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Research Article

Micro-Structure Analysis and Mechanical Behaviour of Hot Mix Asphalt Modified with Reclaimed Asphalt Pavement Using Palm Kernel Shell Ash as Mineral Filler

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Abstract

In pavement construction and production of hot mix asphalt HMA, the use of industrial and agricultural waste has gained much relevance because of its economic and environmental benefits. This research examined the effects of palm kernel shell ash PKSA on the physical and volumetric properties of HMA modified with reclaimed asphalt pavement RAP. All preliminary test conducted on the modified asphalt mixture in accordance with relevant standards showed adequacy for use in production of HMA. Marshall method of mix design was adopted for the HMA production. The bitumen content was varied from 4.5 to 6.5% (at intervals of 0.5%). The palm kernel shell ash was varied from 25% to 75% (at interval of 25%). A maximum stability of 7.1kN was recorded at 5.5% bitumen content which is a little increment in strength but good significance in material (virgin bitumen) when compared to the maximum stability of 6.9kN at 6% bitumen obtained from the control mix. The microstructural analysis of the hot mix asphalt done on the palm kernel shell ash PKSA showed a rough surface texture needed in flexible pavement construction and when comparison was done between the control specimen and the modified specimen, it shows an improvement in the interlocking arrangement of aggregates resulting in a denser mixture for the modified hot mix asphalt. In conclusion this study confirms that a blend of a 50% RAP and 50% virgin aggregates with 50% palm kernel shell ash PKSA as mineral filler at 5% bitumen content can improved strength performance of HMA, hence, the effect of PKSA as a mineral filler in HMA containing RAP is significant.

Keywords

Pavement, Asphalt, Bitumen, Stability

1. Introduction

The conventional asphalt production is cost intensive because of high demand on its constituent materials. The use of alternative materials like reclaimed asphalt pavement RAP is considered less expensive and environmentally beneficial [1]. Currently, several additives are used either as fillers or rejuvenators to modify the mixture and improve its properties as it relates to performance [2].

Researches carried out worldwide focuses on ways of uti-

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lizing either industrial or agricultural wastes as useful materials for the road construction, the use of these waste has both economic and environmental benefits [3]. This research involves the utilization of palm kernel shell ash PKSA because of its properties that makes it a suitable construction material while incorporating a high quantity of RAP with varying bitumen content.

Palm kernel shell ash is gotten from burning and calcination of palm kernel shell which is an agricultural waste mostly used as fuel and is available in very large quantities in tropical countries of the world [4]. The indiscriminate disposal of theses wastes contributes to environment pollution. Hence, the need to convert these wastes into useful materials.

In a study, Murana and Sani [5] investigated the partial replacement of rice husk ash RHA with ordinary Portland cement OPC as mineral filler in asphaltic concrete containing RAP. The result showed that the mixture at 70% RHA satisfied criteria for road designs in Nigeria.

In another study, Sadeeq et al [6] again replaced OPC with RHA but the bitumen contents were varied at lower RAP content. The result showed that the optimum bitumen content OBC was 5.5%. However, the indirect tensile strength test conducted on the samples showed that the sample with 25% RHA content had the highest tensile strength while the samples containing OPC had a lower tensile strength.

Another research was conducted by Adeala et al [7] on the partial replacement of cement with coconut shell ash in asphalt concrete. The study was laboratory based and consist of various bitumen content 4.5 - 7.5% (at interval 0.5), the OBC was obtained at 5.0% and used in production of hot mix asphalt focusing on partial replacement of OPC with coconut shell ash from 5 – 25% (at interval of 2.5%). From experimental results obtained, the sample containing 10% coconut shell ash satisfied the requirements of Asphalt Institute (1983) criteria for Marshall-stability-flow, VMA and total voids in the mixture.

Studies generally supports utilization of RAP because it is sustainable, economically viable, economically reliable, and environmentally considerate [8]. Several studies have paid little or no attention to PKSA, hence, this study aims to establish the effect of using PKSA as a mineral filler in production of HMA containing RAP.

2. Materials and Method

2.1. Materials

The reclaimed asphalt used in this study was obtained from a road rehabilitation site. The coarse aggregates were obtained clean from a quarry within the location of this study. The coarse aggregate is from the basalt family. The fine aggregates and bituminous material were obtained from asphalt production company. The palm kernel shell ash PKSA was obtain from a local palm fruit processing factory. Palm kernel shells were incinerated and calcinated at a temperature of 600 ℃, thereafter, it was sieved with sieve #200 and %passing this sieve was preserved for this study [4].

