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

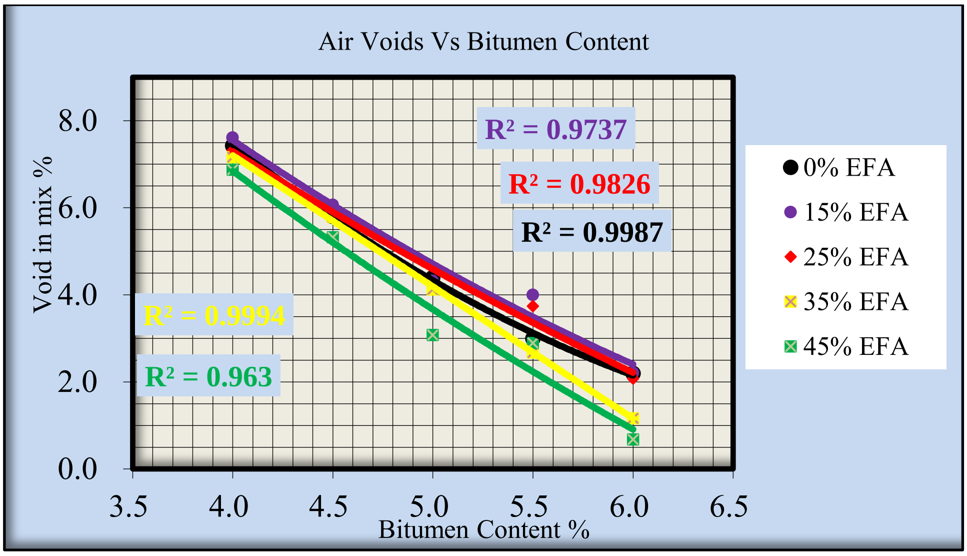

Figure 7 Air Void vs. Bitumen Content

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

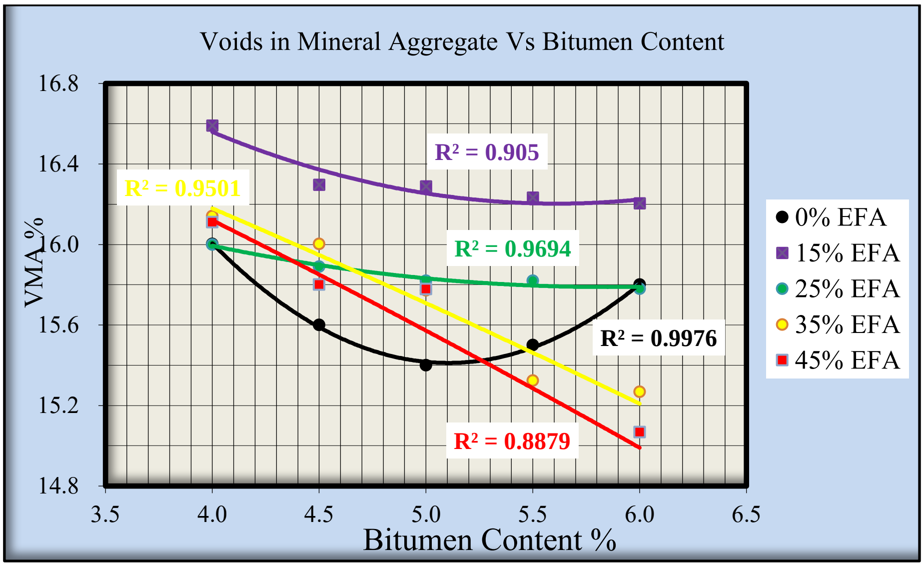

Figure 8 VMA Vs Bitumen Content

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

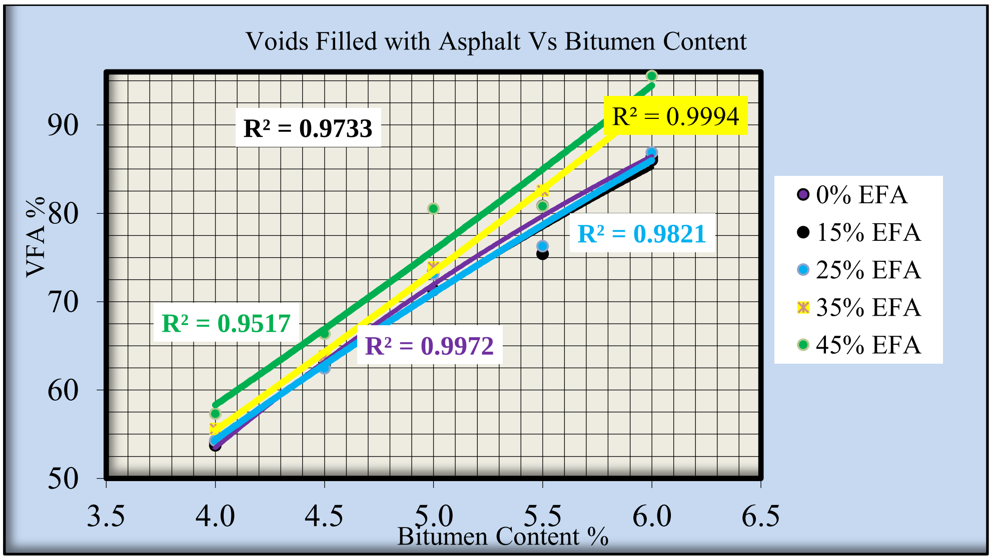

Figure 9 VFA Vs Bitumen Content

