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Research Article

Potential Use of Reclaimed Asphalt Pavement Aggregate and Waste Plastic Bottles for Sustainable Asphalt Pavement Production

Tibebu Birega[1], **Anteneh Geremew**[2] and **Mekonnen Nigatu**[1]

[1]*Faculty of Civil Engineering, Arba Minch University, Arba Minch, Ethiopia*
[2]*Faculty of Civil and Environmental Engineering, Jimma University, Jimma, Ethiopia*

Correspondence should be addressed to Anteneh Geremew; anteneh.gerdi@ju.edu.et

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The main objective of this study was to evaluate the potential use of reclaimed asphalt pavement aggregate (RAPA) and waste plastic bottles (WPBs) for sustainable asphalt pavements production in hot weather conditions. To enhance the adhesion between neat bitumen, RAPA, and WPBs-coated aggregates, a rougher surface texture is created for aggregate particles in the modified asphalt mix. This improvement enhances asphalt mix engineering properties, rutting resistance, and stability. However, bituminous mixtures containing 20% RAPA exhibit tendencies toward strip resistance, this mixture is weak in terms of strength and incapable of supporting loads when utilizing the RAPA. Therefore, due to the moisture susceptibility of the RAPA, it is advised to employ several types of aggregates in future studies to determine the optimal aggregate that can resist stripping and, at the same time, handle heavy loads. Finally, for better asphalt mix performance, it is recommended to use a combination of 70% crushed stone aggregate, 20% RAPA, and 10% WPBs in asphalt mix with a 5.0% optimum modifier content. The experimental results for tensile strength ratio, proportional rut depth, and mean rut depth meet the required specifications of the Ethiopian Road Authority for all properties tested. Therefore, this combination is strongly advised for use in hot mix asphalt production.

1. Introduction

Road construction is one of the largest worldwide sector; however, urbanization and industrialization are accelerating infrastructure development, leading to increased trash disposal and a severe shortage of building materials [1]. This depletion of natural resources is causing environmental consequences and global CO_2 emissions [2]. Furthermore, the dramatic rise in the price of virgin materials and the dwindling resources for road construction, pose additional challenges [3, 4]. In this study, the aim is to enhance the volumetric qualities of asphalt mixtures by utilizing reclaimed asphalt pavement aggregate (RAPA) and waste plastic bottles (WPBs) for bitumen modification. This approach aims to improve pavement performance and address associated issues. Although Pakistan has emerged as one of the world's leading road-building nations, many of its roads are deteriorating or approaching the end of their useful lives [3]. In Ethiopia, traditional disposal practices involve sacrificing old asphalt layers by discarding them as garbage instead of replacing them with new asphalt [5]. WPB and RAPA are increasingly employed for pavement rehabilitation worldwide. The primary focus of this research is on the popularity, effectiveness, and chemical compatibility of aggregate additives with RAPA and WPB.

In the early 1970s, RAPA was initially incorporated into asphalt mixes at a 3% addition to crushed stone aggregate (CSA). Over time, larger percentages were permitted and increased to 30% or even 50% [6], driven by rising binder costs. In Europe, countries such as Sweden, Germany, Denmark, and the Netherlands each utilize approximately 0.84, 7.30, 0.53, and roughly 0.12 million tons of RAPA [7]. The use of RAPA is acknowledged as a sustainable choice, as it conserves resources, reduces costs, diminishes aggregate disposal in landfills, minimizes the need for coarse aggregate (CA) and binder, and saves energy. To achieve these benefits, transportation authorities globally began incorporating between 20% and 50% RAPA in hot mix asphalt (HMA) mixtures, with some HMA pavements even reaching up to 80% RAP [8]. Ethiopia, experiencing a 10.9% economic development between 2004 and 2015, has recently allocated 3% of its gross domestic product to road projects, with a significant portion of these investments directed toward the reconstruction, expansion, and modernization of existing highways [5]. Despite this, RAPA aggregate in the country still holds significant untapped potential and is not widely utilized in surface, base, and sub-base courses. Therefore, RAPA with 10%, 20%, and 30% can serve as suitable substitutes for CSA, offering a way to navigate restrictions while meeting standards. RAPA and WPB are frequently employed in the construction of new asphalt concrete pavements due to their financial and environmental advantages.

The addition of WPBs enhances asphalt's resistance to temperature variations and helps prevent rutting compared to standard blends [9]. Additionally, a waste plastic modifier was introduced into the asphalt mixture to improve its resistance to moisture degradation, thereby extending its useful life [10]. The incorporation of WPB blends demonstrated significant improvements in the performance of the asphalt mixture, reducing cracking, stiffening mixes at high temperatures, minimizing rutting, improving blend quality, enhancing oxidation resistance, and reducing asphalt thickness and life costs. The study conducted by Lim et al. [3] and Hayat et al. [4] evaluated varying properties of aggregate, asphalt, and asphalt blend, including different percentages (0%, 2%, 4%, 6%, and 8% by weight of asphalt). In this particular research, seven distinct WPB concentrations were tested at 2%, 4%, 6%, 8%, 10%, 12%, and 14% by weight of asphalt, respectively. The study concluded that adding 10% WPB to the material constituted a modification.

RAPA and WPB in bituminous mixes enhance durability and resistance to deformation and water-induced damage, contributing to user satisfaction and accident reduction [1]. Additionally, they are utilized to reduce the amount of bitumen and aggregate required for a high-quality asphalt mixture [11]. WPB materials are produced through a series of steps, including collecting WPB from various garbage locations, packing, removing semiparticles, washing, drying, shredding, screening, and blending with CSA and RAPA. This process is designed to meet performance requirements and improve the stability, strength, and other desired properties of bituminous mixes in small quantities. As a result, the utilization of WPB and RAPA addresses the significant issue of WPB and RAP disposal in Arba Minch.

Several studies have revealed that pavements using RAPA fared comparably to those using standard combinations. Utilizing these hazardous and nonbiodegradable wastes as a binder can help minimize environmental issues caused by improper WPBs and RAPA disposal, as well as reduce the need for mining asphalt pavement materials for road construction. Depending on their physical properties, they can serve as aggregate substitutes, aggregate coatings, or binder modifiers in the asphalt mix, thereby enhancing the performance of modified asphalt mixtures [12–15]. This study evaluates the combination of CSA, WPB, and RAPA, specifically assessing the effects of adding 4%–6% CSA, 10%–30% RAPA, and 2%–14% WPB as an aggregate cover. The objective is to provide an experimental performance evaluation of HMA concrete incorporating RAPA and WPB. In measuring moisture susceptibility in compacted asphalt mixes, while the Marshall stability test is relatively simple to conduct, the modified Lottman test, and the Hamburg wheel track test proved to be more accurate [16]. Therefore, this study assesses the in situ mix's Marshall Mix design, moisture susceptibility, indirect tensile strength (ITS), and rutting. The findings indicate that as modifier content increases, ductility, specific gravity, and penetration decrease, while the softening point increases. Additionally, with a 20% RAPA and 10% WPB substitution, the experimental tensile strength ratio, proportionate rut depth, and mean rut depth were 80.17, 5.72%, and 2.86 mm, respectively.