2.2. Method

The methods employed in this study is as listed in tables 1-6.

Table 1. *Coarse and Fine Aggregate Test.*

TEST	SPECIFICATION CODE
Aggregate impact value	BS 812 – 112 (1990)
Aggregate crushing value	BS 812 – 110 (1990)
Elongation index	ASTM 4791 – 19 (2019)
Flakiness index	BS-EN 933 – 3 (2017)
Specific gravity	ASTM C 127 & C128– 15 (2015)
Sieve analysis	ASTM C I36 – 19 (2019)

Table 2. *Bitumen Test.*

TEST	SPECIFICATION CODE
Penetration	ASTM D5M – 20 (2020)
Ductility	ASTM D113 – 17 (2017)
Softening point	ASTM D36 – 14 (2020)
Flash and fire point	ASTM D92 – 18 (2018)
Specific gravity	ASTM D70 – 18a (2018)
Solubility	ASTM D2042 – 15 (2015)
viscosity	ASTM 4402 – 15 (2015)

Table 3. *Chemical Analysis of PKSA.*

TEST	SPECIFICATION CODE
x-ray fluorescence	ASTM E1621 - 13 (2013)
Sieve analysis	ASTM C136 - 19 (2019)
Specific gravity	ASTM D854 – 14 (2014)

Table 4. Analysis on HMA.

TEST	SPECIFICATION CODE
Marshall stability and flow	ASTM D6926 -20 (2020)
Scanning electron microscopy SEM	ASTM E986 – 04 (2017)

The computation and blending of RAP in the HMA were done in accordance with FMW&H 2016 specification with guidance from Asphalt institute (2014) methods [9, 10] as shown in tables 5 & 6.

Table 5. Gradation of RAP Aggregates.

SIEVE SIZE	COARSE AGGREGATE		FINE AGGREGATE		% MINERAL	TOTAL
	%RAP	%VA	%RAP	%VA		
19.05	0	0				0
12.7	16	8.6				24.6
9.52	12.29	7				19.29
6.35	13	4				17
2.36	21.7	5				26.7
1.18			12.5	13		25.5
0.6			9.3	12.3		21.6
0.3			4.4	13.4		17.8
0.15			6.8	9		15.8
0.075			3.01	18.3	15	36.31
Pan			0.9	9.34	85	94.41

Table 6. Computation of RAP Aggregates.

Sieve Size	Coarse Aggregate		Fine Aggregate		% Mineral	Total
	%RAP	%VA	%RAP	%VA		
19.05	0x0.7=0	0x0.24=0				0
12.7	16x0.7=11.2	8.6x0.24=2.07				24.6
9.52	12.29x0.7=8.60	7x0.24=1,68				19.29
6.35	13x0.7=9.1	4x0.24=0.96				17
2.36	21.7x0.7=15.19	5x0.24=1.2				26.7
1.18			12.5x0.7=8.75	13x0.24=3.12		25.5
0.6			9.3x0.7=6.51	12.3x0.24=2.96		21.6
0.3			4.4x0.7=3.08	13.4x0.24=3.22		17.8
0.15			6.8x0.7=4.76	9x0.24=2.16		15.8
0.075			3.01x0.7=2.11	18.3x0.24=4.39	15x0.06=0.9	36.31

Sieve Size	Coarse Aggregate		Fine Aggregate		% Mineral	Total
	%RAP	%VA	%RAP	%VA		
Pan			0.9x0.7=0.63	9.34x0.24=2.24	85x0.06=5,1	94.41
Total	50		44		6	100

The design of bitumen content DBC in accordance with asphalt institute (2014) method was achieved using the expression,

$$DBC = 0.035a + 0.04b + Kc + F$$

Where,
a = % of aggregates on sieve 2.36mm
b = % of aggregates passing sieve 2.36mm
c = % of mineral aggregates passing sieve 0.075 µm
F = 0-2% of absorption of bitumen (0.8 assumed)
Therefore,

$$DBC = 0.035(50) + 0.04(44) + 0.18(6) + 0.8$$

$$= 5.39 \text{ approx } = 5.5\%$$

Asphalt institute method requires that two extra limits be added above and below the DBC, hence, the range of bitumen adopted for this research is as follows, 4.5%, 5.0%, 5.5%, 6.0%, & 6.5%.