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

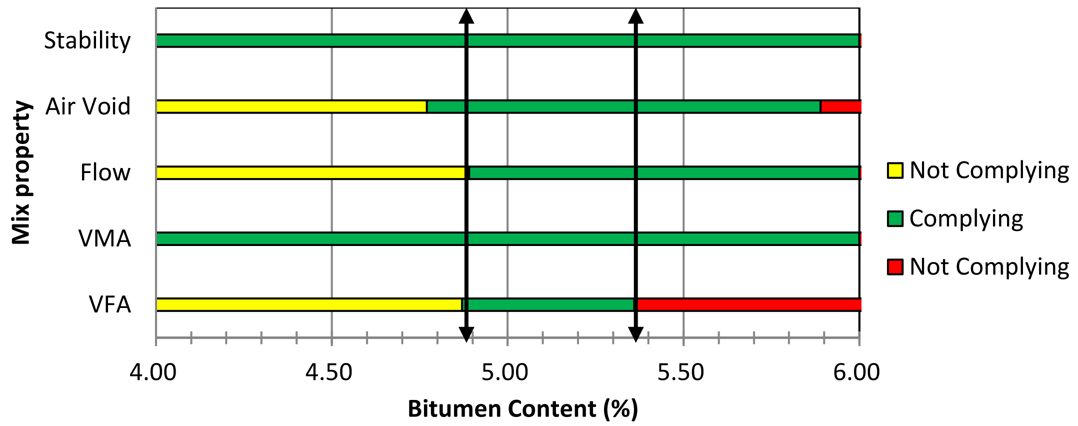

Figure 10 Acceptable Bitumen range complying with design criteria

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.

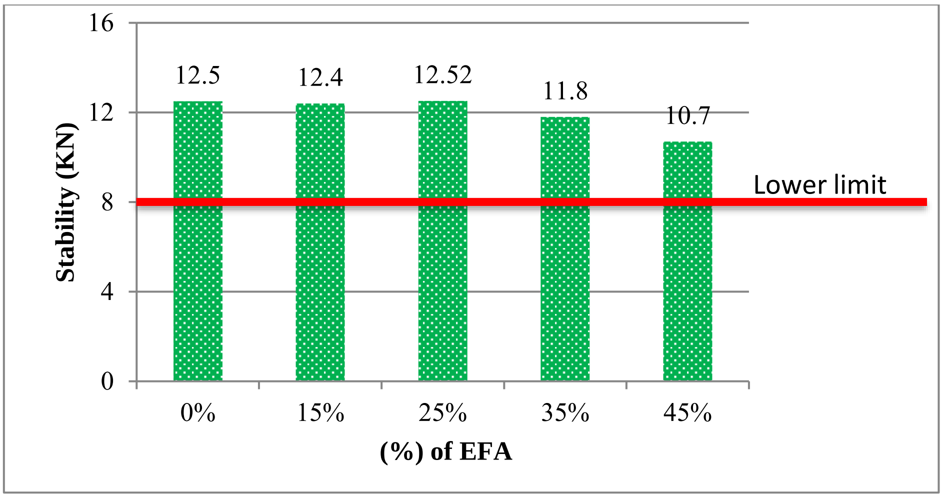

Figure 11 Relationship between Stability and replacement rate of EFA fillers at 5.1% bitumen content

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.

