SSRG International Journal of Civil Engineering
ISSN: 2348-8352/ https://doi.org/10.14445/23488352/IJCE-V11I3P108

Volume 11 Issue 3, 94-106, March 2024
© 2024 Seventh Sense Research Group®

Original Article

Investigation of the Effect of Cement Kiln Dust-Rice Husk Ash Composite Fillers on Volumetrics and Durability Properties of Recycled Hot-Mix Asphalt

Vihunina Rikambura[1], Mung'athia M'tulatia[2], Samuel Waweru[3]

[1]*Department of Civil Engineering, Pan African University Institute for Basic Sciences, Technology and Innovation (PAUSTI), Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya.*
[2]*Department of Civil, Construction and Environmental Engineering, Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya.*
[3]*Department of Civil and Structural Engineering, Masinde Muliro University of Science and Technology, Kakamega, Kenya.*

[1]*Corresponding Author : vrikambura@gmail.com*

Received: 16 January 2024 Revised: 16 February 2024 Accepted: 14 March 2024 Published: 31 March 2024

Abstract - *Flexible pavements typically employ asphalt concrete mixtures as surface materials, comprising mineral aggregates, fillers, and bitumen in specific proportions to ensure durability and strength. Over time, heavy traffic and harsh environmental conditions cause deterioration, leading to defects like rutting, cracking, and stripping. Moreover, the increasing production of solid waste and escalating greenhouse emissions pose significant concerns. Utilizing Reclaimed Asphalt Pavement (RAP) materials and agro-industrial waste fillers have become popular for rehabilitating roads and airport pavements due to rising asphalt production costs, scarcity of high-quality aggregates, and environmental considerations. Mineral fillers play a critical role in optimizing hot mix asphalt performance, including binder-aggregate bonding, resistance to moisture damage, and pavement durability. The present study, therefore, aimed to evaluate the performance of incorporating 30% RAP in hot mix asphalt produced with Cement Kiln Dust (CKD) and Rice Husk Ash (RHA) as a partial and full replacement of a conventional mineral filler, granite stone dust. The results showed that the replacement of 75%CKD and 25% RHA was an optimum blend, as it significantly improved Marshall stability, rutting potential, cracking resistance and moisture susceptibility amongst other studied blends of fillers as well as the control mix. The rough texture and angular morphology of CKD may positively affect the strength and durability of recycled hot mix asphalt.*

Keywords - *RAP, Cement Kiln Dust, Rice Husk Ash, Moisture susceptibility, Rutting.*

1. Introduction

The rapid increase in human population results in heightened utilization of natural resources, subsequently escalating waste production. The escalating production of solid waste, predicted to reach 2.2 billion tons annually by 2025, accompanies the challenges of global warming and greenhouse emissions [1]. Transportation infrastructure projects are significant consumers of natural materials. Utilizing waste as an alternative to virgin materials addresses both eco-friendly waste disposal concerns and the need for suitable alternatives to conventional materials [2].

Globally, road authorities are reconstructing primary roads and infrastructure systems that have reached a point where maintenance and repair costs substantiate replacement to maintain reliability and level of service. Consequently, the demolishment and replacement of old roads lead to the generation of substantial quantities of waste materials. The resulting generation is known as Reclaimed Asphalt Pavement (RAP) and contains aged binder and aggregates [3]. Due to the increasing cost of asphalt binder, significant economic savings can be realized using a high content of RAP in the production of new Hot Mix Asphalt (HMA). Additionally, the utilization of RAP is widely implemented due to its demonstrated potential to enhance the performance properties of asphalt mixes, such as increased resistance to cracking, prolonged fatigue life, improved rutting resistance, and reduced susceptibility to moisture damage [4].

Research conducted on laboratory-produced mixtures has shown that incorporating small quantities of RAP in HMA between 0-30% can perform similarly to those with no RAP, with some even performing better [5]. However, the success of these mixtures depends on factors such as RAP fractionation and the use of appropriate binder grades [6]. Furthermore, in particular, [7] examined substituting fresh aggregate with recycled asphalt aggregate in hot asphalt mixtures. Marshall stability, moisture susceptibility, and rutting tests on various mixtures, exploring replacement ratios up to 65%.

Results indicated that increasing RAP content led to a decrease in the tensile strength ratio, yet standards were maintained, offering resistance against deformation and moisture-induced damage. Substituting 45% of crushed aggregate with RAP material met stability, flow, and volumetric property specifications. Another study [8] stated that the duration of mixing affects the blending and dispersion of hot asphalt mixes with RAP. Longer mixing durations enhance the performance of recycled asphalt mixtures. However, determining the acceptable proportion of RAP in hot mix asphalt depends on factors such as the recycling method, RAP quality, mixture composition, and pavement performance standards.

The surface layer of any flexible pavement is built with asphalt mixes, which are prepared with aggregates and bitumen. The top layer of every flexible pavement consists of asphalt mixes comprising aggregates and bitumen. The performance of asphalt concretes relies on aggregate packing and the adhesion facilitated by bitumen. Particularly, HMA typically consists of around 95% coarse and fine aggregates, combined with 5% asphalt that acts as a binding agent to create a cohesive mixture [9].

Furthermore, to break down into more specific components, in asphalt mixtures, three significant components exist, namely the aggregates, filler, and asphalt binder. The mineral fillers are fine mineral powders, typically passing through a No. 200 (75 μm) sieve, that are added to asphalt mixtures to improve their performance characteristics [10]. Moreover, the finer fraction of filler replaces the asphalt binder to create asphalt mastics and modify the behavior of the asphalt mix. Therefore, the choice and amount of filler have a significant impact on the performance of the asphalt mix, particularly in terms of its workability, susceptibility to moisture damage, tendency to become brittle, and how it ages [11].

Over the last few decades, a significant number of researchers globally have utilized a range of industrial and agricultural waste materials in asphalt mixes as substitutes for conventional fillers. This was done with the aim of improving the stiffness characteristics of the mix through either partial or complete substitution. Several past studies have utilized agro-industrial waste fillers in asphalt mixes, such as bauxite residue [12], fly ash [13], bagasse ash [14], and waste glass powder [15]. Specifically, [16] studied the impact of steel slag and silica fume additives on recycled hot mix asphalt. Steel slag filler improved Marshall stability load values, ranging from 11.73 to 32.73 kN, with the highest value achieved at 75% RAP and 50% steel slag. Silica fume showed varying strength, reaching a maximum load value of 31.02 kN with 75% RAP and 100% silica fume. Despite water's adverse effects on stability, asphalt mixes with steel slag met ASTM standards even after exposure to moisture.

In another study, [17] evaluated the mechanical properties and ageing resistance potential of different waste fillers (Jarosite, Hydrated lime mud, Fly ash, Sugarcane ash) compared to conventional filler (Stone Dust) in recycled asphalt mixtures. It was found that Jarosite and Hydrated lime mud significantly improved moisture, rutting, and crack resistance in unaged and long-term aged recycled mix that the other studied fillers, which are critical factors in extending the durability of pavement.

In certain research, fillers derived from blending two distinct materials exhibited better performance compared to when each material was used separately [18, 19]. In particular, [20] used Rice Husk Ash (RHA) as a mineral filler in HMA and found out that the optimum ratio of mineral filler is 25% RHA and 75% limestone. The study also shows that the mechanical properties of HMA, such as Marshall Stability, Marshall Flow, indirect tensile strength, and tensile strength ratio, are affected by the type and percentage of mineral filler used.

Another study [21] assessed the viability of using glass-fiber-reinforced polyester and pipe waste powder composite as a filler substitute in HMA, aiming to exploit waste materials for asphalt mixtures, enhancing mechanical properties, reducing costs, and managing waste sustainably. The optimal mix design comprised 4.5% binder, 3.75% composite, and 1.25% limestone filler using 5% filler by weight of total aggregates. Overall, composite fillers play a crucial role in hot mix asphalt by enhancing mechanical properties, moisture sensitivity their ability to influence aggregate packing and adhesion, thus optimizing asphalt performance under various conditions.