3. Results and Discussions

3.1. Aggregate Properties Test Result

The results of the physical property test carried out on the fine and coarse aggregate of both the virgin aggregate and RAP aggregate used in the HMA is given in table 7. It can be seen that the specific gravities of the aggregates and the mineral filler (PKSA) which are 2.69 for the coarse aggregate, 2.58 for the fine aggregate, and 2.631 for the PKSA all satisfy the specification range of 2.5-3.0 according to ASTM standards [11, 12, 13, 18, 26, 27, 28]. The results for flakiness, elongation, crushing value, and impact value were all within acceptable limits specified by FMW&H and relevant BS codes.

Table 7. *Aggregate Properties.*

PROPERTIES	RAP	NATURAL AGGREGATES	SPECIFICATION		REMARKS
			Minimum	Maximum	
Specific gravity (coarse)	2.621	2.69	2.5	3.0	Satisfactory
Specific gravity (fine)	2.580	2.58	-	-	"
Specific gravity (filler)	2.604	2.631	-	-	"
Flakiness index (%)	28.61		-	35	"
Elongation index (%)	24.30		-	25	"
Agg. Crushing value (%)	26.61		-	30	"
Agg. Impact value (%)	28.11		-	35	Satisfactory

3.2. Aggregates Gradation Test

The combined (coarse aggregates, fine aggregates, and mineral filler) particle size distribution is as shown in figure 1. The gradation envelope shows the particle size distribution of the HMA aggregates together with the lowest and highest boundary values as specified by FMW&H (2016). The results agree with the specifications and the study done by Kumar et al [29] which confirmed that a well graded aggregates ensures proper interlock of particles to reduce moisture attack in the pavement.

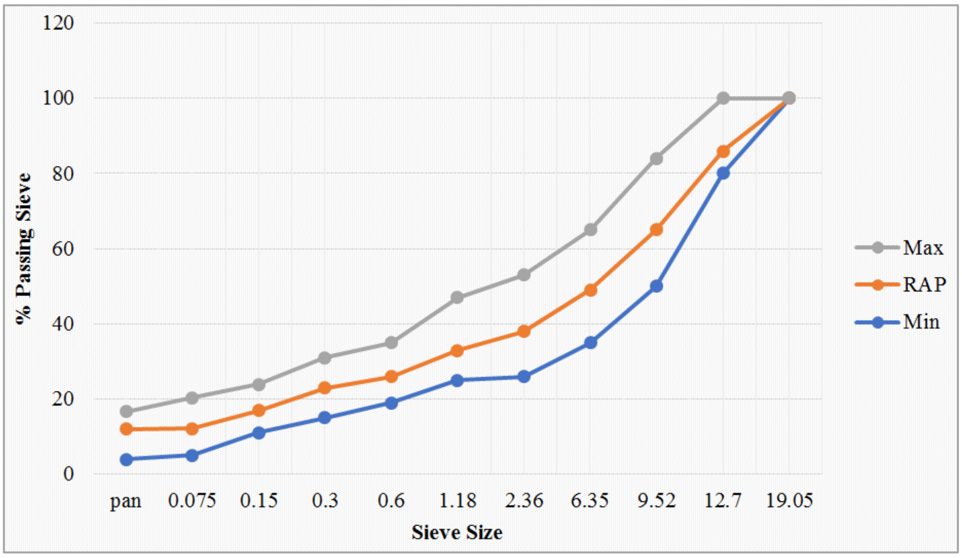

Figure 1. *Particle size distribution of combined aggregate with specification limit.*

3.3. Bitumen Test Result

The result of physical property test conducted on the bitumen is recorded table 8. The penetration was 66 per 0.1mm which is within the range of the 60/70 bitumen grade. The bitumen flashed at 186℃ as against 232℃ maximum specified in ASTM standard, also the specific gravity was 1.03 which satisfies ASTM standard range of 1.01-1.06 for this bitumen grade. The rest of the properties as shown in the table 8 was satisfactorily within the acceptable limits of the ASTM standards [14-17, 19, 21, 23].