1.1. Statement of the Problem. In Arba Minch, there is an excessive amount of solid waste, primarily composed of reclaimed asphalt pavement (RAP) and WPBs scattered in catchments, gorges, ditches, bridges, etc. However, Ethiopia has yet to utilize recycled WPB and RAPA in this manner, despite facing environmental consequences and making a sustainable scientific solution for such identified problems. Moreover, the price of virgin aggregate materials in Ethiopia is rising steeply, currently exceeding 177.92$ for 40.4 tonnes. The severe scarcity of building materials is exacerbated by factors such as the distance from the quarry site, infrastructure development, and the escalating cost of Virginia aggregate materials.

Ethiopia has observed an increase in pavement distress in recent years, attributed to rising traffic volumes. Heavy truck traffic, overloading, and observable daily and seasonal changes in pavement temperature are all contributing factors to the emergence of distress in bituminous surfaces, including raveling, undulations, rutting, cracking, bleeding, shoving, and potholes. Although periodic and routine repairs have been undertaken to mitigate the problem, the issue persists, and distress continues to manifest.

The study aims to assess the feasibility of incorporating WPB and RAPA to enhance the performance of asphalt mixes. Laboratory assessments are conducted to create HMA under hot weather conditions. Virginia aggregate, commonly used globally in building projects, exhibits low affinity for bitumen and limited aggregate-to-aggregate interaction properties, resulting in asphalt mixtures with lower strength and stiffness. This research investigates the effects of using RAPA and WPB as aggregate in the asphalt binder under local conditions in Arba Minch across a wide range of temperatures.

2. Materials and Methods Used

2.1. Materials. To get the information, nonprobable purposive sampling techniques were used.

(i) Crushed stone aggregate (coarse and fine).

(ii) Bitumen (60/70 penetration grade).

(iii) Mineral filler (crushed stone dust).

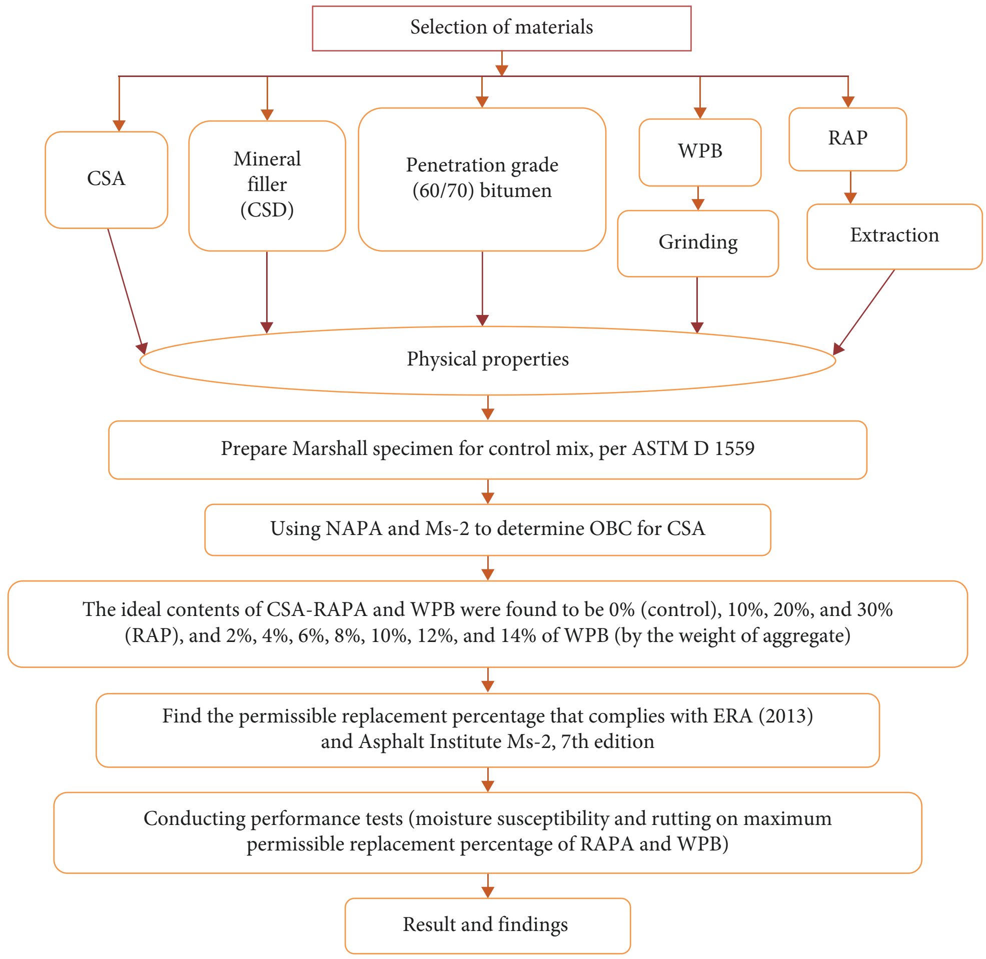

Figure 1: Flowchart for experimental work.

(iv) Reclaimed asphalt pavement aggregate (extracted coarse and fine).

(v) WPBs (ground various mineral water plastic bottles)—polyethylene terephthalate (PET).

2.2. Study Design. To determine the compatibility of recycled WPB and RAPA in the production of HMA to achieve the study's purpose, an experimental type design was employed for this research project, as shown in Figure 1.

2.3. Standards and Requirements for the Study. To evaluate the engineering properties of the materials used in this study, there are a lot of tests were conducted by standard specifications requirement, including those presented in Tables 1–4.

