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Research Article

Performance Evaluation of Hospital Waste Ash-Modified Asphalt Mixtures

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Using waste materials in road construction is a sustainable technique that will promote waste reduction, a cleaner environment, cost savings in road construction projects, and serve as an alternative material. This study evaluated the performance of hospital waste ash (HWA) modified asphalt mixtures. The modified asphalt mixtures were produced using HWA as mineral filler at 0%–100% at an interval of 10% by weight. The performance of the mixtures was evaluated with the Marshall, Cantabro, and retained strength index (RSI) tests. The Marshall parameters indicate that the modified asphalt mixtures met the General Specification for Roads and Bridges of Nigeria with satisfactory results. Except for mixes prepared with 90% and 100%, HWA-modified mixtures fulfill the RSI and Cantabro durability requirement at up to 80% filler content. However, to ensure the optimum performance of the HWA-modified asphalt mixtures, a 40% HWA is recommended.

1. Introduction

A greater variety of hazardous and nonbiodegradable solid wastes are being produced and released into the environment due to urbanization, industry, and infrastructure development [1, 2]. Large amounts of waste are building up in stockpiles and landfills, creating costly disposal issues on both a financial and environmental levels. These wastes are brought on by a growth in industrialization and population, with hospital waste having a substantial value.

Hospital operations produce a lot of waste and byproducts that can influence the environment and human health, even while saving lives and protecting and restoring health [3]. These wastes comprise sharps, nonsharps, blood, body parts, chemicals, medications, medical equipment, and radioactive substances, of which 20% of it is hazardous stuff, which may be infectious, poisonous, or radioactive, and 80% of it is general waste [4, 5].

Hence, these wastes must be properly managed because exposure to them can cause illnesses like AIDS, cholera, typhoid, hepatitis, and other viral infections through sharps contaminated with blood. It can also cause asthma, hormonally triggered cancers, infertility, mutagenicity, genital deformities, dermatitis, and neurological disorders in children.

Addressing the issue of waste disposal, which is becoming increasingly problematic, takes cooperation and dedication from all parties involved. Recycling and utilizing these materials to construct pavement surfaces is one approach to solving waste disposal issues [6]. Byproducts can be used to build road pavements that perform better and are more environmentally friendly than traditional materials [1]. Furthermore, a significant amount of money every year is spent on road construction; this serves as the finest

Table 1: Properties of the bitumen.

Parameters	Value	Standard (FMWHM, 2013)
Penetration (mm)	63	60–70
Softening (°C)	57.3	Min 45
Ductility (cm)	89	Min 75
Viscosity (Pa·s)	115.3	Min 100
Flashpoint (°C)	274.3	Min 200
Fire point (°C)	303.7	Min 240
Specific gravity	0.97	
Loss on heating (%)	0.86	

illustration of a situation in which other materials might be employed. In addition to lowering the amount of garbage that needs to be disposed of using waste materials in road building or pavement can result in significant cost savings compared to using new resources. Also, using these materials can add value to what was formerly an expensive disposal issue. According to Dimulescu and Burlacu [7], reusing diverse waste products and byproducts in place of still-expensive new resources is a more appealing approach from an economic standpoint. Reusing different waste products also benefits the environment because it frees up space for permitted landfills and deposits, which promotes resource efficiency. Hence, using waste in asphalt mixtures would lead to environmentally friendly and long-lasting pavement construction, improving smart cities' overall sustainability and getting them closer to reaching SDG-11 [8, 9].

Many wastes and byproducts are available that could be utilized in pavement construction. These wastes include waste glass, polyethylene terephthalate trash, ceramic tiles, cement kiln dust, blast furnace slag, steel slags, gypsum, cassava peel, and pulverized fuel ash [10–13]. For instance, Dimulescu and Burlacu [7] evaluated industrial waste powders used as fillers in asphalt mixture. The results showed that adding wastes to asphaltic mixtures during manufacture may benefit the environment, the waste management industry, and the construction sector.

The study's findings, as mentioned above, support the use of waste materials in pavement construction. As a result, this study aims to examine hospital waste as fillers in asphalt mixtures, with limestone filler as the control. The acceptability of the waste materials for the creation of asphalt mixtures was assessed using the Marshall properties of the asphalt mixtures, and its durability was determined using the abrasion loss and retained strength index (RSI).