On the other hand, ordinary Portland cement stands as a cornerstone within the construction industry. Cement Kiln Dust (CKD), a significant by-product waste generated during cement manufacturing, comprises micron-sized particles known as bypass dust collected from electrostatic precipitators during the clinker production process under high-temperature conditions. It is utilized in asphalt paving mixes as a filler substance to prevent stripping, enhance soil quality, and in cement mortar applications [22]. Specifically, [23] explored the impact of CKD as a filler on the low-temperature durability and fatigue life of HMA. Mixtures incorporating CKD filler exhibited superior resistance to freeze-thaw cycles compared to those containing limestone filler.

Additionally, CKD mixes showed enhanced fatigue life, particularly at higher strain levels, compared to the control mix. However, numerous researchers have directed their studies toward employing CKD in cold mixes. There exists a paucity of comprehensive research within the domain of HMA. The assessment indicated that fillers with predominantly hematite, portlandite, and calcite materials showed the highest retention of moisture susceptibility. Conversely, fillers with a high presence of quartz demonstrated lower susceptibility to retained moisture due to the prevalence of silica in their fillers. Hence, there exists a gap in determining the optimal combination of silica and calcium-based mineral waste fillers and their impact on the mechanical, moisture resistance, and durability properties of hot mix asphalt mixes. The objective of this study is to evaluate the effectiveness of utilizing rice husk ash and cement kiln dust fillers in improving the volumetrics and durability of hot mix asphalt containing reclaimed asphalt pavement aggregates.

2. Materials and Methods

2.1. Materials

2.1.1. RAP and Virgin Aggregates

The crushed granite aggregates were sourced from Mlolongo quarries in Athi River, Machakos county, Kenya. At the same time, the RAP material was obtained from the uncontrolled demolition of a deteriorated pavement along Kangundo - Kamulu road during maintenance operations. The RAP underwent heating in the oven, followed by crushing and fractionation, yielding individual-sized aggregates categorized into size ranges of 0/6 mm, 6/10 mm, and 10/20 mm, constituting proportions of 13%, 12%, and 5%, respectively, as depicted in Figure 4.

Moreover, Virgin aggregates, available in sizes of 0/6 mm, 6/10 mm, 10/14 mm, and 14/20 mm, were also procured, with proportions of 37%, 10%, 10%, and 7% respectively. Blended aggregate gradation, as shown in Figure 1, is used throughout the study. All aggregates underwent sieving to separate them into various sieve sizes according to the specifications [24]. The physical and mechanical properties of aggregates are presented in Table 5.

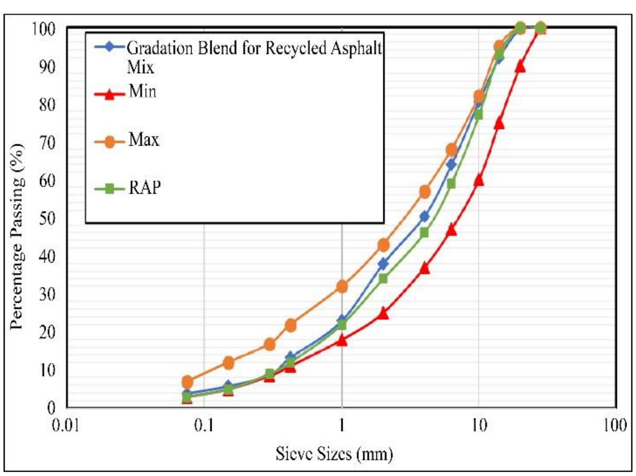


Fig. 1 Adopted gradation of the study

2.1.2. Extracted RAP and Virgin Bitumen

In the research, the binder content of RAP was determined to be 5.1% by aggregate weight through the centrifuge rotavapor extraction method [25]. Table 1 presents the physical properties of both the extracted RAP and the virgin binder.

It is noteworthy to highlight that high penetration asphalt binder was chosen to counterbalance the rigid nature of the RAP asphalt and to guarantee optimal performance of the blended bitumen. The research employed asphalt cement obtained from a nearby supplier, with a penetration grade of 80/100 as per ASTM D5-20, for all tested asphalt mixtures.

Table 1. Reclaimed Asphalt Pavement (RAP) and virgin bitumen properties

Properties	Bitumen	RAP Binder [a)]	Standard
Specific Gravity	1.01	1.05	ASTM D70
Penetration (@ 25°C)	86.5	-	ASTM D5
Softening Point (°C)	48	92	ASTM D36
Viscosity (@ 135°C)	280.1	-	ASTM D2170
Ductility (@25°C)	100	-	ASTM D113

[a)]*(Extracted with trichloroethylene (TCE))*

2.1.3. Fillers

The rice husk was sourced from Mwea in Kenya and then burnt at an elevated temperature of 600-750°C in a controlled environment to obtain its ash. Cement kiln dust was collected from Bamburi cement in the Mombasa manufacturing plant. All filler materials were sieved using a 0.075 µm sieve and oven-dried before their use. The physical appearances are shown in Figure 2. The adopted total fillers used throughout the study by weight of aggregates was 6%.

(a) **(b)** **(c)**

Fig. 2 Shows the physical appearance of the fillers used: (a) Granite Stone Dust, (b) Cement Kiln Dust, and (c) Rice Husk Ash.

2.2. Methods

2.2.1. Marshall Mix Design and Samples Preparations

For this research study, the preparation of an asphalt mix containing 30% RAP and 70 % virgin aggregates and GSD filler was conducted. Test samples for the aforementioned mixture were fabricated with different asphalt binder contents ranging from 2.5 % to 4.5% to ascertain the Optimum Asphalt Content (OAC) for the mixture.

Crushed granite and RAP aggregates underwent preheating at 105 °C for 24 hours before mixing with other materials. Marshall design specifications were followed to prepare surface-type asphalt mixtures. Three mixes per asphalt content were tested for Marshall stability using an automatic compactor, carried out using the Marshall compaction apparatus as per ASTM D6926-20 [26], with 75 blows on each side.

The mix design was designed to meet the requirement for asphalt concrete for a binder course (Type 1), heavy traffic surface as stated. The study plan is shown in Figure. Table 2 gives a summary of the various filler combinations employed.

Table 2. Combination of fillers used in the study

Mixture No.	Constitute	Mixture Type
1	100% GSD	Control
2	100% RHA	100% RHA
3	100% CKD	100% CKD
4	75% CKD + 25% RHA	75% CKD
5	50% CKD + 50% RHA	50%CKD/RHA
6	25% CKD + 75% RHA	75% RHA

2.2.2. Characterization of Fillers

In this research, conventional filler granite stone dust, rice husk ash, and cement kiln dust were used. The physical properties, morphology, and composition were to study their effect as well as composite on recycled hot asphalt mixes. The specific gravities of all selected fillers were determined following ASTM D 854 guidelines. The fillers' shape and texture were analyzed using scanning electron microscopy (SEM) in accordance with the appropriate ASTM specification. Additionally, X-ray diffraction (XRD) and X-ray Fluorescence (XRF) analysis were conducted to study the main chemical composition, respectively.

2.2.3. Indirect Tensile Strength and Tensile Strength Ratio

The Indirect Tensile Strength (ITS) test, conducted following AASHTO T 283 specifications, evaluated the cracking resistance of recycled mix. Cylindrical samples, measuring 150 mm in diameter and 63.5 mm in thickness, were fabricated using a Marshall hammer, aiming for an air void content of approximately 7% with a tolerance of ±0.5%. After compaction, these specimens were left to stabilize at room temperature for a period of 24 ± 3 hours prior to moisture conditioning.