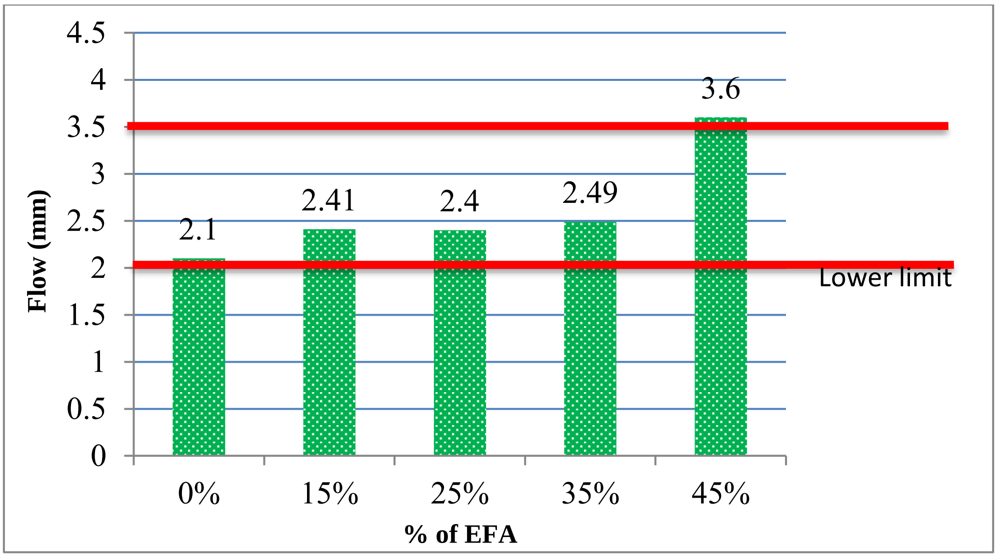

Figure 12 Relationship between flow and replacement rate of EFA fillers at 5.1% bitumen content

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.

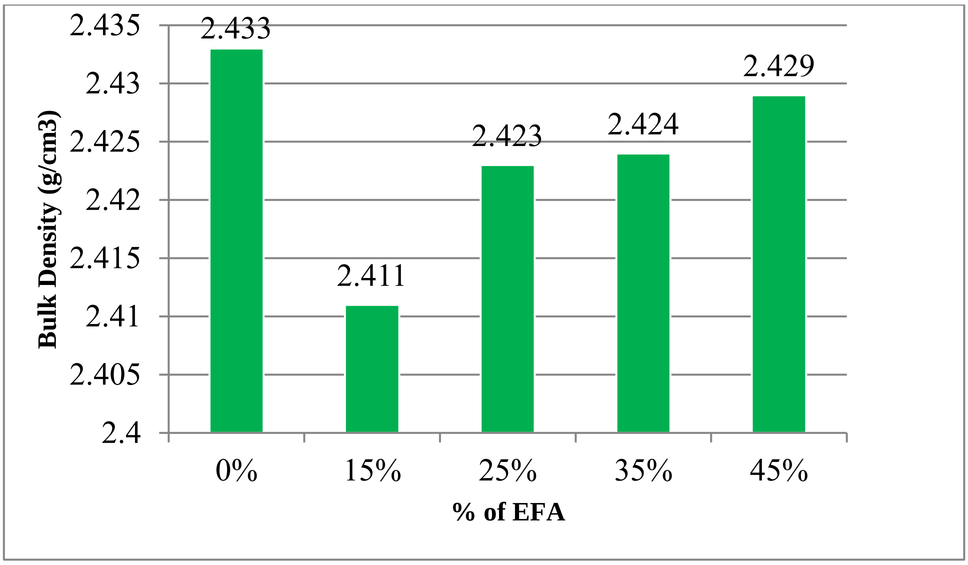

Figure 13 Relationship between bulk density and replacement rate of EFA fillers at 5.1% bitumen content

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.