Table 8. *Bitumen Test Result.*

TEST	UNIT	RESULT	ASTM SPECIFICATION	REMARKS
Penetration	0.1mm	66	60/70	Satisfactory
Softening point	℃	52	48-56	“
Ductility @ 25℃	Cm	79.6	100 max.	“
Specific gravity	-	1.03	1,01-1.06	“
Flash point	℃	186	232 max.	“
Fire point	℃	263	-	“
Solubility in C_2S	%	99.3	99	“
Viscosity @ 60℃	Sec	364	-	satisfactory

3.4. Test Results for Chemical Analysis of PKSA

The analysis of chemical composition of PKSA was carried out using x-ray fluorescence in accordance with relevant specification codes [13, 22, 24, 25]. The results as shown in table 9 indicated the presence of the following oxides,

Table 9. *Chemical Composition of PKSA Result.*

Oxides	CaO	Fe_20_3	SiO_2	CuO	ZnO	P_2O_5	AL_2O_3	LOI
% Composition	47.602	5.721	10.914	0.411	0.671	0.162	19.411	2.33

The combination of calcium oxide CaO, aluminum oxide AL_2O_3, iron oxide Fe_20_3, and silicon oxide SiO_2. is greater than 70%, and the PKSA contains less non-pozzolanic oxides like zinc, copper, and phosphate [4].

4. Effect of PKSA on HMA

4.1. Effect of PKSA on Marshall Stability

In accordance with FMW&H (2016) standard, a minimum stability value of 3.5KN is required for HMA used in wearing coarse with a high traffic volume. At control (0%) PKSA, the maximum stability was 6.9KN with a bitumen content of 6.0%. For the various proportions of PKSA added with varied bitumen content, the maximum stability value recorded was 7.01KN at 5.5% PKSA and 5% bitumen. Further addition of PKSA even with varied bitumen contents was insignificant on the Marshall stability, however the 2% improvement recorded in the stability value at a lower (5%) bitumen content is significant as shown in figure 2.

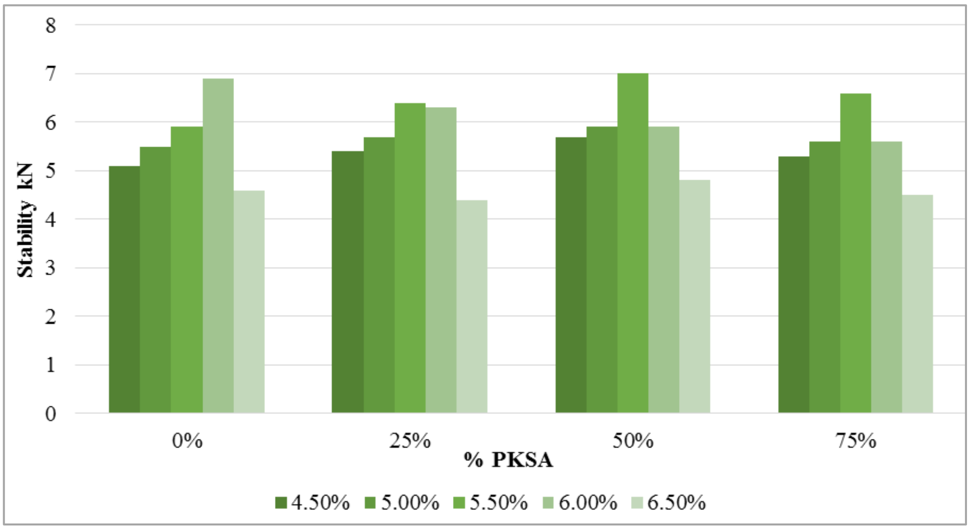

Figure 2. *Variation of stability with bitumen content and PKSA.*

4.2. Effect of PKSA on Marshall Flow

An increase in Marshall flow value was observed in all proportions of the PKSA as shown in figure 3. However, it should be noticed the result meets the specifications of the FMW&H (2016) given 2-4mm except at bitumen content of 6.5%.