3. Results and Discussion

3.1. Aggregate Quality and Physical Property Test Result. The detailed physical characteristics of CSA, RAPA, and WPB and their suitability for road construction are investigated as per the standard requirements. The materials used in this study fulfill the requirement as per ERA specifications. The size distribution of aggregate due to sieve analysis, the maximum aggregate size of 100% of the sample must pass on 25 mm sieve size and 0% retained. The nominal maximum aggregate sieve size through which the majority of the sample passes (up to 15% can be retained) is 19 mm sieve size passed was 96.25 and retained was 3.75. In this study, CSA, (6%) of CSD, (10%, 20%, and 30%) of RAPA, and (2%, 4%, 6%, 8%, 10%, 12%, and 14%) WPB for fine aggregate were used. The result obtained is compared with standards and materials of CSA with RAPA and WPB, RAPA with WPB. The physical characteristics of RAPA and the crashed stone aggregate's compared, the RAP has the lowest values for water absorption, bulk specific gravity, bulk specific gravity (SSD basis), theoretical specific gravity, and the highest Los Angeles abrasion value. The physical characteristics of WPB and the crashed stone aggregate's compared, the WPB has the lowest values for moisture content, bulk specific gravity, bulk specific gravity, compacted weight, and loss weight of coarse aggregate. Additionally, the aggregate crushing value is higher (ACV). As a result, it is comparable to RAPA and difficult to obtain such values standardized grinding machine, shape, character, and size of WPB.

3.2. Bitumen Quality Test Result. In this study, a series of bitumen quality and performance tests were conducted as shown Bitumen properties such as specific gravity 1.02, ductility 143.6,

Table 1: The physical characteristics of CSA's, RAPA's, and WPB's quality tests and methods.

Material	Test conducted	Test method
RAPA	Centrifugal centrifuge extraction	AASHTO T164/ASTM D2172
WPB	Grinding	—
The aggregate test for crushed stone aggregates and RAPA	Water absorption value (%)	AASHTO T 85
	Moisture content	AASHTO T 85
	Lose weight from coarse aggregate	ASTM C-337
	Aggregate crushing value (ACV) (%)	BS 812, Part 110
	Aggregate impact value (AIV) (%)	BS 812, Part 112
	Los Angeles abrasion value (%)	AASHTO T 96
	Compacted weight of coarse aggregate	ASTM C-337
Crushed stone aggregate, RAPA, and WPB aggregate testing	Gmb of coarse aggregate	AASHTO T 85
	Gmb coarse aggregate (SSD basis)	AASHTO T 85
	Gmm of coarse aggregate	AASHTO T209
	Blending	ASTMD 3515

Gmb, bulk specific gravity; Gmm, maximum theoretical specific gravity.

Table 2: Bitumen test and methods.

Material	Test conducted	Test method
Penetration (0.01 mm)	Penetration (0.01 mm)	ASTM D5-06
Ductility (cm)	Ductility (cm)	ASTM D113-86
Softening point (°C)	Softening point (°C)	ASTM D36-2002
Flashpoint (°C)	Flashpoint (°C)	ASTM D92-02
Fire point (°C)	Fire point (°C)	ASTM D92-90
Specific gravity (g/cm)	Specific gravity (g/cm)	ASTM D70

Table 3: Methods for testing mineral filler materials.

Material	Test conducted	Test method
Filler	Specific gravity	ASTM D-854
	Plasticity index (PI)	ASTM D-4318
	Graduation	ASTM D-242

Table 4: Performance tests for control and modified mix.

Test conducted	Test method
TSR	AASHTO T 283
Rutting test	AASHTO TP 63

flashpoint 279.3, fire point 284.5, and softening point 48.4 satisfy standard specifications.

3.3. Crushed Stone Dust (CSD) Mineral Filler Properties. From the physical characteristics, it is observed that CSD is a gray color fine aggregate consisting of medium to fine sand-size particles and of angular shape with rough surface texture. The detailed experimental results are shown in Table 5.

3.4. Analysis of Asphalt Mixture Properties

3.4.1. Marshall Test Result of Conventional Asphalt Mix. The CSA was in charge of replacing RAPA and WPB. Since bitumen content values are shown in Table 6, all figures used in this study to calculate bitumen content were drawn at the fourth order of magnitude.

The asphalt mix rises with bitumen content, peaking at 5% with a stability of 10.9 kN before progressively declining at higher bitumen content. The flow of asphalt mix decreases as the bitumen percentage rises until it reaches 3 mm at 4.35% bitumen content, at a point where it starts to gradually incline. The bulk density value increased with increasing bitumen content up to a particular 2.63 gm/cc at a bitumen concentration of 4.95%, and then gradually decreased with increasing bitumen content. The value of air void (VA) was 3.7% with 6% bitumen, and it lowers as the bitumen content of the asphalt mix increases due to an increase in the proportion of voids filled with asphalt (VFB) content. Bitumen content decreases as more VFB, reaching a value of void in mineral aggregate (VMA) 14.05% with 4.8% of bitumen, and then increases as the bitumen content of an asphalt mix rises. With increasing bitumen composition, VFB content progressively rises and can exceed standards from 5.7 to 6.

3.4.2. Determination of Optimum Bitumen Content (OBC) for Convectional Asphalt Mix (0% RAPA and 0% WPB). The maximum stability, the highest value of bulk density, the median authorized percentage of VA and allowed percentage of VFB, and the average of these values (NAPA) method used, the OBC is 5.1 for CSA.

3.4.3. Effect of Adding RAPA on the Mechanical Properties of Asphalt Mix. Examining 10 levels of RAPA generates 15 samples at OBC to investigate the impact of adding RAPA to asphalt mixture samples and the mechanical properties of various RAPA% in asphalt mixes, i.e., in experimental testing on asphalt mixtures, five different bitumen content—4%, 4.5%, 5%, 5.5%, and 6%—were employed to achieve this goal. Three Marshall mixtures were developed for the amount of asphalt. For Marshall, the appropriate bitumen content of each tested mix was determined by conducting stability and flow tests in compliance with ASTM recommendations [17].

Table 5: Physical properties of filler material (CSD).

S./no.	Test description	Test method	Result	ERA 2002
1	Apparent specific gravity (kg/m^3)	ASTM D-854	2.783	N/A
2	Plasticity index (PI)	ASTM D-423	NP	≤4
3	Percentage of passing 0.6 mm sieve	ASTM D-242	100	100
4	Percentage of passing 0.3 mm sieve	ASTM D-242	97.8	95–100
5	Percentage of passing 0.075 mm sieve	ASTM D-242	91.2	70–100

Table 6: Marshall properties test results of asphalt mixes with 6.0% mineral filler.