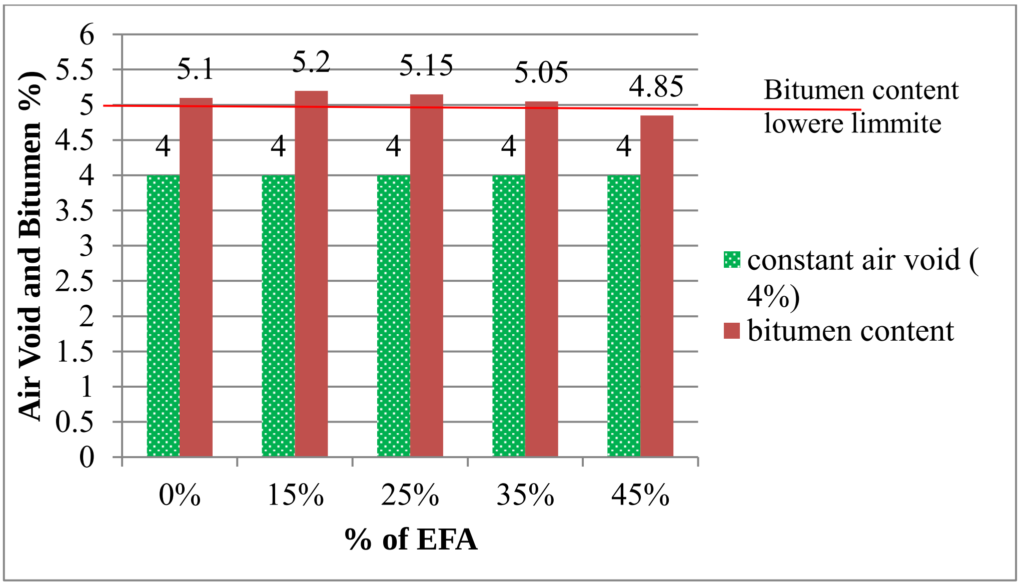

Figure 14 Relationship between Air voids and replacement rate of EFA fillers at 5.1% bitumen content

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).

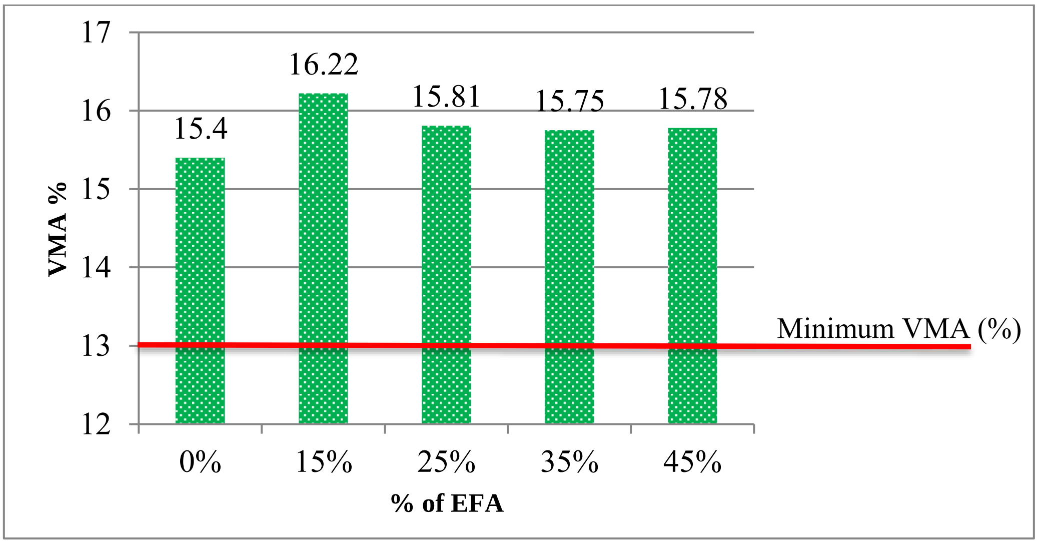

Figure 15 Relationship between VMA and replacement rate of EFA fillers at 5.1% bitumen content

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.