A compressive load was applied vertically to the specimen at a rate of 50.8 mm/minute at 25ºC. Additionally, this method assessed the resistance of asphalt mixtures to moisture-induced damage through the Tensile Strength Ratio (TSR), which compares the tensile strength of conditioned samples to unconditioned ones. It helps evaluate potential stripping and loss of adhesion within the asphalt mixture, aiding in the assessment of pavement material durability.

Indirect tensile strength is measured for both conditioned and unconditioned specimens according to Equation 1, as per the specified requirements.

$$S_t = \frac{2000XP}{\pi XDXT} \quad (1)$$

Where: S_t = tensile strength (kPa); D = sample diameter (mm); T = sample thickness (mm), P = maximum load (N).

The computation of indirect tensile strength between conditioned and unconditioned samples was expressed as TSR using Equation 2. A higher value is preferred for less moisture-susceptible mixtures, while the opposite holds true.

$$TSR = \frac{ITS_{Conditioned}}{ITS_{Unconditioned}} X100 \quad (2)$$

Where: $ITS_{conditioned}$ = average tensile strength of conditioned sample; $ITS_{unconditioned}$= average tensile strength of unconditioned sample.

2.2.4. Immersion Marshall Stability Test

The study used ASTM D6927's Marshall mix design to optimize HMA compositions. Six samples per mix type were compacted with 75 blows each. Samples were then split into conditioned and unconditioned groups for each filler combination at the AOC control mix for 3 replicate samples for each group.

Conditioned samples were soaked in 60°C water for 24 hours, while unconditioned ones were immersed for 40 minutes. Stability, indicating load-bearing capacity, was recorded, and RSI was calculated using Equation 3.

$$RSI = \frac{S_2}{S_1} X100 \quad (3)$$

Where: S_1 represents the stability of the control samples, while S_2 denotes the stability of the conditioned samples.

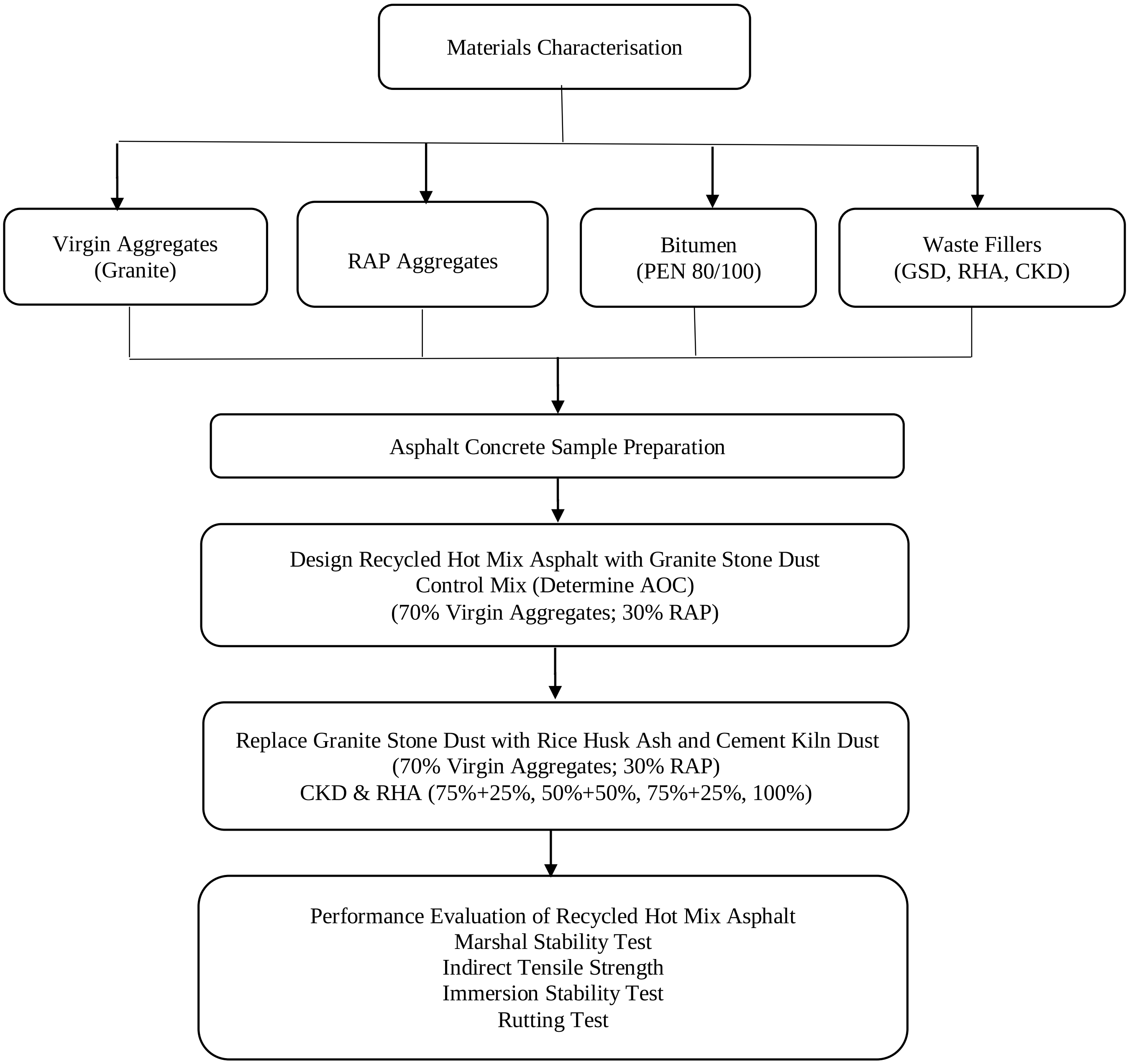


Fig. 3 Flow diagram of research methodology used in this research

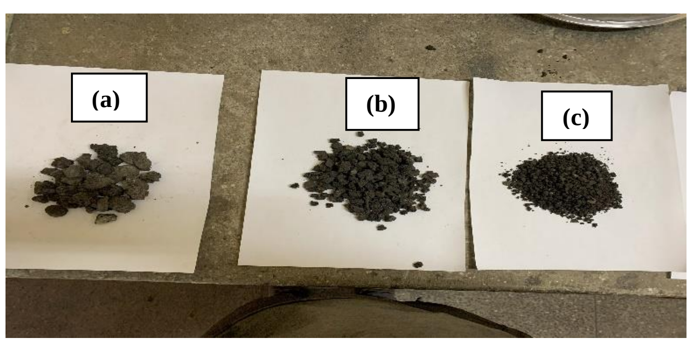


Fig. 4 Fractionated RAP aggregates; (a) 10/20 mm, (b) 6/10, and (c) 0/6mm.

2.2.5. Rutting Test

This assessment measures the enduring deformation caused by repetitive traffic loads on the wheel path. It evaluates rut depth in millimeters on specimens after a set number of passes using the double wheel tracking device according to EN12697-22 standards. Specimens measuring 400 mm × 300 mm x 60 mm were prepared with fillers compacted to achieve 7% air void density. The test simulated the peak pavement temperature of summer, conducted at 60ºC for 10,000 passes. The samples were tested at repetitive cycles of 25 cycles per minute.

3. Results and Discussion

3.1. Physical Properties, Microstructure and Chemical Compositions of Fillers

The fundamental physical characteristics and chemical composition of fillers were assessed, and the findings are presented in Table 3. XRF results show that their GSD and RHA are predominantly silica dioxide. At the same time, CKD has over 70% calcium oxide content, which signifies greater alkalinity. This results in enhanced bonding between filler particles and asphalt, leading to improved adhesion with the aggregate. Results showed that the specific gravity of granite dust filler, cement kiln dust and rice husk ash were 2.69, 2.77 and 1.78, respectively. CKD is denser and heavier relative to its volume compared to other fillers with lesser specific gravity. This indicates that the particles have more mass per unit volume.