2. Materials and Methods

2.1. Materials

2.1.1. Bitumen. Bitumen utilized in this investigation came from the local Omu-Ara, Kwara State, Nigeria, market. Additionally, for this investigation, 60/70 pen-grade bitumen was used. Table 1 displays the bitumen's properties.

2.1.2. Aggregates. The aggregate type utilized was granite (as coarse aggregate) and quarry dust (as fine aggregate), taken from a quarry site in Omu-Aran, Kwara State. The aggregates used were in dry condition. The properties of the aggregates and the gradation for the blend used are presented in Figure 1 and Table 2, respectively.

2.1.3. Hospital Waste Ash (HWA). The HWA finer than 150 μm (shown in Figure 2) was used. It was obtained from the incineration of hospital waste from the Federal Medical Center, *Ido*, Nigeria. The material composition of HWA is shown in Table 3.

2.2. Samples Preparation and Testing. Stone dust and HWA were used as filler in 1,200 g of different aggregates preheated to a temperature between 160 and 178°C. The chosen bitumen content was melted at 150°C. The bitumen and aggregates were thoroughly mixed in the steel bowl at a mixing temperature of about 185°C. Seventy-five blows were applied to each face of the sample to compact the mixture in the fore-heat Marshall mold. By substituting HWA for filler (stone dust) in quantities ranging from 0% to 100% at intervals of 10%, samples of asphalt mixtures were produced (see Figure 3). The Marshall properties, such as stability, flow, air void, void in mineral aggregate, void filled with bitumen and bulk density, were carried out to determine the optimum bitumen content (OBC). Using the compacted mixtures at OBC, the durability properties (RSI and abrasion loss) were determined.

The RSI was conducted in accordance with ASTM D 1075 [14]. The specimens were divided into two portions to condition the samples before the test. While the other portion is left at room temperature, one is kept in a water bath at 60°C for 24 hr. Following the curing days, a simple compression force is applied to both specimens, with a continuous deformation speed of 5.08 mm/min, until they break. The RSI was calculated using Equation (1):

$$\mathrm{RSI} = \frac{S_1}{S_2} \times 100\%, \qquad (1)$$

where RSI is the retained strength index, S_1 is the standard Marshall stability with a soaking time of 30 min at a temperature of 60°C, and S_2 is the Marshall stability after immersion at a temperature of 60°C.

According to AASHTO TP108-14 [15], the weight loss of the mixes was measured using the cantabro loss test. The specimen was weighed to determine its weight before being subjected to abrasion and placed into the Los Angeles machine drum (W_1). After that, a drum without a steel ball in it was used in the Los Angeles machine. Then, up to 300 bullets are fired through the Los Angeles machine at 30–33 rpm rates. The specimen is retrieved after completion and weighed (W_2) following abrasion. Equation (2) was used to compute the Cantabro abrasion loss.

$$\text{Cantabro loss}\ (\%) = \frac{(W_1 - W_2)}{W_1} \times 100, \qquad (2)$$

where W_1 is the initial weight of the sample (g) and W_2 is the final weight of the sample (g).