Binder content (%)	Stability (kN)	Flow 0.01 (mm)	Gmb (gm/cc)	Gmm (%)	VA (%)	VMA (%)	VFB (%)
4	9.13	3.67	2.41	2.53	5.07	15.8	67.7
4.5	10	3.33	2.48	2.6	4.45	13.7	67.8
5	11.2	3	2.47	2.65	4.12	14.4	71.4
5.5	10.23	3.83	2.45	2.56	3.99	15.4	74
6	8.6	4.33	2.42	2.52	3.8	17	77.6
Average	9.83	3.63	2.45	2.45	4.2	15.3	71.7

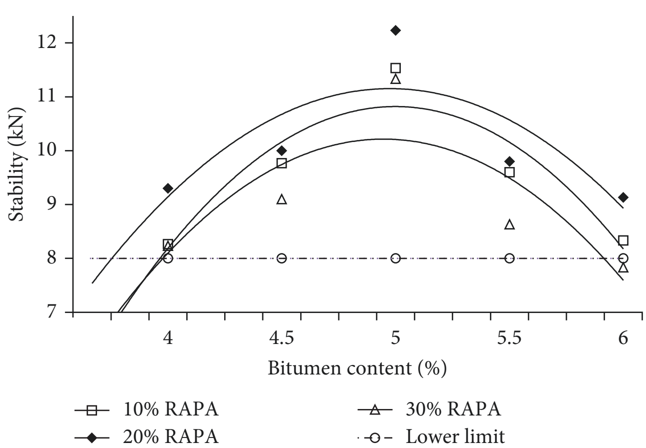

Figure 2: Stability—RAPA vs. bitumen content (%) relationship.

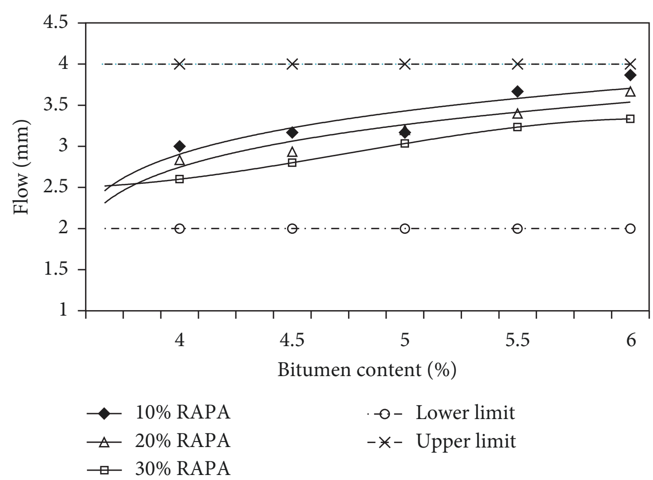

Figure 3: Flow—RAPA vs. bitumen content (%) relationship.

3.4.4. Relationship between RAPA Content and Stability. Using higher RAP content increased the stability and, more importantly, reduced the asphalt content. This finding agrees well with the literature that concludes as the RAPA contents of a mix increase, the ability to resist loads also increases [17]. With the stability of 7.5 kN at 2% and 10.8 kN at 5% bitumen concentration, as illustrated in Figure 2 depicts the stability, which increases with the addition of 10% RAPA content. The stability content was 7.5 and 7.9 kN for 20% RAPA concentration, and 10.2 kN for 30% RAPA content. While 30% RAPA content equals 9.2 kN at 4.5% and bitumen content is 11.1 kN at 5.5%, 20% RAPA content equals 10.2 kN at 4.5%.

3.4.5. Relationship between Flow and RAPA Content. With an increase in the asphalt cement ratio, mixes with the same RAP content showed higher flow values. Furthermore, flow values fall as RAPA percentages rise but stability improves [17]. The flow of HMA serves as a gauge for its ability to withstand long-term vertical deformation. Low flow values may suggest a mix has more voids and insufficient asphalt binder, which makes a crack mixture brittle. High flow values, on the other hand, show that the mix contains a high amount of asphalt binder that fills all voids and affects the resistance to permanent deformation under traffic [5]. The flow of the RAPA partially replaced content is higher than the flow of the CSA mix and the flow rises steadily over time. The results of the experiments show that they plummeted to the bottom as the RAPA concentration increased from 10% to 20%, but rose to the top when it reached 30%. This was not always the case, especially at 30% RAPA replacement, where the mix took on a new character and increased the flow content to a greater extent as a result of the considerable amount of substitution, as shown in Figure 3.

3.4.6. Relationship between Bulk Density (Gmb) and RAPA Content. Following its volume-based batching, the bulk density of aggregates is the mass of aggregates needed to fill a container with a certain volume. In bulk density, it is the

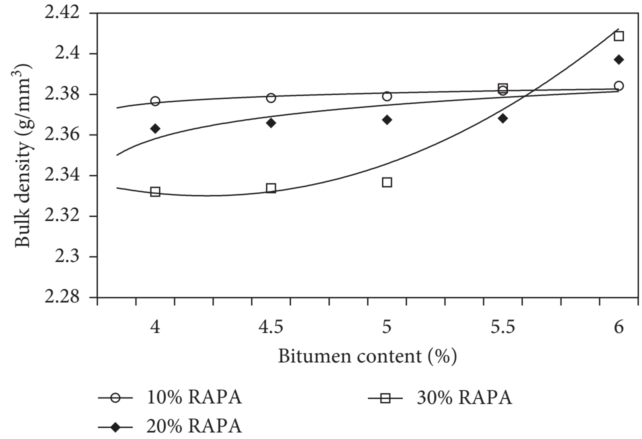

Figure 4: Bulk densities—RAPA vs. bitumen content (%) relationship.