The surface structure of the fillers under investigation was analyzed using Scanning Electron Microscopy (SEM). It was noted that the surface texture of the CKD filler appeared notably rougher compared to the other fillers. This roughness likely enhances the interlocking between aggregates and mineral fillers within the asphalt mixture, as the uneven surface potentially increases asphalt absorption in the mix [27]. As observed in Figure 6, the geometrical irregularity of RHA filler particles may impact the aggregate cohesion and bonding in the mixture, potentially leading to a negative effect on the mix's moisture resistance [28].

Table 3. Physical property and chemical composition of fillers

Chemical Name	GSD (%)	CKD (%)	RHA (%)
SiO_2	63.31	18.56	95.53
CaO	1.79	71.10	1.07
Al_2O_3	21.86	5.9	-
Fe_2O_3	4.04	-	-
MgO	2.75		-
K_2O	4.97	-	1.95
Other Oxides	1.28	1.44	1.45
Specific Gravity	2.69	2.77	1.78

The particle size distribution of the fillers under investigation was assessed through hydrometer analysis following standards [29], and the results are depicted in Figure 4. GSD and CKD show particle sizes that are well distributed over a range of sieve sizes, while RHA shows that most particles occupy the same size.

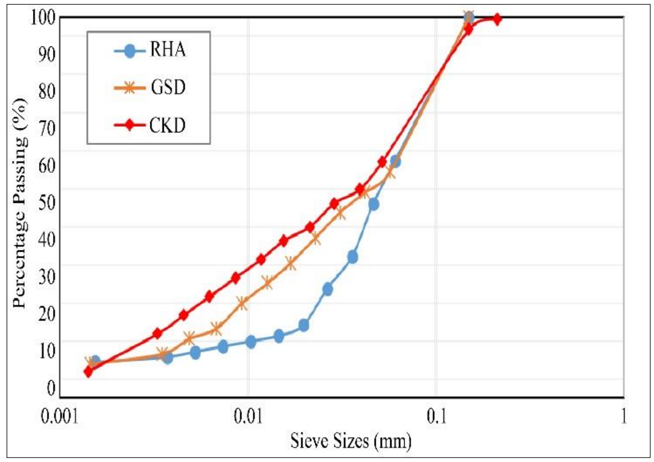


Fig. 5 Shows gradation curve of studied fillers

3.2. Marshall and Volumetric Properties

The characteristics of recycled blends containing various fillers have a notable impact on their endurance and mechanical attributes, essentially dictating their real-world performance in the field. The optimal asphalt content is derived from the graphs depicted in Figure 7 namely: (i) the bitumen content corresponding to maximum stability, (ii) the bitumen content corresponding to maximum bulk density, and (iii) the bitumen content corresponding to the mean of the designed limit of percent air voids in the total mix.

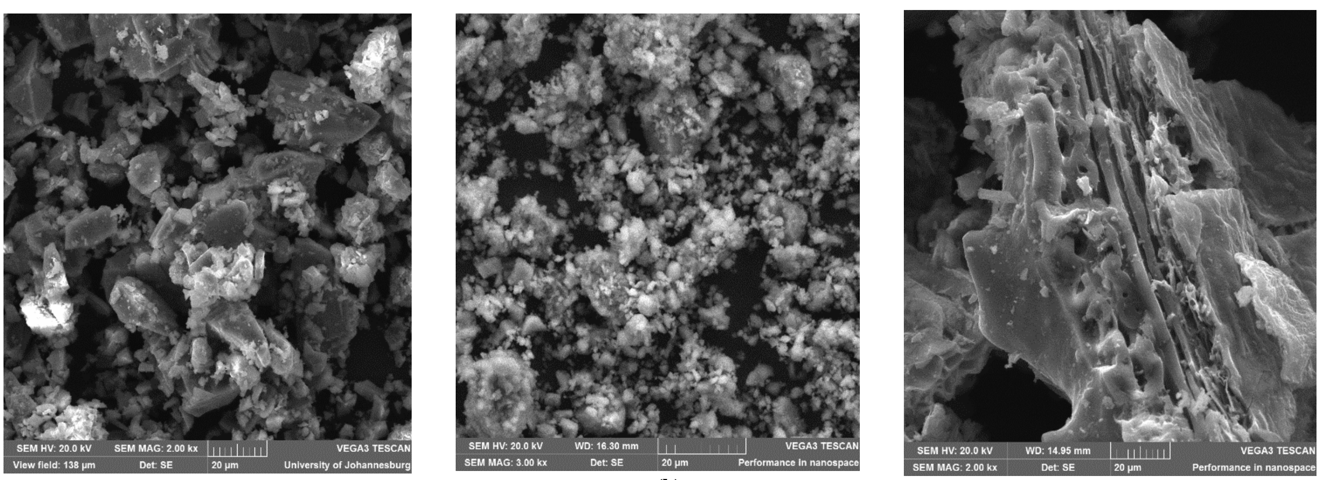
As presented in Figure 7, it is observed that the bitumen content corresponding to maximum stability, maximum bulk density, and the mid-value of air voids are 3.70%, 3.85%, and 4.15%, respectively. Consequently, the optimum asphalt content is determined as the average of these three of 3.90%. The Marshall stability, flow value, and volumetric properties of OAC and the optimum flow rate are summarized in the following Table 4.

Table 4. The results of the test of the control mix design

Properties	Results	Standard
OAC	3.9	-
Air Voids (%)	4.5	3 - 7
Stability (kN)	19.87	Min. 7 kN
Flow (mm)	3.2	2 - 4
VMA (%)	13.0	Min. 13
VFA (%)	65.4	65 - 78
Bulk Density (kg/m^3)	2215	-

Table 5. Properties of the aggregates used

Properties	Standard	RAP Aggregates	Virgin Aggregates	Specification Limits
Bulk Specific Gravity CA	ASTM C127	2.485	2.504	-
Water Absorption of CA (%)	ASTM C127	2.9	2.5	-
Bulk Specific Gravity FA	ASTM C128	2.282	2.452	-
Water Absorption of FA (%)	ASTM C128	3.5	3.3	-
Elongation Index (%)	BS 112: Sec. 105.1(1990)	-	13.99	-
Flakiness Index (%)	BS 112: Sec. 105.1 (1990)	-	13.69	Max 25
Impact Value (%)	ASTM C131	15.32	17.65	-
Loss Angles Abrasion (%)	ASTM C131 - 89	10.30	14.92	Max 35



(a) (b) (c)

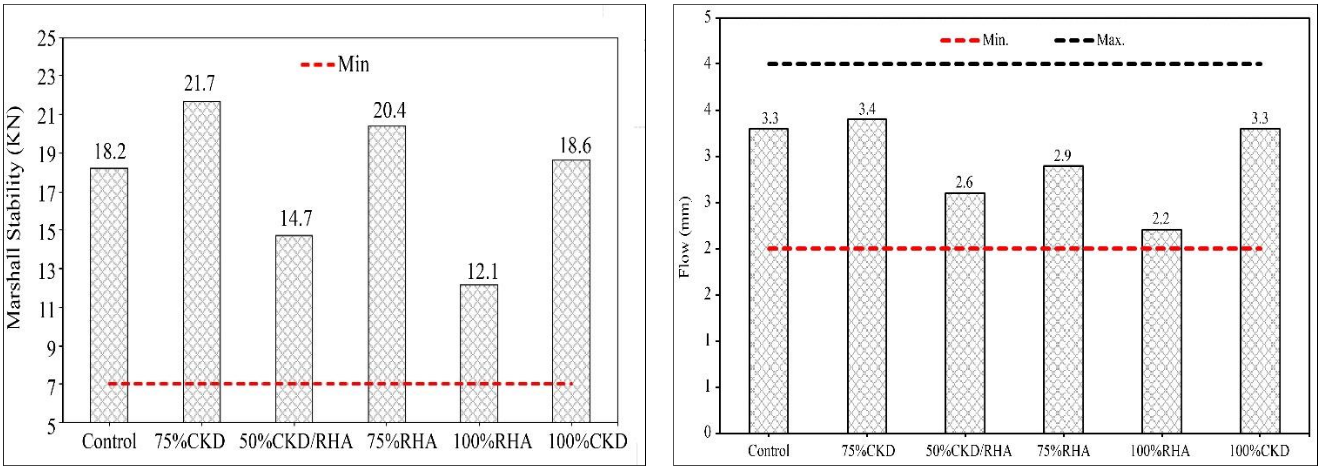
Fig. 6 SEM images of studied fillers (a) GSD, (b) CKD, and (c) RHA.