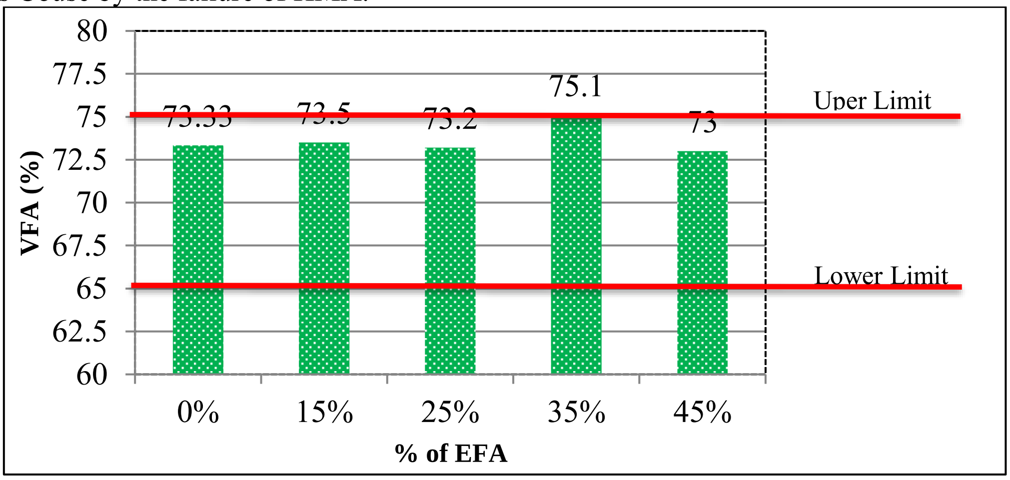

Figure 16 Relationship between VFA and replacement rate of EFA fillers at 5.1% bitumen content

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

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

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.

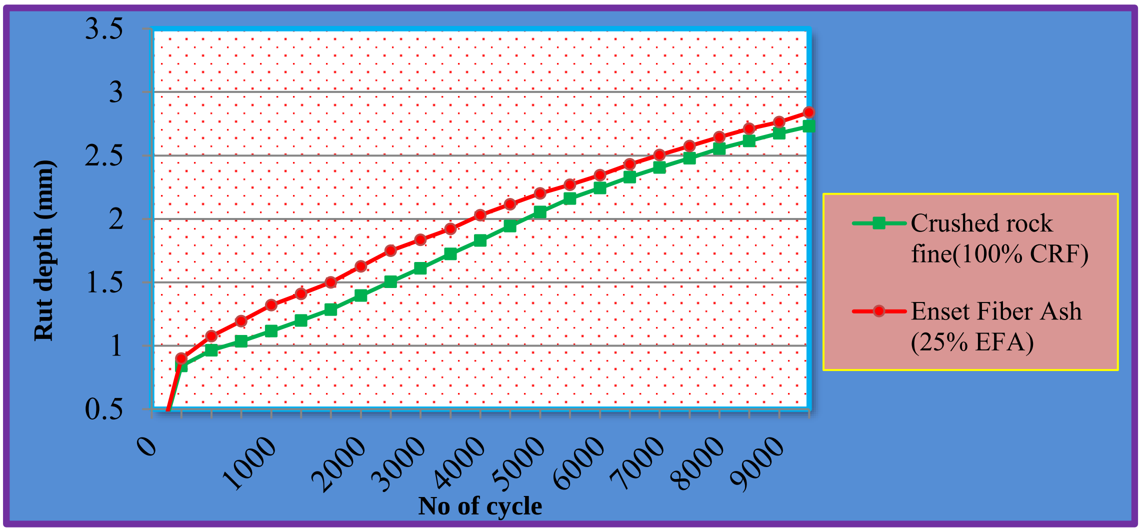

Figure 17 Wheel Tracking Test results for conventional and modified HMA

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

The authors wish to thank the Jimma Institute of Technology, Jimma University in providing the necessary support for carrying out this research study

References

[1] Geremew, A., Quezon, E. T. and Kebede, G. (2016). Influence Of Subsurface Courses Materials On Pavement Performance: A Case Study in Yebu-Agaro Road. 7(10), 1252–1260.

[2] Mesfun, R. T., Quezon, E. T.and Geremew, A. (2019). Experimental Study Of Stabilized Expansive Soil Using Pumice Mixed With Lime For Subgrade Road Construction. Int. J. Res. Granthaalayah, 7(7), 118–124. http://dx.doi.org/10.29121/granthaalayah.v7.i7.2019.736.

[3] Geremew, A. and Fayissa, B. (2018). Experimental Performance Studies on the Improved Expansive Subgrade Soil Formation by Using Mechanical Stabilization with Natural Gravel Around Jimma Quarry Sites. American Journal of Civil Engineering, 6(5), 154–161. doi: 10.11648/j.ajce.20180605.13.