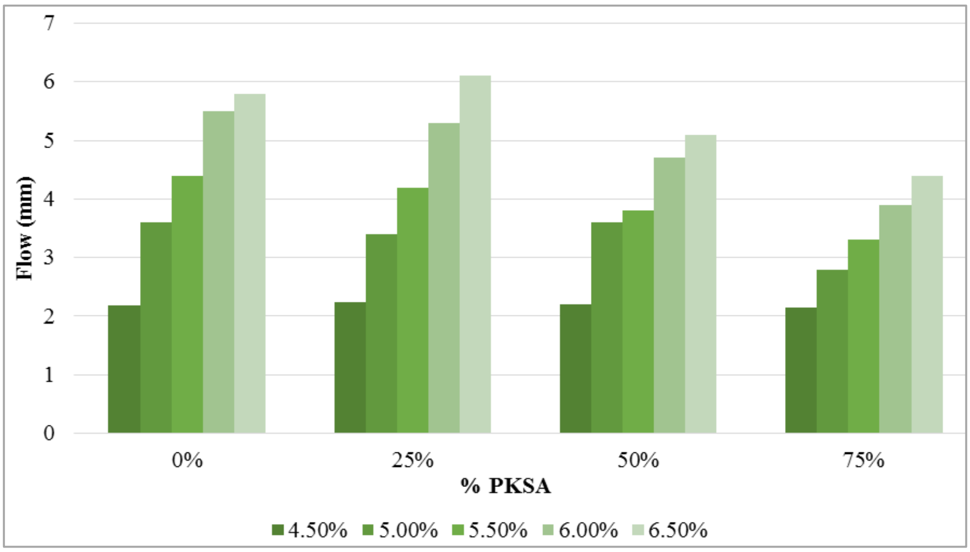

Figure 3. *Variation of flow with bitumen content and PKSA.*

4.3. Effect of PKSA on Unit Weight

The variation of unit weight and proportions of PKSA is shown in figure 4. It is noticed that the virgin HMA had the highest unit weight at 6.5% bitumen. Generally, there was a increase in the unit weight as the %PKSA increased.

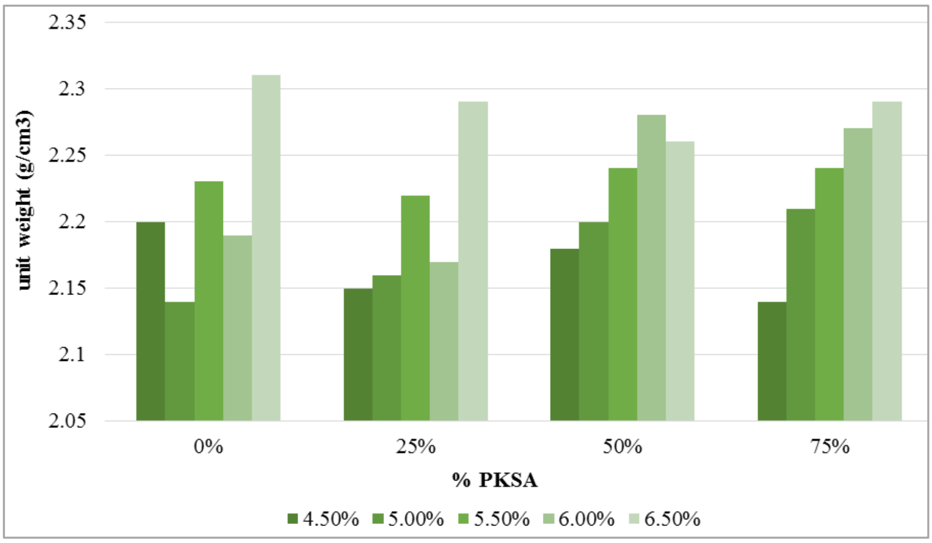

Figure 4. Variation of unit weight with bitumen content and PKSA.

4.4. Effect of PKSA on VMA

The voids in the mineral aggregates VMA value increased with increase in bitumen content as shown in figure 5. It was noticed that with increased % PKSA, VMA varied significantly. The highest VMA value was recorded at 50% PKSA with 5.5% bitumen content as 24% against the control mix which was 21.3% at 5.5%. This is a remarkable 12.6% improvement.