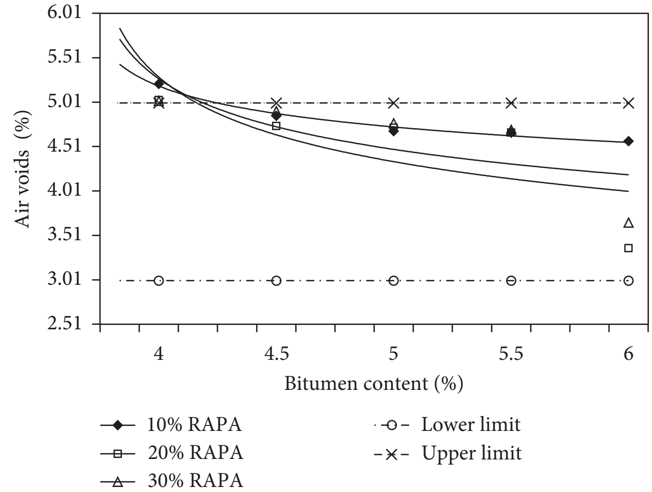

Figure 5: Air voids (VA)—RAPA vs. bitumen content (%) relationship.

quantity of the combined material volume of aggregate particles that have spaces between them. There exist multiple techniques to ascertain the bulk density (Gmb) of RAP. Nevertheless, there has not been a definitive suggestion for identifying this attribute [18]. In this study, asphalt mixes with known aggregate properties were produced and tested in the laboratory to simulate RAPA. The Gmb normally declines with increasing RAPA concentrations of 10%, 20%, and 30%, and the highest bulk density (2.44, 2.43, and 2.42) has a 6% RAPA, whilst the lowest Gmb (2.4 and 2.38) has a 2% RAPA. This was not always the case, especially at 30% RAPA replacement, where a different aspect of the mix led to the GMB content increasing once more as a result of the significant quantity of substitution, as shown in Figure 4.

3.4.7. Relationship between Air Void (VA) and RAPA Content. The bitumen content is too high; the compaction mixture might be too easily, moreover resulting in low air voids. When the bitumen content is too low, the compact of a mixture may be stiff and difficult to the specified density. Asphalt pavements are constructed with initial air voids of 6%–8% depending on the type of mixture and pavement layer. Asphalt mixtures have high air void content during construction, it is expected to reduce and this densification can be considered as a predominant cause of rutting during initial periods of traffic. Due to air void reduction, the material becomes stiffer leading to increased rut resistance. Such an increase could also be attributed to the age hardening of the material. Inadequate compaction is one of the leading causes of early deterioration and failure of these pavements [19]. The VA requirement for all combinations may be satisfied between 4.3% and 6.0% of bitumen content, as shown in Figure 5.

3.4.8. Relationship between Void in Mineral Aggregate (VMA) and RAPA Content. The term "voids in mineral aggregate" (VMA) refers to the space where bitumen may sufficiently cover each aggregate particle within a compacted mix. Balanced mix design is a combination of volumetric design and performance testing made possible by the growing usage of recycled materials. Air voids and voids in mineral aggregate (VMA) are now achieved through a labor-intensive, time-consuming, and resource-intensive trial-and-error procedure

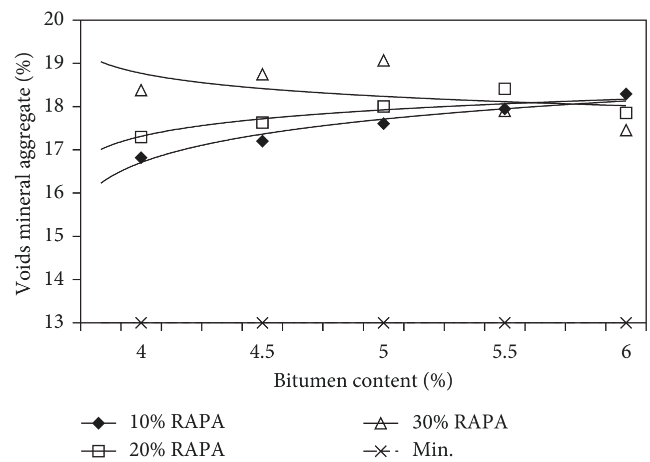

Figure 6: VMA (%)—RAPA vs. bitumen content (%) relationship.

to meet the volumetric stage of specifications. With varying degrees of success, earlier studies explored several techniques to achieve ideal volumetric values. Furthermore, previous research has not examined the impact of recycled asphalt pavement (RAP) or recycled asphalt shingles (RAS), particularly in high RAP/RAS designs [20]. When the VMA% of modified asphalt mixes is higher than that of conventional asphalt mixes, their VMA% decreases as the RAPA content increases until it reaches %, as shown in the RAPA content percent graph in Figure 6. The VMA% of modified asphalt mixes increases as the RAPA content increases. The graph of %RAPA content versus VMA% shows that the VMA% of modified asphalt mixes is higher than the VMA% of convectional asphalt mixes, as illustrated in Figure 6.

3.4.9. Relationship between Volumes of Voids Filled with Bitumen (VFB) vs. RAPA Content. Two functions of mineral filler, an essential component of asphalt mixture, are to fill the pores between fine- and coarse-grained aggregate and to structure bitumen. Mineral filler is crucial for maintaining the quality of asphalt mixtures [21]. The void filled with

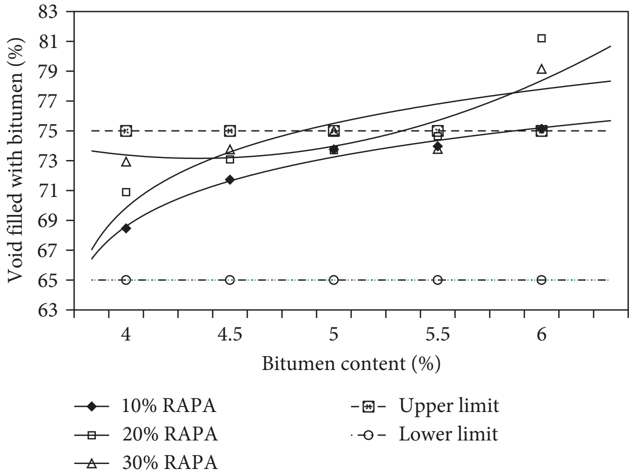

Figure 7: VFB (%)—RAPA vs. bitumen content (%) relationship.

bitumen (VFB) is the volume of void space between the particles in the aggregate that the effective bitumen occupies [22]. The void filled with bitumen increases as the percentage replacement of RAPA increases. This is because the particles of RAPA take up the effective bitumen, thereby increasing it. The VMA% of modified asphalt mixes increases as the RAPA content increases. The graph of %RAPA content versus VMA% shows that the VMA% of modified asphalt mixes is higher than the VMA% of traditional asphalt mixes, as illustrated in Figure 7.

3.4.10. Optimum Modifier Content. The National Asphalt Pavement Association (NAPA) specifies the ideal bitumen content for each RAPA proportion. The bitumen content is equal to the specification's median air void content, which is usually 4%. This is the ideal bitumen concentration. Next, the values for Marshall stability, VMA, flow, bulk density, and percent voids filled from each plot are calculated using the bitumen content. The ideal bitumen content is found at 4% air voids; compare each of these values to the standard values for that property to see if they are all within the range. The mixing needs to be redone if any of these characteristics fall outside of the specified range. Table 7 shows that the OBC produced a set of control results that offer the best mechanical qualities for an asphalt mixture on RAPA might lessen the need for bitumen of 20%RAPA in minimal OBC but its limitations, RAPA's value can be negligible. OBC values in 10% RAP and 30% were 5.3, whereas they were 5.1 in 20%.