The Marshall Stability (MS) of a bituminous mixture represents the maximum load sustained by the specimens until failure. At the same time, the Marshall flow indicates the deformation experienced by the specimen at the peak load.

As shown in Figure 7, the highest MS value was obtained for the mixture type 75%CKD, which was 21.7 kN, followed by 75%RHA (21.4kN), 100%RHA (20.9 kN), 100%CKD (18.6 kN), Control (18.2 kN), 50%CKD/RHA, and 100%RHA (12.1 kN). Substantial improvement of MS noted in 75%CKD can be attributed to the surface roughness characteristic of CKD and the high surface area composite of RHA [20]. The flow value serves as an indicator of how asphalt mixes respond under traffic loads, reflecting their plasticity and elasticity.

Additionally, the vertical deformation value at maximum load correlates with the internal friction and cohesion of compacted asphalt mixes, with an inverse relationship to the internal friction value.

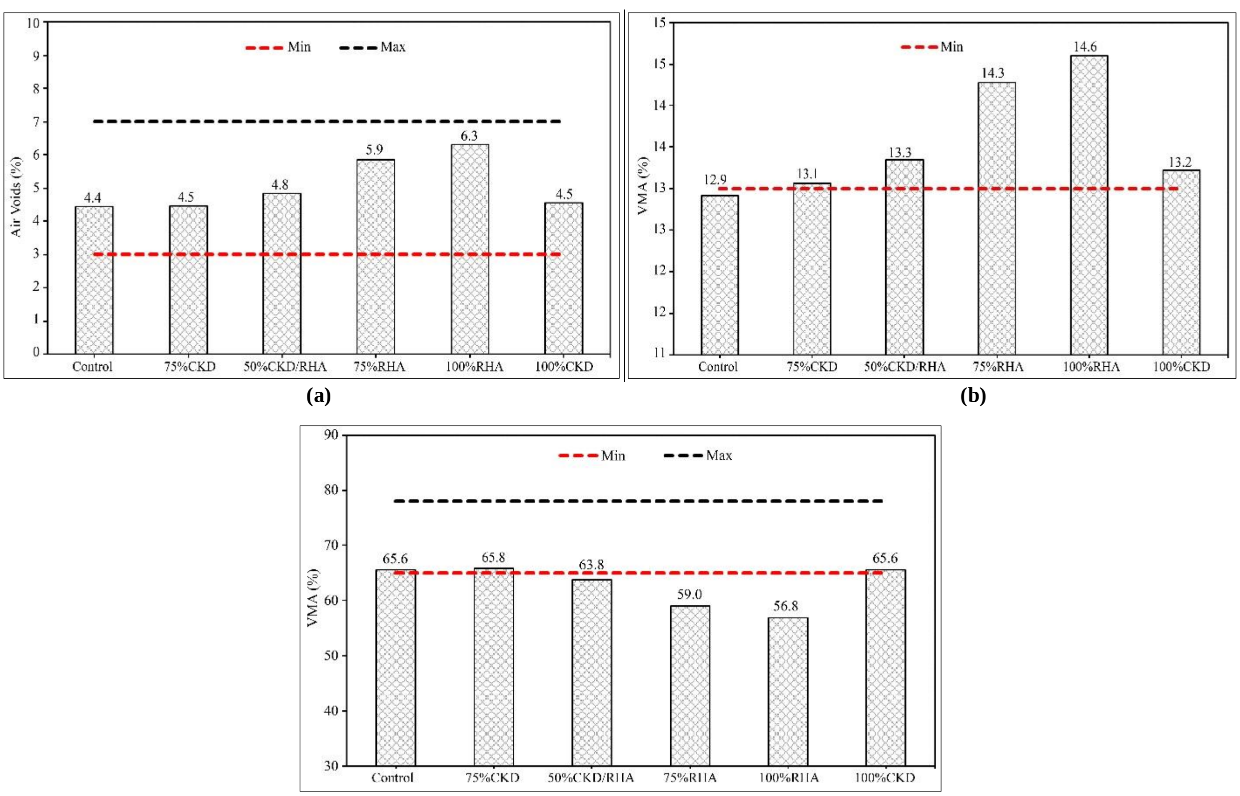
Until failure, while the Marshall flow indicates the deformation experienced [21]. Flow values were obtained and presented in Figure 7, it indicated that the highest being from a mixture of proportion 75%CKD and the lowest being 100%RHA. RHA's lowest value is attributed to reduced plasticity and elasticity. However, considering the MS and Flow test results were found to produce adequate values to meet the specifications requirement as stated for the high stability asphalt concrete type 1 for binder courses [24].



(a) (b)

Fig. 7 Marshall stability and flow for fillers and combinations (a) Marshal stability, and (b) Flow.

The increase in air voids observed in the mixtures containing a high proportion of RHA compared to the control mixtures could be attributed to the heightened stiffness of the binder resulting from the addition of RHA particles. Furthermore, the presence of high silica in its chemical composition and the irregular shape of RHA as obtainable in surface morphology led to high voids in those mixtures compared to the other mixture. It is observed that air voids increased with the addition of more than 50% of RHA. The maximum air voids were recorded at 6.7% of mixture type 100% RHA. Voids in Mineral Aggregate (VMA) represent the intergranular gaps among aggregate particles and include both air voids and bitumen volume not absorbed by the aggregates, showing that all filler types and composites met air voids and VMA specifications for a binder course. However, there was a slight discrepancy in Voids Filled with Asphalt (VFA) due to the established air voids and VMA values. Mixes with 50% CKD/RHA, 75% RHA, and 100% RHA did not meet specifications due to the irregular shape of RHA and high binder absorption.



(a) (b)

(c)

Fig. 8 Volumetrics properties of recycled mixes, (a) Air voids, (b) Voids in mineral aggregates, and (c) Voids filled with asphalt.