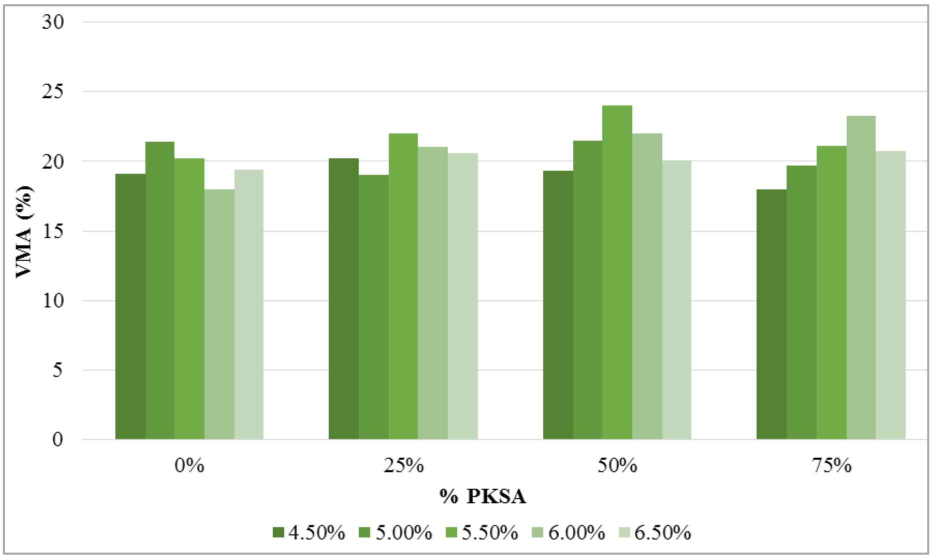

Figure 5. Variation of VMA with bitumen content and PKSA.

4.5. Effect of PKSA on VFB

Across all percentages of PKSA with corresponding bitumen content, VFA increase as bitumen content increase. However, the FMW&H (2016) specification says that voids filled with bitumen should be in the range of 75-82% in other to reduce air or water penetration. This specification was fully satisfied as shown in figure 6.

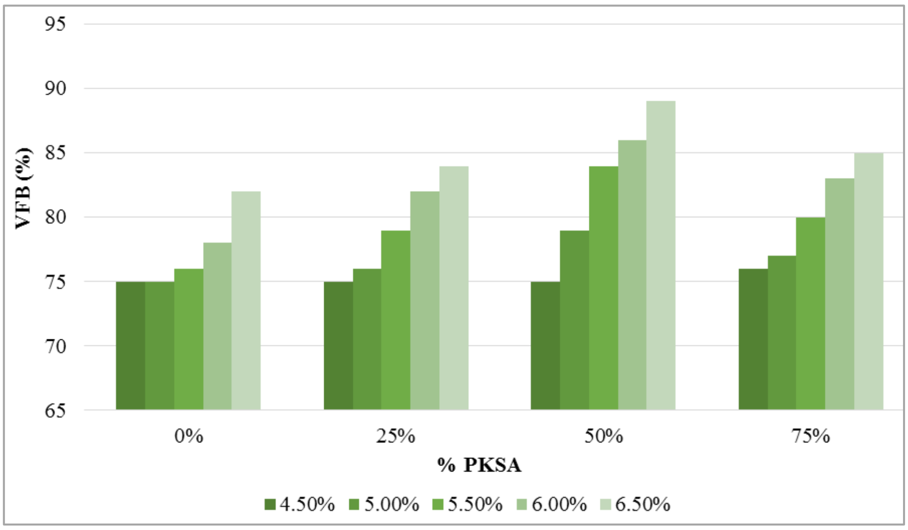

Figure 6*. Variation of VFB with bitumen content and PKSA.*

4.6. SEM of HMA Mixture

Figure 7 shows the micrograph of the control sample and the modified sample containing 50% PKSA. Plate (a) shows the interlocking particle arrangement of the control mixture, it can be seen that the passive (non-reactive) filler like granite did not affect the viscosity of the bitumen in order to flow and fill up pores in the mix, the resulting particle arrangement impacts on the strength and durability of the mix.