3.4.11. Comparison of the Control and RAPA Mixes. It is possible that the aged asphalt in the used RAP aggregate material influenced the amounts of asphalt cement required for the mixes containing higher RAP concentrations to be closer to their ideal values. Furthermore, the decrease in the ideal values may be associated with a fall in the effective bitumen's content, which will finally result in a 4% air void content [12]. The findings of the experimental tests demonstrated that substituting RAPA for CSA had an impact on the hot asphalt mixes' mechanical properties, particularly their volumetric qualities. The study looked into three distinct replacement percentages: 10%, 20%, and 30% of the mixtures' total weight. The mixtures contain reclaimed asphalt pavement aggregate as shown in Table 8. To determine the appropriate RAPA concentration and the minimum and maximum allowable limits for the mechanical properties of the RAPA-modified asphalt mix. Enhanced stability and stiffness compared to a regular asphalt mix and benefit from a customized mix with adjustable parameters.

Table 8 shows that the modified asphalt mix 5.1% and 5.3% RAPA by OBC meet the ERA standards and have better flow, stability, and VFB than the CSA mix. While having nearly identical Gmb and a higher proportion of VA and VMA than the CSA, the revised asphalt mix shows a slight increase in flow and VA. RAPA gives aggregate particles in modified asphalt mix a rougher surface finish, boosting the asphalt mix's engineering properties.

3.4.12. Effect of Adding WPB on the Mechanical Properties of Asphalt Mix. To define the OBC of the control and modified asphalt concretes the standard process known as NAPA was chosen. The bitumen content that corresponds to 4% air void is the OBC in all specimen types. The OBC set allowable values for the other Marshall parameters, which were regulated for all varieties of asphalt concrete [23]. The effect of adding WPB on the mechanical properties of asphalt mix was found that 21 samples were prepared at OBC using seven different proportions of WPB so that the impact of adding WPB to asphalt mixture samples to evaluate their mechanical properties was assessed.

3.4.13. Effect of Waste Plastic on Marshall Stability. The results showed that the addition of WPB increased the Marshall quotient in the modified asphalt concrete and that the values of Marshall stability for all specimens were higher than the minimum value, with the exception of the specimen containing 50% untreated recycled concrete aggregate [23]. In this study, bitumen's content from Figure 8, how the inclusion of WPB can increase the stability of the mixture while larger replacement levels can occasionally make it worse. In studies, it was discovered that when the WPB content was raised from 6%, 10%, and 12%, the mix outperformed other mixes with the same WPB percentage. Things were not always as they are now; when WPB was replaced with 12%, the mixture had an unexpected characteristic that increased stability because there was a considerable amount of substitution going on.

3.4.14. Effect of Waste Plastic on Flow. The test results of the WPB grew from 6% to 8% and 12% to 10% and 14%, respectively, this shows that they had dropped to the bottom of other mixes from the top. However, this was not always the case, particularly at 10% and 14% WPB substitution where the mix showed a different personality that caused the flow to change, as shown in Figure 9.

3.4.15. Effect of WPB on Bulk Density. Plastic can reduce the weight of conventional concrete by 2.0%–6.0%, according to concrete, a rise in the proportion of plastic that when the amount of plastic particles in bulk concrete increases, the density of the concrete decreases [24]. In this study, Figure 10 shows how WPB content affects the Gmb of compacted mixes. When WPB is added to mixes with total aggregate

Table 7: OBC of HMA consisting of different percentages of RAPA.

Property	10% RAPA	20% RAPA	30% RAPA	ERA (1998)		Asphalt Institute (1997)		Remark
OBC (%)	5.25	5.13	5.25	Min.	Max.	Min.	Max.	Comply
Stability (kN)	9.5	10.1	9.03	8	—	8.17	—	Comply
Flow (mm)	3.37	3.2	3	2	4	2	3.5	Comply
Bulk density	2.38	2.37	2.4	—	—	2.3	—	Comply
Air voids (%)	4.79	4.5	4.6	—	—	3	5	Comply
VMA (%)	17.57	17.8	18.3	13	—	13	—	Comply
VFB (%)	72.6	74.7	74.9	65	75	—	—	Comply

Table 8: Comparison of RAPA-modified asphalt mix and conventional mix properly.

Property	Normal mix	10% RAPA	20% RAPA	30% RAPA	Change amount			Percentage of Change amount		
					10%	20%	30%	10%	20%	30%
OBC (%)	5.1	5.25	5.13	5.25	0.15	0.03	0.15	2.86	0.58	2.857
Stability (kN)	9	9.5	9.7	9.3	0.5	0.7	0.3	5.26	7.22	3.226
Flow	3.2	3.6	3.6	3.47	0.4	0.4	0.27	11.1	11.1	7.781
Gmb	2.35	2.4	2.4	2.4	0.05	0.05	0.05	2.08	2.08	2.083
VA (%)	4.2	4.2	4.3	4.3	0	0.1	0.1	0	2.33	2.326
VMA (%)	15.8	15.9	16.7	16.6	0.1	0.9	0.8	0.63	5.39	4.819
VFB (%)	72.85	73.3	74.5	74.1	0.45	1.65	1.25	0.61	2.21	1.687

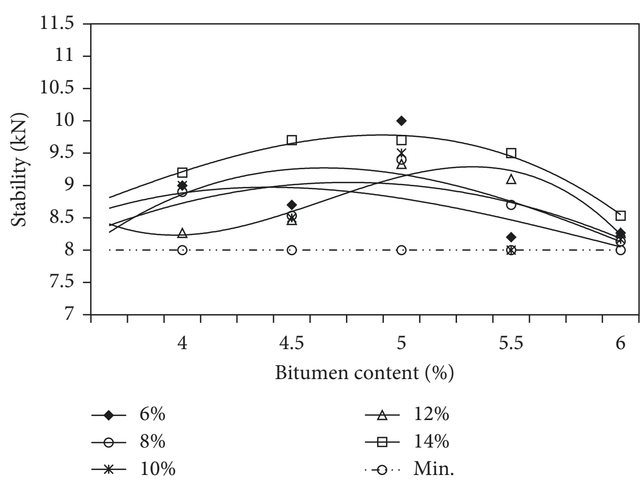

Figure 8: Effect of waste content on stability at various bitumen content (%).