[4] Gonfa, L. G., Tucay Quezon, E. T. Q. and Geremew, A. (2020). Experimental Study On Application Of Marble Waste As Conventional Aggregate For Base Course Materials. Journal of Civil Engineering, Science and Technology, 11(2), 144–163. doi: 10.33736/jcest.2620.2020.

[5] Seyfe M. and Geremew, A. (2019). Potential Use Of Cinder Gravel As An Alternative Base Course Material Through Blending With Crushed Stone Aggregate And Cement Treatment. Journal of Civil Engineering, Science and Technology, 10(2), 101–112. doi: 10.33736/jcest.1465.2019.

[6] Jemal, A., Agon, E. C. and Geremew, A. (2019). Utilization Of Crushed Stone Dust As A Stabilizer For Sub Grade Soil: A Case Study In Jimma Town. International Journal of Engineering, XVII(4), 55–64.

[7] Brasileiro, L., Moreno-Navarro, F., Tauste-Martínez, R., Matos, J. and Rubio-Gámez, M. (2019). Reclaimed Polymers as Asphalt Binder Modifiers for More Sustainable Roads: A Review. Sustainability, 11(3), 646. doi: 10.3390/su11030646.

[8] Dash S. B. and Panda, M. (2016). A Study on Use of Natural Fiber for Improvement in Engineering Properties of Dense Graded Bituminous Mixes with Coal Ash. Transp. in Dev. Econ., 2(1), 4. doi: 10.1007/s40890-015-0008-z.

[9] Boyle, A. and O'Flaherty, C. A. (2002). *Highways: the location, design, construction and maintenance of road pavements*, 4th ed. Oxford: Butterworth-Heinemann.

[10] Berhanu, H., Neiva, D., Gominho, J., Kiflie, Z., Feleke, S., Yimam, A. and Pereira, H. (2021). Bio-Refinery Potential of Enset/*Ensete ventricosum*/Fiber Bundle Using Non-catalyzed and Alkali Catalyzed Hydrothermal Pretreatment. Waste and Biomass Valorization, 12, 663–672. https://doi.org/10.1007/s12649-020-01015-3

[11] Tsegaye A. and Struik P. C. (2001). Enset (Ensete ventricosum (Welw.) Cheesman) kocho yield under different crop establishment methods as compared to yields of other carbohydrate-rich food crops. NJAS: Wageningen Journal of Life Sciences, 49(1), 81–94. doi: 10.1016/S1573-5214(01)80017-8.

[12] Gezie, M. (2019). Farmer's response to climate change and variability in Ethiopia: A review. Cogent Food & Agriculture, 5(1), 1–13. doi: 10.1080/23311932.2019.1613770.

[13] Belay, S., Quezon, E. T. and Geremew, A. (2021). Effect of Selected Conventional and Non-conventional Mineral Fillers with 'Enset' Fibers on Compaction Characteristics of Stone Mastic Asphalt Pavement (SMAP). Jordan Journal of Civil Engineering, 15(1), 30–40.

[14] Muniandy, R., Aburkaba, E. and Taha, R. (2013). Effect of Mineral Filler Type and Particle Size on the Engineering Properties of Stone Mastic Asphalt Pavements. Jou. Eng. Res., 10(2), 13–32. doi: 10.24200/tjer.vol10iss2pp13-32.

[15] Yohannes, B., Quezon, E. T. and Tsegaye, M. (2020). Evaluation on the Potential Use of Pulverized Natural Subbase Dust as Alternative Filler Material for Hot Mix Asphalt Design, Jimma Town. American Journal of Civil Engineering and Architecture, 8(2), 62–77. doi: DOI:10.12691/ajcea-8-2-6.

[16] Wagaw, F., Quezon, E. T. and Geremew, A. (2018). Evaluation of the Performance of Brick Dust as a Filler Material for Hot Asphalt Mix Design: A Case Study in Jimma Zone. The International Journal of Engineering and Science (IJES), 7(3), 64–72. doi:10.9790/1813-0703026472

[17] Institute, A. (2014). *Ms-2 asphalt mix design methods*, 7th edition. Lexington, KY: Asphalt Institute.