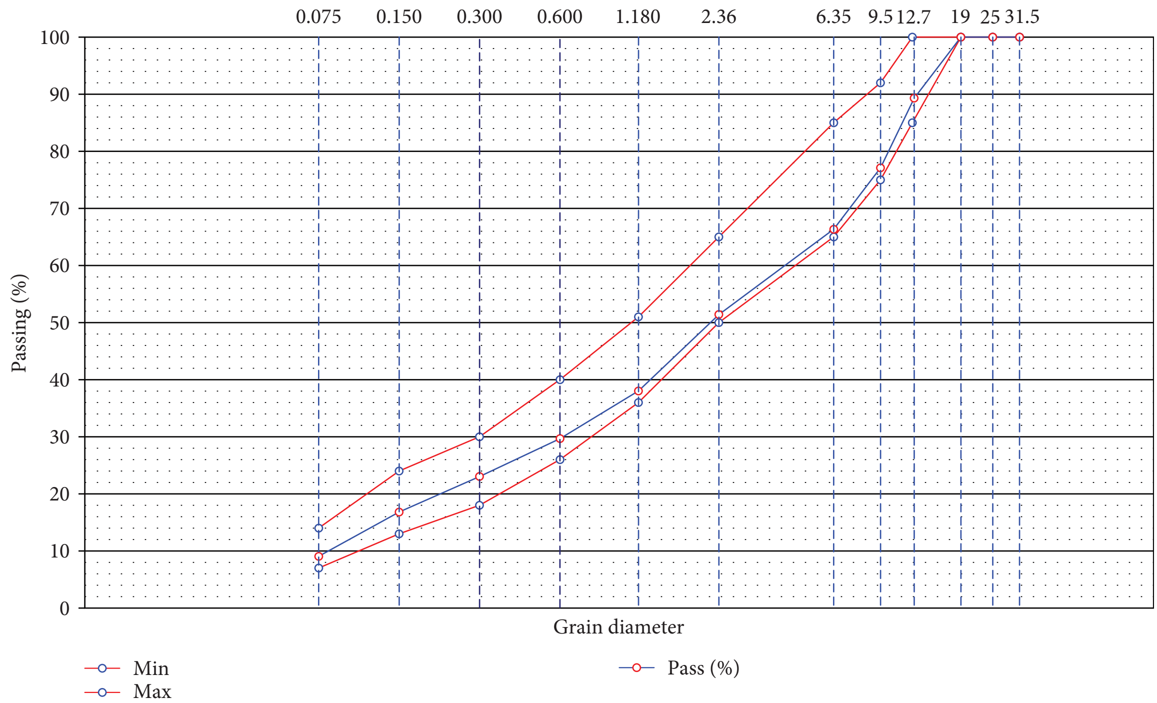

FIGURE 1: Aggregate gradation for the asphalt mixtures.

TABLE 2: Aggregate properties.

Test	Value	Standard (FMWHM, 2013)
Elongation index	29.53%	30% maximum
Aggregate impact test	15.9%	30% maximum
Abrasion test	47.45%	60% maximum
Flakiness index	28.62%	30% maximum
Aggregate crushing test	44.93%	45% maximum
Density	1,840 kg/m^3	
Specific gravity	2.84	3 maximum

FIGURE 2: Hospital waste ash (HWA).

TABLE 3: Properties of HWA.

Compound	Content (%)
SiO_2	5.71
Al_2O_3	3.08
Fe_2O_3	6.40
CaO	67.10
Cl	6.61
ZnO	1.69
K_2O	2.54
MnO	0.15
P_2O_5	0.26
TiO_2	2.18
SO_3	3.19
LOI	6.2
Specific gravity	2.52

FIGURE 3: Samples of HWA-modified asphalt mixtures.

3. Results and Discussion

3.1. Marshall Properties of HWA Modified Asphalt Mixtures Stability. The Marshall method takes a comprehensive approach to designing the asphalt pavement mix. It can