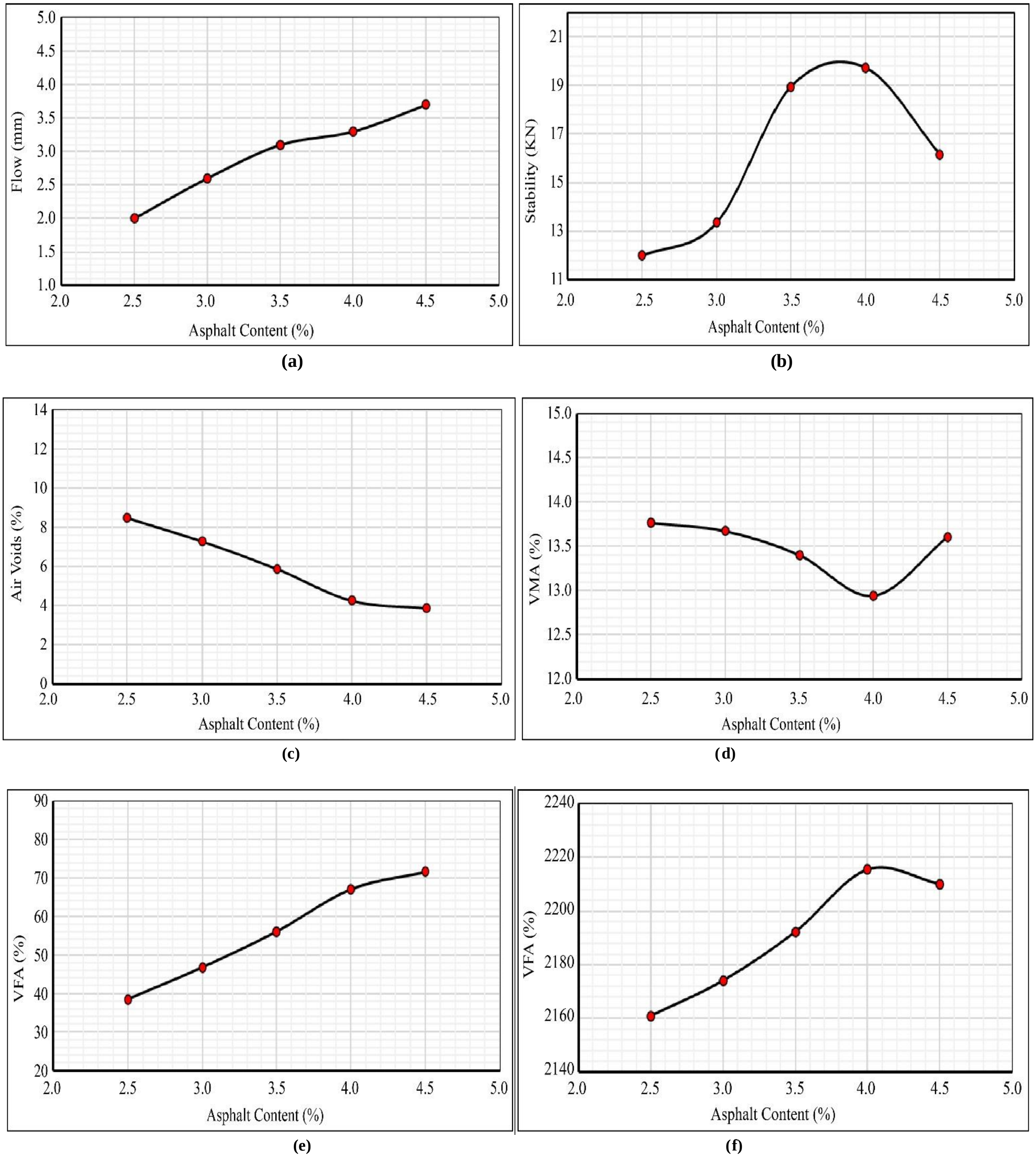


Fig. 9 Results of the control mix in terms of (a) Flow, (b) Marshall stability, (c) Air voids, (d) VMA, (e) VFA, and (f) Bulk density.

3.3. Cracking Resistance and Moisture Susceptibility

To evaluate the cracking resistance of recycled mix, the Indirect Tensile Strength (ITS) test was performed to evaluate how different filler mixture types influence the tensile strength of the specimens. Conditioned and unconditioned samples were analyzed and presented in Figure 10; it can be observed that the mixture type of 75%CKD exhibited the highest value for ITS, indicating a 25.1% greater than a control mixture. Furthermore, it can be observed that the incorporation of more than 50% of RHA lowers the ITS values for both conditioned and unconditioned specimens. This is attributed to high surface area, which increases binder absorption and leads to a reduction of effective binder content in the mixtures. Tensile Strength Ratio (TSR) values were assessed to analyze how various fillers influence the moisture susceptibility of the asphalt mix. A high TSR value indicates increased resistance of the compacted mix to moisture-induced damage. It can be observed that the TSR for 75%CKD, 75%RHA, and 100%CKD was 97.9%, 91.5% and 91.3%, respectively. The presence of CKD in those mixes enabled better moisture resistance, credited to the high presence of Calcium oxide in its composition, which enables bitumen filler adhesion and roughness nature of the particle textures [17]. On the other hand, mixtures with the presence of silica dioxide showed the lowest TSR results. This is aggravated by the irregular geometrical shape of RHA. Interestingly enough, the mixture constituting 75%RHA + 25%CKD showed great moisture tensile strength retention. This may be attributed to particle size distribution of composite fillers giving better aggregate packaging in the mix [30]. It is worth noting that comparable trends of results were obtained by varying percentages of RHA and limestone fillers.

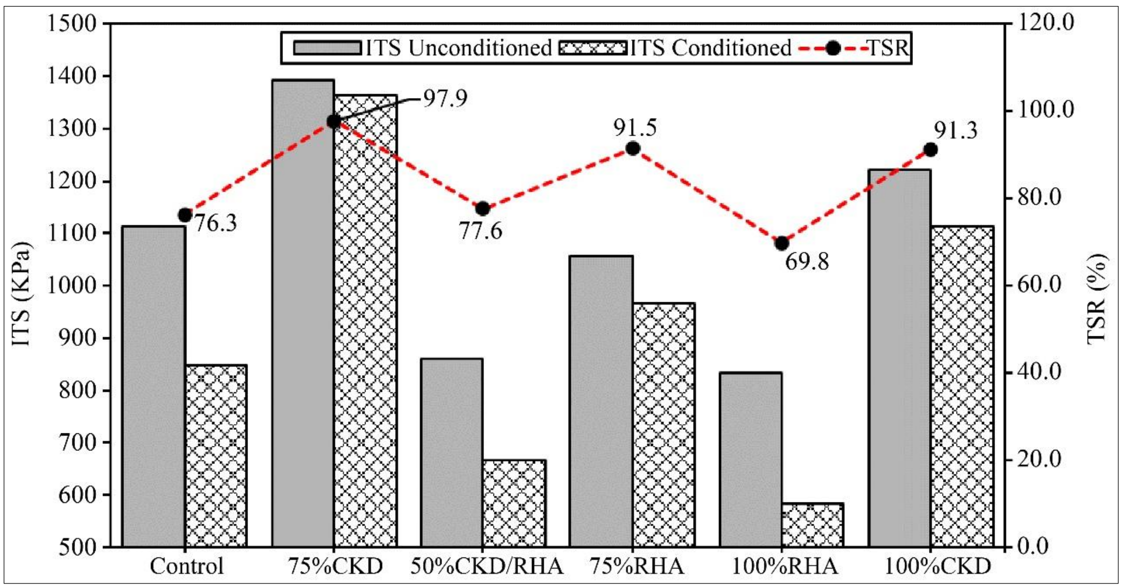


Fig. 10 Indirect tensile strength for conditioned, unconditioned and tensile strength ratio of recycled asphalt mixtures

3.4. Marshal Stability and Moisture Damage Resistance

Marshall stability (S_1, S_2) and retained stability index (RSI) of binder course asphalt mixtures across various levels of fillers and their composite replacement are presented in Figure 11. Replacement of granite stone dust with 75% cement kiln dust and 25% rice hush ask had the peak stability and retained stability index.

This is due to the physical and chemical properties of composite fillers influencing mastic and mixture performance that resulted in the highest retained moisture stability [31, 32]. Nevertheless, as the amount of silica dioxide composition filler content rose, both RSI and Marshall stability started to decline. This is highlighted with results obtained for control, 50%CKD/RHA and 100%RHA modified mixes.

This occurred because the excessive addition of solid waste fillers heightened the void ratio within the mixtures, facilitating the removal of the asphalt film from the aggregate surface. Consequently, water could more readily infiltrate the internal structure of the asphalt mixtures. However, interestingly composite filler replacement of 75% RHA + 25% CKD showed the second highest moisture stability as well as retained stability index and highest of all fillers containing RHA. Similarly, [33] reported that mixtures prepared with RHA had better moisture resistance using Marshall stability and compared to using conventional mineral filler of Ordinary Portland cement.

Lastly, Marshal stability, indirect tensile strength, and moisture susceptibility show similar trends in these mixtures, indicating a correlation between filler replacement and pavement performance.

Additionally, the highest ITS and TSR recorded had a similar composition to the one in this study (75% limestone filler and 25% RHA). The inclusion of silica-based RHA fillers increased the void ratio, assisting in asphalt film removal from aggregate surfaces and enhancing water infiltration into the mixtures [20].