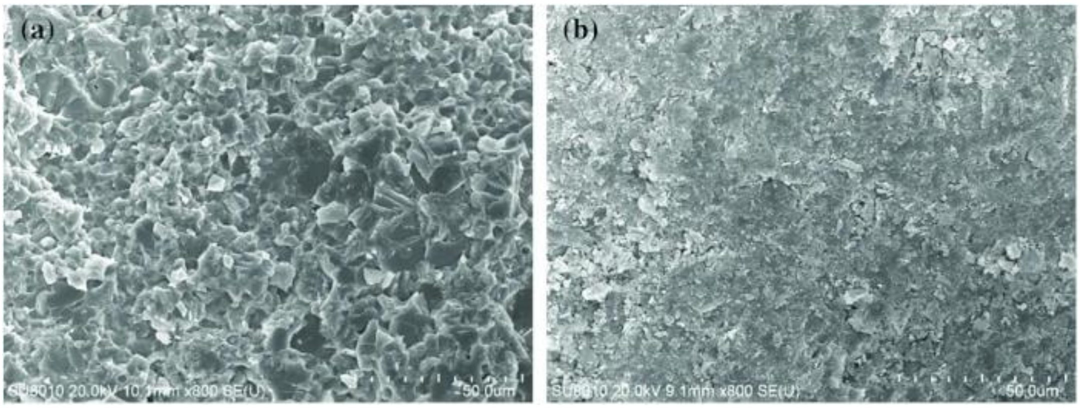

Figure 7*. Micrograph of modified and unmodified asphalt mixtures.*

Similarly, plate (b) shows the modified sample at 5.5% bitumen and 50% PKSA, and it can be seen that it presents a rough textured surface similar to the original mix which is suitable for pavement construction. Also, as seen in micrograph, the interlocking particle arrangement of the mixture has lesser pores between the aggregates, hence, resulting in a denser mix. This can be related to the effect of PKSA on the viscosity of the bitumen which allows it to flow better, coating the aggregates and filling the pores [20, 29].

5. Conclusion

1) Replacement of natural aggregates with 50% RAP is within the acceptable limit specified by standards for modified HMA.
2) The percentage quantity of useful oxides in PKSA is sufficient for it to be considered a mineral filler for HMA concrete.
3) The Marshall stability which represents the HMA

strength and other physical properties of the HMA showed improvement with addition of PKSA to the mixture.

4) Microstructural analysis using SEM revealed superior interlocking arrangement in the modified mixture as against the unmodified mixture.
5) Palm kernel shell ash PKSA is a suitable mineral filler that has the potential to improve the durability and physical properties of hot mix asphalt HMA modified with reclaimed asphalt pavement RAP.

Abbreviations

RAP	Reclaimed Asphalt Pavement
PKSA	Palm Kernel Shell Ash
HMA	Hot Mix Asphalt
SEM	Scanning Electron Microscopy

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Mohammed, A A., Altlomate A., Al-Zarroug, M. A., Hussain, M. K., and Al-Ramash, S. S. 2019. Performance Evaluation of Hot Mix Asphalt Containing Recycled Concrete Aggregate. 2nd Conference for Engineering Sciences and Technology. 1-12.

[2] Remisova, E. 2015. Study Of Mineral Filler Effect on Asphalt Mixtures Properties. Bituminous Mixtures and Pavements, 49-53.

[3] Arshad, A. K., Awang, H., Shaffie, E., Hashim, W. and Abd Rahman, Z. 2017. Performance Evaluation of Hot Mix Asphalt with Different Proportions of RAP Content. E3S Web of Conferences 1-8 Asphalt Institute. 2014. MS-2 Asphalt Mix Design Method (7 ed.). USA; Asphalt Institute.

[4] Adedokun, S. I. and Osuolale, O. M. (2012), "Stabilization of Poor Lateritic Soils with palm kernel shell Ash", International Journal of Engineering Research & Technology (IJERT) Vol. 1 Issue 8, October – 2012.

[5] Murana, A. A. and Sani, L., 2014. Partial Replacement of Cement with Rice Husk Ash (RHA) as Filler in Asphalt Concrete Design. Journal of Engineering and Applied Sciences 10 (2014), 30 – 40, Zaria, Kaduna state.

[6] Sadeeq, J. A., Kaura, J. M., Joshua, O., & Rabilu, A. 2014. Recycling of Reclaimed Asphalt Ravement (RAP) with Rice Husk Ash (RHA)/Ordinary Portland Cement (OPC) Blend as Filler. Jordan Journal of Civil Engineering, 159(3269), 1-9.

[7] Adeala A. J., Olaoye, J. O., & Adeniji, A. A., 2020. Potential of Coconut Shell Ash as Partial Replacement of Ordinary Portland Cement in Concrete Production. International Journal of Engineering Science Invention. 9(1). 4753.