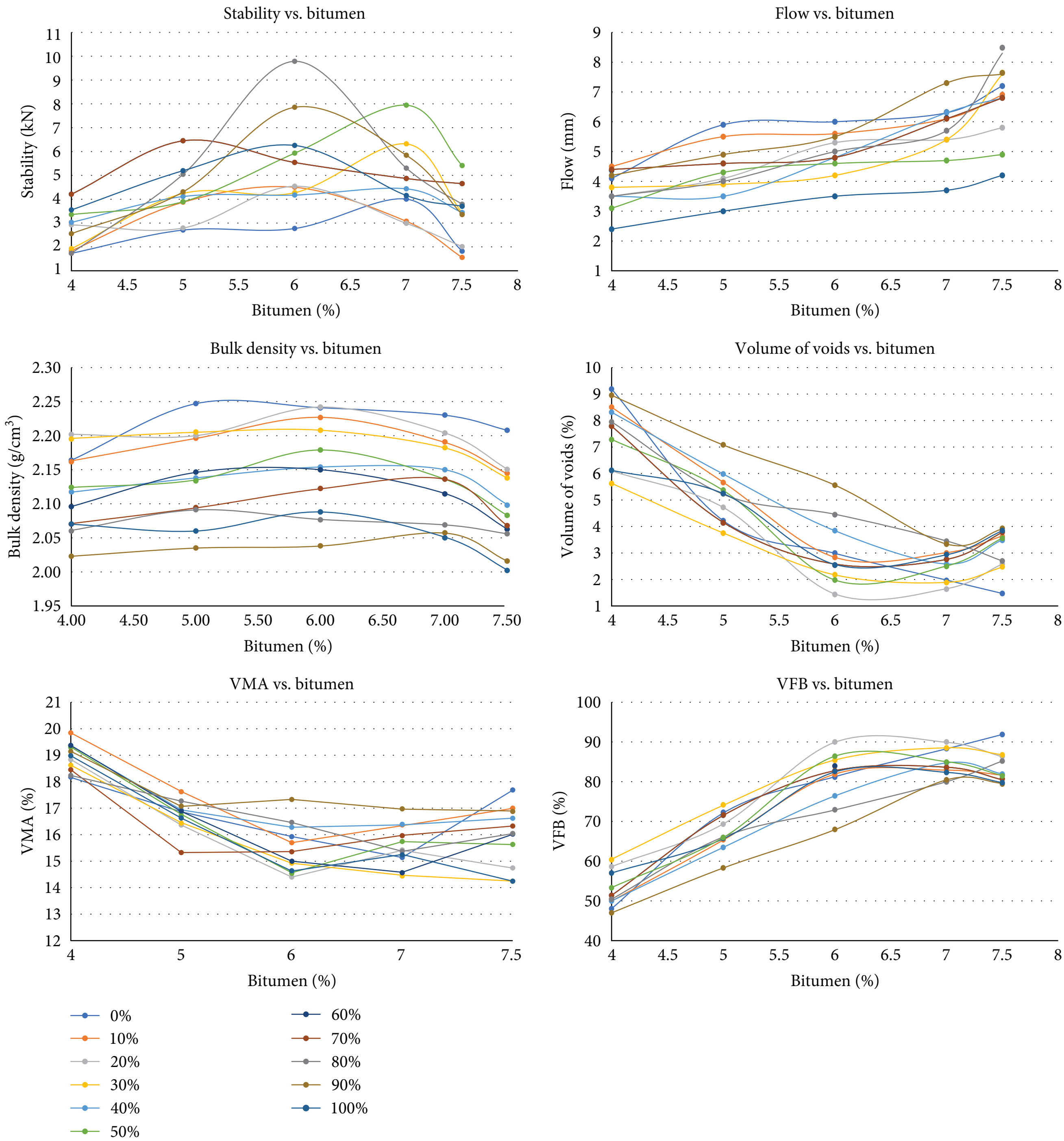

Figure 4: Marshall properties of HWA-modified asphalt mixtures at different bitumen content.

determine the optimal asphalt content for a mix that will offer the greatest stability for its load through a series of steps. The Marshall selects the ideal asphalt content that will give the mix the most stability while deforming the least under axle loads. The Marshall properties of the asphalt mixtures produced are presented in Figure 4. It was observed from the result that there are variations in the values for all the properties. However, the maximum stability and flow of 9.78 kN and 8.3 mm, respectively, with bitumen content of 6%, are observed at the 80% HWA replacement level.

The OBC technique is performed for each filler content replacement since the change in filler content may alter the OBC [1]. The OBC of the various mix proportions is shown in Figure 4. It was determined using the maximum stability, bulk density, and percent air void at 4%, which is in the middle of the standard's suggested minimum and maximum

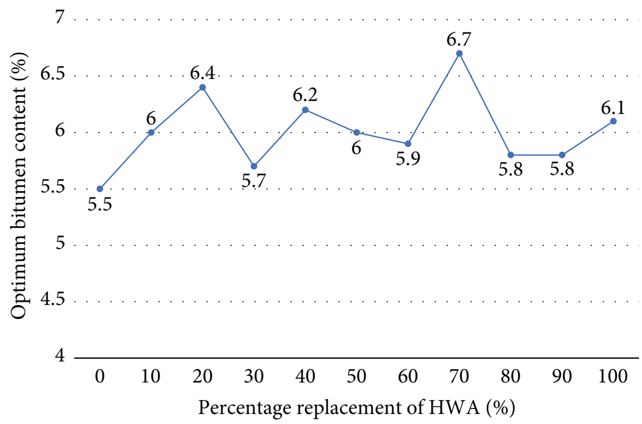

Figure 5: Effects of HWA on the OBC-modified asphalt mixtures.

Table 4: Marshall properties of HWA-modified asphalt mixtures at OBC.