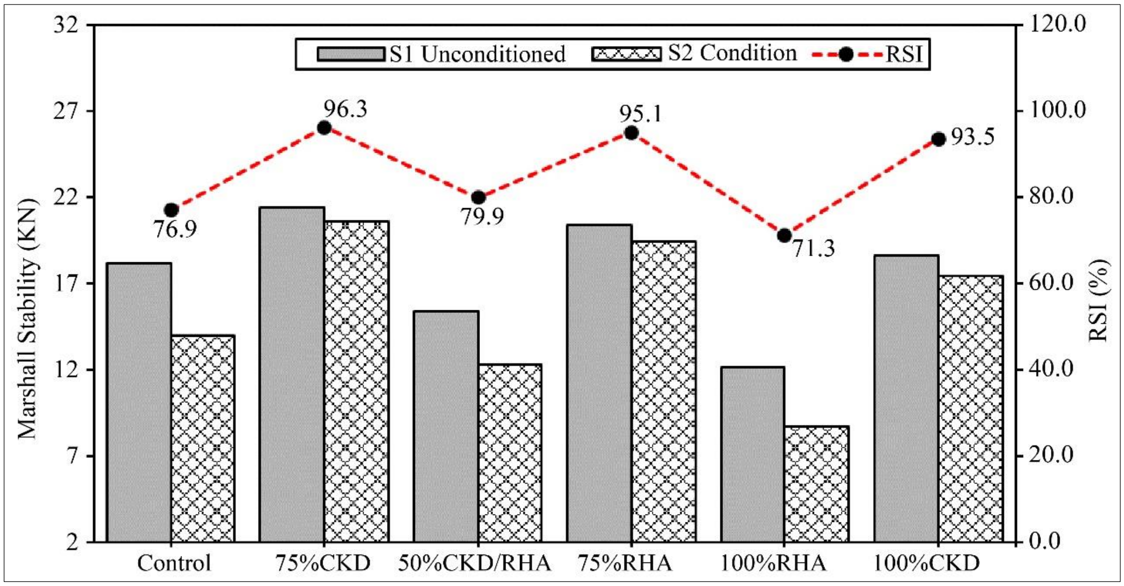


Fig. 11 Marshall stability (S_1, S_2) and Retained Stability Index (RSI) of binder course asphalt mixtures with studied fillers and composite

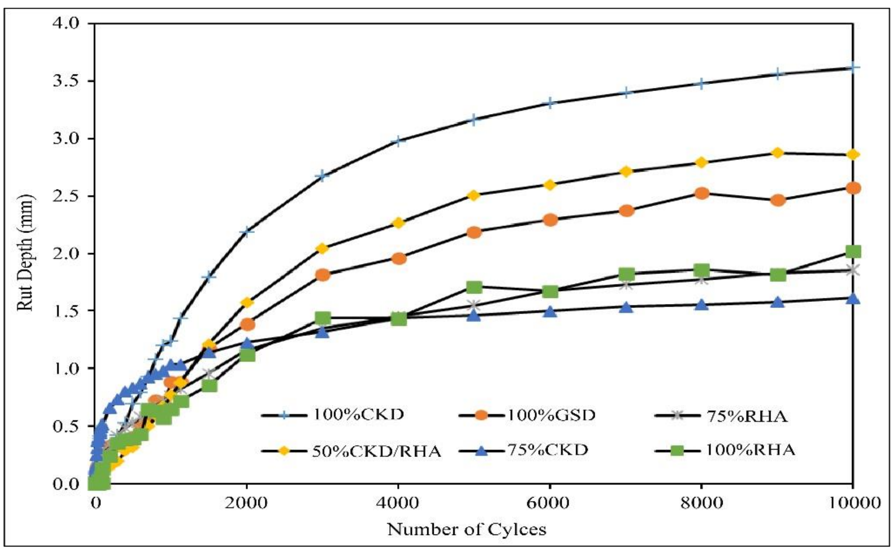


Fig. 12 Rut depth at different number of cycles for studied mixtures

3.5. Rutting Resistance

Rutting, a common form of distress in hot-mix asphalt pavements, often manifests within the asphalt layer due to factors such as elevated traffic loads, poor material choices, or elevated pavement operational temperatures [34]. To investigate the rutting characteristics in this research, a double wheel tracking was utilized and conditioned at 60°C before testing commenced. Six mixture types were tested, one with conventional granite stone dust, as well as replacement with rice husk ash, cement kiln dust and CKD-RHA composite. The rut depth for various fillers' six proportions is presented in Figure 12. As presented, 100%CKD had the highest rut depth at 3.614 mm. Whereas 50%CKD/RHA, 100%GSD, 100%RHA, 75% RHA and 75%CKD resulted in 2.857 mm, 2.576 mm, 2.019 mm, 1.857 mm and 1.613 mm, respectively.

As illustrated in Figure 12, the mixture type with the blend of 75% CKD and 25% RHA showed the lowest rutting depth after 10,000-wheel load passes or cycles. This suggests a 59.7 % enhancement in rutting resistance compared to the control mixture. This can be attributed to the variation of particle sizes of composite filler creating better interlocking in the mixture.

Additionally, the replacement of 75%RHA and 100%RHA gave a decrease in the rut depth of slabs tested, thereby improving rutting resistance, a similar trend as observed at 60°C [35]. The findings suggested that replacing agro-industrial fillers partially or entirely improved the resistance to permanent deformation induced by wheel passes on the HMA pavement in hot regions.

4. Conclusion

This experimental study evaluated the effect of cement kiln dust and rice husk ash on the volumetric, mechanical and durability properties of recycled hot asphalt mixtures. According to the results obtained, the following conclusions were drawn.

It can be observed in this study that at 6% filler of 75%CKD + 25%RHA composite exhibited significantly higher levels of volumetric properties, moisture stability, indirect tensile strength and rutting resistance amongst all fillers and composite. It signifies a 25.1% increase in ITS, a 17.6% increase in Marshall stability, and a 28.3% increase in TSR. Replacement of 75%RHA + 25%CKD was noted to be the second best-performing blend in terms of moisture stability and susceptibility. However, it violated limits specifications in terms of VMA and VFA for the binder course.

The study demonstrated that additional higher content, more than 50% of RHA in composite, decreases voids filled with asphalt, which did not meet standard specifications for the surface layer of the binder course. VFA is inversely related to air voids and VMA. This is observed when the RHA proportion increases, and VFA decreases. This is attributed to the overall percentage of filler employed.

In summary, the use of Cement Kiln Dust (CKD) as waste and composite filler offers an effective solution for asphalt mixes with enhanced engineering performance in a manner that is both cost-effective and environmentally sustainable. To further understand the interaction of filler type and composite as well as interaction with virgin asphalt and aged binder, the authors are recommended to examine viscoelastic properties and mechanical performances of asphalt mastic.

Funding Statement

This research was funded by the African Union through the Pan African University Institute for Basic Sciences, Technology and Innovation (PAUSTI).

Acknowledgments

The researchers would like to acknowledge the Materials Testing and Research Division of Kenya's Ministry of Roads for the provision of technical support and providing the requisite test equipment.

