From Figure 13 it is noticed that all values of bulk density at different filler content were very close to each other and all of them are consistent with the specifications requirements. At 35% and 45% VFA and flow were laid outside the range as showed in Table 17, respectively which means that those replacement out of consideration. Therefore 25% of EFA replacement better in all criteria.

3.8. Performance of test Hot Mix Asphalt

In this study asphalt, performance tests were performed besides with marshal stability test. For both control and modified mix, performance to resist rutting was determined. Wheel tracking tests were performed to determine the mix's performance, which laboratory results showed in Table 19 below.

Table 5 Laboratory result of the wheel-tracking test

<table>
<tr><td colspan="7">Results of the UNE-EN 12697- 22 wheel-tracking test</td></tr>
<tr><td></td><td colspan="3">Enset fiber replacement (25% EFA)</td><td colspan="3">Crushed rock fine(100% CRF)</td></tr>
<tr><td>Mix Name</td><td>WTS_{AIR} =(d10000 −d5000)/5 (mm/10^3load cycles)</td><td>PRD (%) =((RD)*100/h)/2))</td><td>Mean RD (mm)</td><td>WTS_{AIR} =(d10000−d5000)/5 (mm/10^3 load cycles)</td><td>PRD (%) =((RD)*100/h)/2))</td><td>Mean RD (mm)</td></tr>
<tr><td>Trial one</td><td>0.156</td><td>2.87</td><td rowspan="3">2.9</td><td>0.118</td><td>2.68</td><td rowspan="3">2.78</td></tr>
<tr><td>Trial two</td><td>0.120</td><td>2.93</td><td>0.166</td><td>2.88</td></tr>
<tr><td>Average</td><td>0.138</td><td>5.8</td><td>0.142</td><td>5.56</td></tr>
<tr><td colspan="7">Where; WTS wheel tracking slop, PRD- proportional rut depth , RD- rut depth and h – the height of specimen(50mm)</td></tr>
</table>

From the above Table 19 illustrated the laboratory test result for both the control mix and modified mix by Enset fiber ash. 100% CRF or control mix had a better rutting resistance performance than mix blend with Enset fiber ash. Wheel tracker tests were performed for all prepared samples after determining the optimum percent of EFA replacement. Figure 17 illustrates rut depth with respect to the number of passes. The comparison showed that the rutting occurred in the samples blended mix with Enset fiber ash of temperatures 60ºC is less than that of control mix or conventional filler of crushed rock fine. But the result was almost the same average rutting depth. The figure also showed a rate of deformation decrease as the depth of rutting increases.

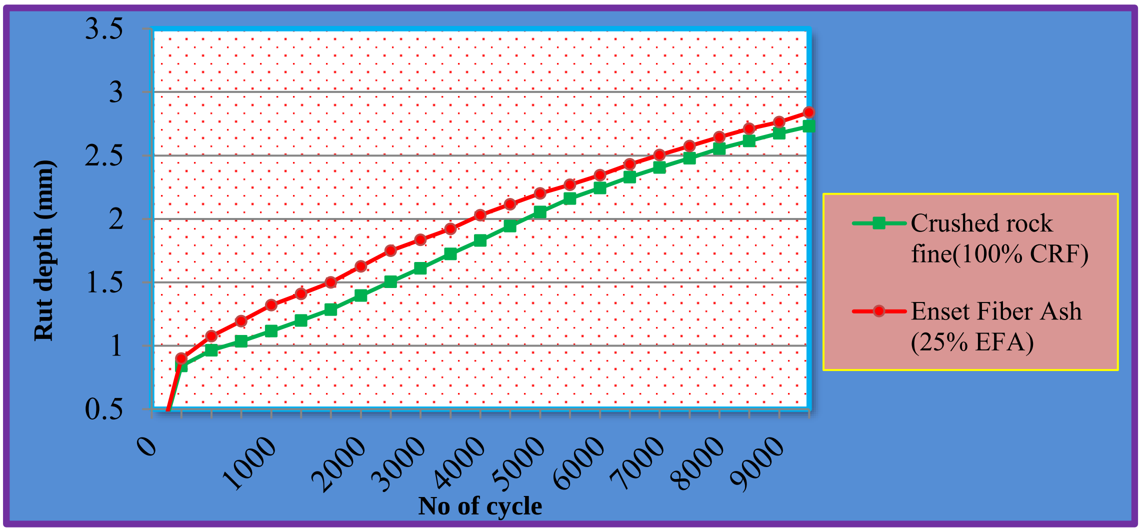

Figure 17 Wheel Tracking Test results for conventional and modified HMA

3.9. Comparison of rutting result with specifications

Table 20 Comparison rutting performance of asphalt mix control and 25 EFA content with standard specification

Results of the UNE-EN 12697- 22 wheel-tracking test						
Mix Name	WTS_{AIR} =(d10000 – d5000)/5 (mm/10^3 load cycles)	PRD (%) =((RD)*100/h)/2))	Mean RD (mm)	specification as per EN 13108		
				Rate (μmm/cycle)	PRD (%)	RD(mm)
100%CRF	0.142	5.56	2.78	<0.15	<8	<6
75%CRF&25%EFA	0.138	5.80	2.90	<0.15	<8	<6

Table 20 showed the result of conventional or control mix and modified mix satisfy the requirement. It showed that Enset fiber ash replaces up to 25% of crushed rock fine by the weight filler used in the control mix.

4.0 CONCLUSION

- The physical property of all aggregate material used for this study satisfies the standard requirement of the specification and laboratory test result of Enset fiber ash.
- The laboratory result for 'Enset' fiber ash gives specific gravity 2.72 and plastic index was 0.8 which is less than 4, satisfying the specification for using as partial replacement filler in hot asphalt mix so that Enset fiber can replace conventional filler in the hot asphalt mix design.
- The optimum asphalt content value was required to fulfill the Marshall requirement is 5.15 and 5.1% for mixture contain 25% 'Enset' fiber ash (EFA) filler and the mixture which contain 100% CRF filler content respectively. Hot Asphalt Mix produced using blend with 'Enset' fiber ash (EFA) Filler performed better under load than HAM made without blend mix with EFA filler. Stability value of mixes prepared without EFA filler is 12.5 KN and the mix prepared with EFA filler gives 12.52KN with their optimum asphalt content.
- The void in mineral aggregate (VMA) values obtained indicate a relative increase due to EFA in the mixture, i.e., for mixture blend without EFA filler gives 15.4% and for mixture blend with EFA filler result 15.81%. Void filled with asphalt (VFA) values of mixture blend without EFA filler result 73.1% and mixture blend with EFA filler gives 73% were found the max value of marshal criteria this was showed void is filled by the EFA filler and CRF almost the same area coated by bitumen.
- The flow and bitumen content in the mixture value obtained generally indicate an increasing and decreasing trend due to the addition of EFA as filler in the mixture than mixture blend with Enset fiber ash, respectively. At 15% and 25% bitumen content slightly increase (5.2% and 5.15%) but decrease as increase EFA, 5.05% and 4.85% for 35% and 45% EFA replacement respectively. Flow was improved by adding EFA, results were given 2.4 and 2.1mm.

- Rutting test results described blend without Enset fiber ash better than blend with Enset fiber ash. Results were given 2.78mm and 2.9 mm, respectively within the specification of less than 6 mm respectively. Filler replacement up to 25% EFA passed all standards specifications which conducted in this study.
- Based on the findings of the study, the researcher forwarded the following recommendations:The researchers suggests that further research be conducted on Enset fiber ash, such as chemical compositions and chemical properties, which are not covered in this study.

Acknowledgement

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