HWA (%)	Stability (kN)	Flow (mm)	MQ (kN/mm)	Bulk density (g/cm^3)	Vv (%)	VMA (%)	VFB (%)
0	9.545	2.7	3.5	2.238	3.576	16.593	78.449
10	11.225	2.4	4.7	2.181	5.009	18.140	72.387
20	11.865	2.6	4.6	2.150	5.743	18.467	68.901
30	14.209	3.3	4.3	2.183	3.279	16.644	80.299
40	15.823	2.4	6.6	2.160	3.139	17.025	81.562
50	12.628	2.2	5.7	2.089	5.901	18.904	68.784
60	12.500	2.8	4.5	2.104	5.481	17.074	67.899
70	10.002	3.6	2.8	2.141	2.103	15.430	86.371
80	9.677	3.1	3.1	2.099	3.716	16.139	76.975
90	8.554	3.9	2.2	2.046	4.526	18.096	74.989
100	7.845	2.5	3.1	2.064	3.955	16.171	75.543
Requirements (FGN, 2013)	3 (min)	2–4			3–5	15 (min)	70–85

values of 3% and 5%. Figure 5 shows that the OBC of the control mix, which contains no HWA, is 5.5%. Also, there is a variation in the OBC as the proportion of HWA in the mix increases. Furthermore, the mix containing 70% of HWA shows the highest consumption of OBC compared to that of the control, while the lowest OBC of 5.7% was obtained at 30% HWA content. The variance in OBC may be attributed to the filler content alone because the aggregate gradation, sources, and binder type are the same in all the mixtures [16].

3.2. Effects of HWA on the Marshall Properties of Modified Asphalt Mixtures. Strong contact points cannot be produced, and a dense layer cannot be formed in HMA when an insufficient filler is utilized [1]. Hence, the amount of filler should be considered carefully. Table 4 displays the influence of HWA proportions on the Marshall characteristics of HMA correlating to OBC. The control mix's Marshall stability value is 9.55 kN. Furthermore, while the stability increases to 15.823 kN when the HWA percentage increases from 10% to 40%, the stability value declines when the HWA content increases further.

Regarding flow values, the highest and lowest values are 3.9 and 2.2 mm, corresponding to HWA content of 90% and 50%, respectively. However, all the created mixes are within the permitted 2–4 mm flow value range for a wearing course [17]. It can be concluded that HWA up to 40% increases the Marshall stability of the mixture while there is a variation in the flow value. According to Moghaddam et al. [18], the Marshall stability of asphalt concrete measures how well it can withstand shoving and rutting under traffic. In contrast, the Marshall flow measures its ability to withstand gradual settlements and movements in the subgrade without cracking. As a result, the higher stability and lower flow are crucial criteria for the Marshall test [19]. Therefore, the Marshall quotient (MQ) may easily explain the nature of the Marshall test results.

The MQ is characterized as the ratio of stability (kN) to flow (mm) and as a hint of the stiffness of mixes [16, 20]. With the help of this value, you may calculate how resistant a material is to rutting, permanent deformation, and shear forces. Table 4 shows that the mixtures with 40% HWA exhibited the highest MQ, corresponding to an 88.57% increase compared to the control. This increase in MQ is due to the gained stability while the flow is still low; the more the flow, the less the strength [21].

Percent air void is the crucial factor influencing asphalt mixtures' performance [22]. Enough air space must be allowed to increase compaction under traffic loading in the compacted mix. Taking the Nigerian specification of 3%–5%

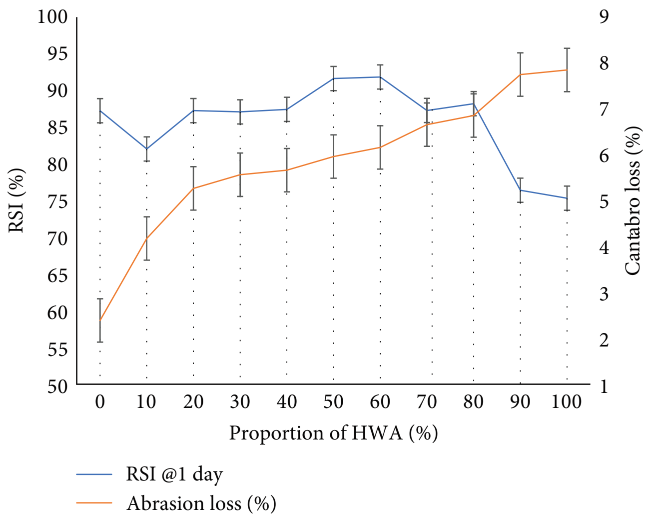

Figure 6: Effects of HWA on the durability properties of the modified asphalt mixtures.

air void into account, HWA-modified mixtures of HWA-10 (5.01%), HWA-20 (5.74%), HWA-50 (5.9%), and HWA-60 (5.48%) is higher than the recommended limits. Therefore, these HWA contents will consume more bitumen, which increases the overall cost of the mix [22] and negatively affects the bituminous mixture's compactability and workability properties.