References

[1] Daniel A. Hoornweg, and Perinaz Bhada-Tata, *What a Waste: A Global Review of Solid Waste Management*, World Bank, Washington, DC, 2012. [Google Scholar] [Publisher Link]

[2] Jayvant Choudhary, Brind Kumar, and Ankit Gupta, "Utilization of Waste Glass Powder and Glass Composite Fillers in Asphalt Pavements," *Advances in Civil Engineering*, vol. 2021, pp. 1-17, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[3] Chui-Te Chiu, Tseng-Hsing Hsu, and Wan-Fa Yang, "Life Cycle Assessment on Using Recycled Materials for Rehabilitating Asphalt Pavements," *Resources, Conservation and Recycling*, vol. 52, no. 3, pp. 545-556, 2008. [CrossRef] [Google Scholar] [Publisher Link]

[4] K. Vislavičius, and H. Sivilevičius, "Effect of Reclaimed Asphalt Pavement Gradation Variation on the Homogeneity of Recycled Hot-Mix Asphalt," *Archives of Civil and Mechanical Engineering*, vol. 13, pp. 345-353, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[5] Imad L. Al-Qadi et al., *Impact of High RAP Content on Structural and Performance Properties of Asphalt Mixtures*, Illinois Center for Transportation, 2012. [Google Scholar] [Publisher Link]

[6] Audrey Copeland, *Reclaimed Asphalt Pavement in Asphalt Mixtures: State of the Practice*, Federal Highway Administration, Office of Research, Development and Technology, Turner-Fairbank Highway Research Center, pp. 1-49, 2011. [Google Scholar] [Publisher Link]

[7] Tiruwork Mulatu, Biruk Yigezu, and Anteneh Geremew, "Study on the Suitability of Reclaimed Asphalt Pavement Aggregate (RAPA) in Hot Mix Asphalt Production," *Journal of Engineering Research*, vol. 11, no. 2, pp. 167-186, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[8] Jie Gao et al., "Effect of Hot Mixing Duration on Blending, Performance, and Environmental Impact of Central Plant Recycled Asphalt Mixture," *Buildings*, vol. 12, no. 7, pp. 1-24, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[9] M. Arabani, and A.R. Azarhoosh, "The Effect of Recycled Concrete Aggregate and Steel Slag on the Dynamic Properties of Asphalt Mixtures," *Construction and Building Materials*, vol. 35, pp. 1-7, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[10] Ambika Kuity, Sandhya Jayaprakasan, and Animesh Das, "Laboratory Investigation on Volume Proportioning Scheme of Mineral Fillers in Asphalt Mixture," *Construction and Building Materials*, vol. 68, pp. 637-643, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[11] Jayvant Choudhary, Brind Kumar, and Ankit Gupta, "Application of Waste Materials as Fillers in Bituminous Mixes," *Waste Management*, vol. 78, pp. 417-425, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[12] Rajan Choudhary, Abhinay Kumar, and Ghazali Rahman, "Rheological and Mechanical Properties of Bauxite Residue as Hot Mix Asphalt Filler," *International Journal of Pavement Research and Technology*, vol. 12, pp. 623-631, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[13] Min Ju Choi et al., "Performance Evaluation of the Use of Tire-Derived Fuel Fly Ash as Mineral Filler in Hot Mix Asphalt Concrete," *Journal of Traffic and Transportation Engineering*, vol. 7, no. 2, pp. 249-258, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[14] Muhammad Sarir et al., "Performance Evaluation of Asphalt Concrete Mixtures Using Bagasse Ash as Filler," *Iranian Journal of Science and Technology, Transactions of Civil Engineering*, vol. 46, pp. 1553-1570, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[15] Gaurang Asthana et al., "Experimental Investigation of Waste Glass Powder as Filler in Asphalt Concrete Mixes," *Recent Developments in Waste Management*, vol. 57, pp. 261-270, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[16] Mohammad Naser et al., "Improving the Mechanical Properties of Recycled Asphalt Pavement Mixtures Using Steel Slag and Silica Fume as a Filler," *Buildings*, vol. 13, no. 1, pp. 1-16, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[17] Abhijit Mondal, and G.D. Ransinchung R.N., "Evaluating the Engineering Properties of Asphalt Mixtures Containing RAP Aggregates Incorporating Different Wastes as Fillers and their Effects on the Ageing Susceptibility," *Cleaner Waste Systems*, vol. 3, pp. 1-13, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[18] Amir Modarres, and Morteza Rahmanzadeh, "Application of Coal Waste Powder as Filler in Hot Mix Asphalt," *Construction and Building Materials*, vol. 66, pp. 476-483, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[19] Zhenyang Fan et al., "Effects of Cement-Mineral Filler on Asphalt Mixture Performance under Different Aging Procedures," *Applied Sciences*, vol. 9, no. 18, pp. 1-5, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[20] Esraa R. Al-gurah, and Basim H. Al-Humeidawi, "Investigation the Effect of Different Types of Mineral Fillers on Mechanical Properties of Hot Mix Asphalt," *Journal of Physics: Conference Series*, vol. 1895, pp. 1-12, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[21] Ahmet Beycioğlu et al., "Use of GRP Pipe Waste Powder as a Filler Replacement in Hot-Mix Asphalt," *Materials*, vol. 13, no. 20, pp. 1-15, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[22] Anmar Dulaimi et al., "A Sustainable Cold Mix Asphalt Mixture Comprising Paper Sludge Ash and Cement Kiln Dust," *Sustainability*, vol. 14, no. 16, pp. 1-15, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[23] Amir Modarres, Hossein Ramyar, and Pooyan Ayar, "Effect of Cement Kiln Dust on the Low-Temperature Durability and Fatigue Life of Hot Mix Asphalt," *Cold Regions Science and Technology*, vol. 110, pp. 59-66, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[24] *Road Design Manual for Roads and Bridges, Road Design Manual: Part 3 Materials & New Pavement Design*, Kenya Ministry of Roads and Public Works, pp. 1-323, 2016. [Publisher Link]

[25] ASTM D2172-05, *Standard Test Methods for Quantitative Extraction of Bitumen From Bituminous Paving Mixtures*, American Society for Testing and Materials, pp. 1-3, 2010. [CrossRef] [Google Scholar] [Publisher Link]

[26] ASTM D6926-20, *Standard Practice for Preparation of Asphalt Mixture Specimens Using Marshall Apparatus*, American Society for Testing and Materials, pp. 1-8, 2020. [CrossRef] [Publisher Link]

[27] Jiangfeng Wu, Linbing Wang, and Lingjian Meng, "Analysis of Mineral Composition and Microstructure of Gravel Aggregate Based on XRD and SEM," *Road Materials and Pavement Design*, vol. 18, no. 3, pp. 139-148, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[28] Konstantin Sobolev et al., "The Effect of Fly Ash on the Rheological Properties of Bituminous Materials," *Fuel*, vol. 116, pp. 471-477, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[29] ASTM D422-63, *Standard Test Method for Particle-Size Analysis of Soils*, American Society for Testing and Materials, pp. 1-8, 2007. [CrossRef] [Google Scholar] [Publisher Link]

[30] I Idorenyin Ndarake Usanga, Fidelis Onyebuchi Okafor, and Chijioke Christopher Ikeagwuani, "Investigation of the Performance of Hot Mix Asphalt Enhanced with Calcined Marl Dust Used as Fillers," *International Journal of Pavement Research and Technology*, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[31] Jinxuan Hu et al., "Research on Moisture Stability of Asphalt Mixtures with Three Solid Waste Fillers," *Materials*, vol. 16, no. 23, pp. 1-23, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[32] Yu Chen et al., "Role of Mineral Filler in Asphalt Mixture," *Road Materials and Pavement Design*, vol. 23, no. 2, pp. 247-286, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[33] Abbas Al-Hdabi, "Laboratory Investigation on the Properties of Asphalt Concrete Mixture with Rice Husk Ash as filler," *Construction and Building Materials*, vol. 126, pp. 544-551, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[34] Marko Oreskovic, Stefan Trifunovic, and Goran Mladenovic, "Use of Hydrated Lime and Cement Bypass Dust as Alternative Fillers in Hot Mix Asphalt," *Proceedings/17th Colloquium Asphalt, Bitumen and Pavements, Bled*, pp. 65-75, 2019. [Google Scholar] [Publisher Link]

[35] Seyed Amid Tahami, Mahyar Arabani, and Ali Foroutan Mirhosseini, "Usage of Two Biomass Ashes as Filler in Hot Mix Asphalt," *Construction and Building Materials*, vol. 170, pp. 547-556, 2018. [CrossRef] [Google Scholar] [Publisher Link]