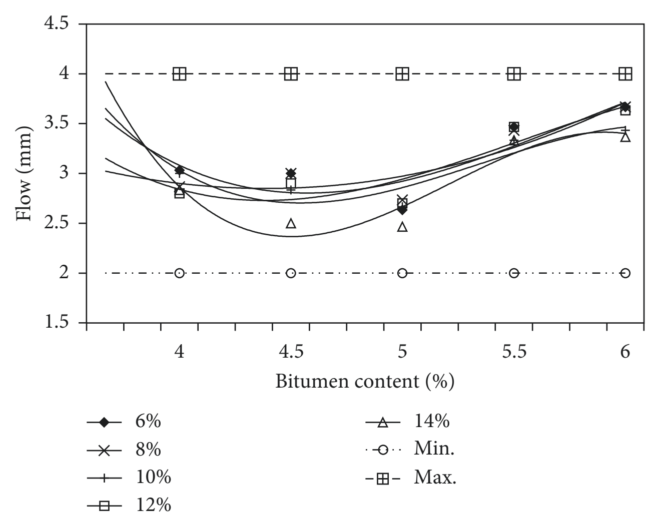

Figure 9: Effect of waste content on flow at various bitumen content (%).

concentrations between 6% and 14%, the values rise. When the waste content rose and the binder value exceeded its optimum level, the performance of asphalt was improved and all confined in some manner. There is no assurance that all WPB elements will enhance asphalt performance.

3.4.16. Effect of Waste Plastic on Air Voids (VA). Results of an air voids (VA) analysis for waste-modified bitumen and virgin bitumen the total volume, expressed as a percentage of the bulk volume of the compacted paving mixture, of the tiny air pockets that exist between the coated aggregate particles throughout the mixture. At 10% waste LDPE plastic content, the maximum VA is achieved. Compared to conventional asphalt mixtures, bitumen mixed with plastic has a stronger adhesive capacity [25]. In this study, the VA of the WPB mix decreases progressively as the waste content increases and reaches standards after 4.4%. The bitumen content ranged from 2% to 10% and 14% except for 12%, and the 12% reached standards after 4.7%. Figure 11 shows that the VA of asphalt combined with varying waste and asphalt content. These demonstrate how adding WPB and 20% RAPA to the test has improved it over time.

3.4.17. Effect of Waste Plastic on Voids in Mineral Aggregate (VMA). The same authors discovered that amounts of PET and VMA and voids in the mix (Vm) are directly correlated:

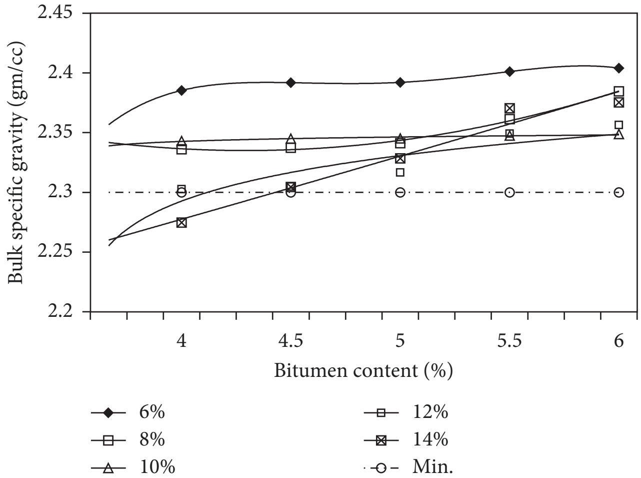

Figure 10: Effect of WPB content on unit weight various bitumen content (%).

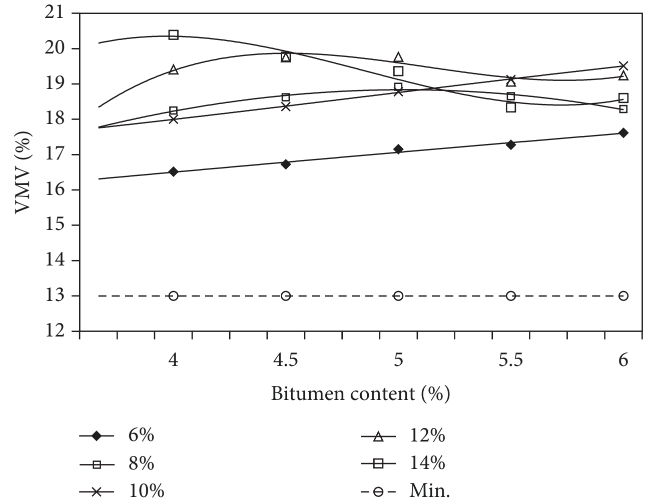

Figure 12: Effect of WPB content on VMA at bitumen content (%).

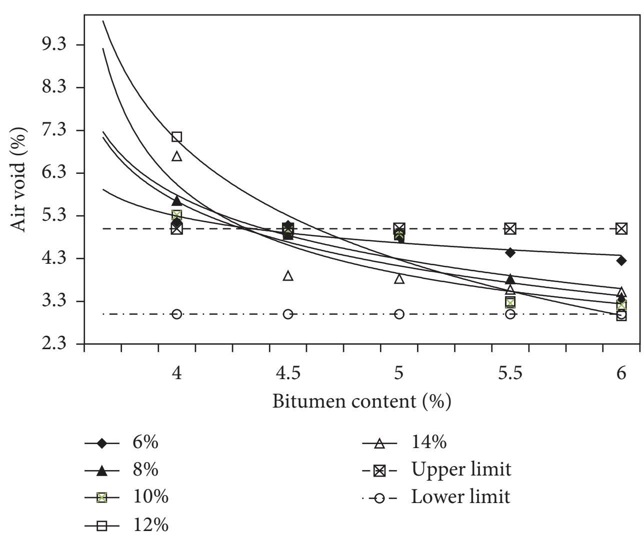

Figure 11: Effect of WPB content on air void at bitumen content (%).