[8] Hussain, A and Qiu Yanjun, 2013, Effect of Reclaimed Asphalt Pavement on the Properties of Asphalt Binders. The 2nd International Conference on Rehabilitation and Maintenance in Civil Engineering. Procedia Engineering 54, pg 840–850.

[9] FMPW&H. 2016. General Specifications (Roads and Bridges) Volume II. Abuja, Nigeria.

[10] Asphalt Institute. 2014. MS-2 Asphalt Mix Design Method (7 ed.). USA; Asphalt Institute.

[11] ASTM C127-15. 2015. Standard Test Method for Relative Density (Specific Gravity) and Absorption of Coarse Aggregate. West Conshohocken, PA: American Society for Testing and Materials (ASTM) International.

[12] ASTM C128-15. 2015. Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate. West Conshohocken, PA: American Society for Testing and Materials (ASTM) International.

[13] ASTM C136/C136M-19. 2019. Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates. West Conshohocken, PA: American Society for Testing and Materials (ASTM) International.

[14] ASTM D113-17. 2017. Standard Test Method for Ductility of Asphalt Materials (Vol. 04.03). West Conshohocken, Philadelphia. PA: American Society for Testing and Materials (ASTM) International.

[15] ASTM D2042-15. 2015. Standard Test Method for Solubility of Asphalt Materials in Trichloroethylene. West Conshohocken, PA: American Society for Testing and Materials (ASTM) International.

[16] ASTM D36/D36M-14. 2020. Standard Test Method for Softening Point of Bitumen (Ring-and-Ball Apparatus) (Vol. 04.04). West Conshohocken, PA: American Society for Testing and Materials (ASTM) International.

[17] ASTM D4402-15. 2015. Standard Test Method for Viscosity Determination of Asphalt at Elevated Temperatures Using a Rotational Viscometer. West Conshohocken, PA: American Society for Testing and Materials (ASTM) International.

[18] ASTM D4791-19. 2019. Standard Test Method for Flat Particles, Elongated Particles, or Flat and Elongated Particles in Coarse Aggregate. West Conshohocken, PA: American Society for Testing and Materials (ASTM) International.

[19] ASTM D5/D5M-20. 2020. Standard Test Method for Penetration of Bituminous Materials. West Conshohocken, PA: American Society for Testing and Materials (ASTM) International.

[20] ASTM D6926-20. 2020. Standard Practice for Preparation of Asphalt Mixture Specimens Using Marshall Apparatus. West Conshohocken, PA: American Society for Testing and Materials (ASTM) International.

[21] ASTM D70-18a 2018. Standard Test Method for Density of Semi-Solid Asphalt Binder (Pycnometer Method), West Conshohocken, PA: American Society for Testing and Materials (ASTM) International.

[22] ASTM D854 – 14 2014. Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer. West Conshohocken, PA: American Society for Testing and Materials (ASTM) International.

[23] ASTM D92-18. 2018. Standard Test Method for Flash and Fire points by Cleveland Open Cup Tester (Vol. 05.01). West Conshohocken, PA: American Society for Testing and Materials (ASTM) International.

[24] ASTM E1621-13. 2013. Standard Guide for Elemental Analysis by Wavelength Dispersive X-Ray Fluorescence Spectrometry. West Conshohocken, PA: American Society for Testing and Materials (ASTM) International.

[25] ASTM E986-04. 2017, Standard Practice for Scanning Electron Microscope Beam Size Characterization, West Conshohocken, PA: American Society for Testing and Materials (ASTM) International.

[26] BS 812-110. 1990. Testing Aggregates. Methods for Determination of Aggregate Crushing Value (ACV). London, United Kingdom: British Standard Institution.

[27] BS 812-112. 1990. Testing Aggregates. Methods for Determination of Aggregate Impact Value (AIV). London, United Kingdom: British Standard Institution.

[28] BS EN 933-3. 2017. Tests for Geometrical Properties of Aggregates Part 3: Determination of Particle Shape — Flakiness Index (12th ed.). London, United Kingdom: British Standards Institution (BSI).

[29] Kumar, L., Pandey, K. K., and Khan, S. 2017. Use of Coconut Shell Ash as Aggregates. International Journal of Research in Engineering and Social Sciences. 7(2). 15-19.