The void space in the bituminous-filled mineral aggregate is the volume filled with bitumen (VFB). According to Dhir et al. [23], this measure, related to VMA, air voids, and effective bitumen content (the amount not absorbed by aggregates), defines the richness of a bituminous bound mix. The results of the VFB of the HWA-modified asphalt mixtures, as observed in Table 3, show that only mixtures with VFB values of 72.387%, 80.299%, 81,562%, 76.975%, 74.989%, and 75.543% for HWA contents of 10%, 30%, 40%, 80%, 90%, and 100%, respectively, are within the recommended value of 70%–85% VFB.

3.3. Effects of HWA on the Durability Properties. The pavement layer's capacity to maintain its original characteristics under the impact of weather and traffic during road service is known as durability. For an extended duration under a specific level of traffic loading, the components in asphalt pavement construction should endure environmental factors such as water, temperature changes, and aging without significantly degrading [24]. The RSI was performed to find the strength of asphalt mixtures containing HWA after 24 hr of immersion in water at 60°C. In this test, the less durable the pavement is, the lower the index value [25, 26]. The effect of the HWA on the asphalt mixture durability is shown in Figure 6. An examination of RSI values for the 24 hr immersion period of the samples showed values greater than 80% for the mixtures except for 90 and 100% HWA-modified mixtures. Also, it can be seen that the value of the RSI decreases at 10% HWA and afterward increases up to 80% HWA-modified asphalt mixtures. A 5.30% increase over the control (87.53%) was seen in the RSI value of the modified asphalt mixtures at 60% HWA (92.17%), which was the highest of all the combinations under study. So, based on the results of this experiment, it would appear that adding 60% HWA to modified asphalt mixes significantly increases the mixtures' ability to resist moisture.

The pavement surface must meet the essential condition of durability. Therefore, the loss of particles on the pavement surface when subjected to an abrasive load must be as minimal as possible for structural reliability [13, 27]. A compacted bituminous specimen's ability to resist abrasion is measured by the Cantabro loss, represented as a percentage of weight loss [28]. The mixture's resistance to ravelling improves with decreasing Cantabro loss and vice versa [8]. Figure 6 depicts HWA's effects on the Cantabro value of the modified asphalt mixtures. It can be seen that the Cantabro value increases with increasing HWA contents. Hence, the HWA mixture displays a poor performance against raveling. However, the HWA mixtures up to 80% of HWA content are less than the balanced mix design (BMD) Cantabro mass loss threshold of 7.5%. Hence, the HWA mixtures with up to 80% of HWA content meet the BMD durability criteria. Also, study by Usman et al. [28] observed increased Canatbro loss with rising palm oil fuel ash content.

4. Conclusions

In this study, the Marshall and durability characteristics of modified asphalt mixtures were examined in relation to using HWA as filler in varied quantities. These inferences were made in light of the experimental findings:

(1) The HWA-modified asphalt mixtures' volumetric and Marshall parameters meet the minimum standards in Nigeria's General Specification for Roads and Bridges.
(2) The modified asphalt mixtures with 40% HWA content performed best among substitution levels.
(3) HWA-modified asphalt mixtures displayed a satisfying moisture susceptibility performance. HWA mixes fulfill the minimum requirement of RSI at filler content up to 80%.
(4) The HWA-modified mixture's resistance against raveling decreased with the HWA contents. However, HWA mixtures with up to 80% of HWA content meet the BMD durability criteria.

It could be said that utilizing HWA in asphalt mixtures could be an efficient solution for the eco-friendly disposal of HWA and a step toward sustainability in asphalt mixtures.

The influence of HWA on the fatigue and rutting properties of asphalt mixtures should be examined for future research.

Data Availability

All the data used to support the findings of the study are included in the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Oguntayo, Ogundipe, and Aransiola conceived of the presented idea. All authors contributed for sourcing of the materials. Oguntayo, Aladegboye, and Aransiola performed the experiment. Ogundipe and Ogunkunbi performed the computations. Ogunayo, Ogunkunbi, and Babatunde discussed the results and contributed to the final manuscript.

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