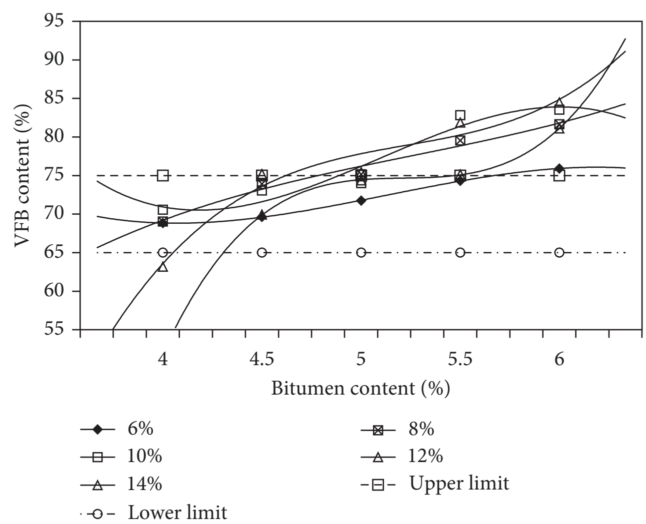

Figure 13: Effect of WPB content on VFB—bitumen content (%).

adding more than 0.3% of PET had the least impact on the VMA and 4%–6% had the greatest effect on the voids in the mix [26]. The findings of this study are shown in Figure 12, which also looks at the influence of different WPB concentrations on gaps in mineral aggregate. It demonstrates that mixtures with 12% and 14% WPB components have lower VMA and, as a result, have lower effective asphalt content at 4 and 4.5. It was discovered that mixes created with 6% and some with 8% WPB coated had higher mineral aggregate voids, resulting in mixes with higher effective asphalt contents of 4–5. Less waste plastic may have been absorbed by asphalt, which may have caused this. It can be seen from this that it is advantageous to use 9%–15% waste plastic.

3.4.18. Effect of Waste Plastic on Voids Filled with Bitumen (VFB). The maximum value of VFB is reached at 4% PET with reference to bitumen-filled voids. Conversely, it shows that the lowest value is recorded at 6% PET. Therefore, it can be concluded that the 6% PET-modified asphalt mix leads to the development of strong resistance to plastic deformation, which improves the stiffness of the mix [27]. In this study, Figure 13 illustrates how the WPB content affects the asphalt mixture's capacity to fill voids. VFB had values of greater than 40% for all WPB contents as compared to the Marshall criteria for VFB, which is 65%–75%. For mixes to last, it is essential to meet this requirement, which has to do with the mix's actual asphalt component. The mix's stiffness decreases and bleeding takes place as a result of the higher effective asphalt concentration. VFB increases together with the WPB content of the mixture. Most WPBs are decent and maintain the required minimum and maximum range.

3.4.19. Determination of Optimum Bitumen Content. A set of controls to obtain the OBC that provides the best mechanical properties in an asphalt mix. As indicated in Table 9 that the minimum OBC required for bitumen is 10% WPB can reduce the demand for it. It has several drawbacks and the worth of recycled plastic can be minimal.

Table 9: Marshall properties of bituminous mixture at OBC.

WPB (%) (by OBC)	Sample	Bitumen (%) (by OBC)	Stability (kN)	Flow (mm)	Gmb (gm/cc)	VA (%)	VMA (%)	VFB (%)
0	0	5.1	9.17	3.17	2.334	4.8	19.26	74.99
2	A	7.7	9.07	3.32	2.336	4.6	19.45	76.03
6	B	5.5	8.929	3.19	2.344	4.87	19.3	74.74
8	C	5.4	8.29	3.19	2.350	4.88	19.22	74.57
10	D	5.0	8.93	3.19	2.346	4.87	19.1	74.47
12	E	5.5	9.1	3.17	2.358	4.75	19.02	74.84
14	F	5.4	8.88	3.3	2.346	4.32	18.75	76.8
Average	—	5.7	8.91	3.22	2.345	4.73	19.16	75

Table 10: Property comparison between WPB-modified asphalt with standard mix.

Property	(Normal, 7.7, 5.5, 5.4, 5.0, and 5.5) WPB modified asphalt mix (by OBC weight)										
	Change amount						Percentage of change amount				
OBC	2.6	0.4	0.3	0.3	0.0	−0.1	33.5	6.59	6.08	0.00	−2.0	33.5
Stability (kN)	−0.7	−0.9	−1.5	−0.4	−0.9	−0.7	−7.69	−10.1	−18.1	−10.11	−7.7	−7.69
Flow (mm)	−0.3	−0.4	−0.4	−0.1	−0.1	−0.4	−9.09	−12.5	−12.5	−12.50	−12.5	−9.09
Gmb (gm/cc)	0.2	0.1	0.1	0.1	0.1	0.1	6.00	−2.17	2.08	2.08	2.08	6.00
VA (%)	0.4	0.7	0.7	0.7	0.5	0.5	8.70	14.3	14.3	14.29	10.6	8.70
VMA	3.7	3.5	3.4	3.3	3.2	3.2	19	18.13	17.7	17.28	16.8	18.9
VFB	3.2	1.9	1.8	1.7	2	2.0	4.21	2.54	2.41	2.28	2.67	4.21

Table 11: WPB modified asphalt mix properties compared to requirements.

Property	(5.0%) WPB modified asphalt mix	Specification limit			
		ERA (1998)		Asphalt Institute (1997)	
		Min.	Max.	Min.	Max.
Stability (kN)	8.9	8	—	8	—
Flow (mm)	3.2	2	4	2	3.5
Bulk density (gm/cm^3)	2.4	—	—	2.3	—
Air voids (%)	4.9	—	—	3	5
VMA (%)	19.1	15	—	13	—
VFB (%)	74.5	65	75	—	—
OBC (%)	5.4	4	8	—	—

Table 12: Comparison of WPB and RAPA modified asphalt mix properly.

Property	Change amount from 5.13 WPB						Percentage of change amount from 5.1 OBC				
	5.13	7.67	5.46	5.43	5.03	5.53					
OBC	5.13	1.87	0.47	0.57	0.27	0.67	26.7	8.39	10	5	11.55
Stability (kN)	9.7	−0.6	−0.8	−1.4	−0.8	−0.6	−6.59	−8.99	−16.9	−8.99	−6.59
Flow (mm)	3.6	−0.3	−0.4	−0.4	−0.4	−0.4	−9.09	−12.5	−12.5	−12.5	−12.5
Gmb (gm/cc)	2.4	0.9	−0.1	0	0	0	27.27	−4.35	0	0	0
VA (%)	4.3	0.3	0.6	0.6	0.6	0.4	6.52	12.2	12.2	12.2	8.511
VMA	16.7	2.8	2.6	2.5	2.4	2.3	14.4	13.5	13.0	12.6	12.11
VFB	74.5	1.5	0.2	0.1	0	0.3	1.97	0.27	0.13	0	0.401

3.4.20. Comparison of Control Mix with WPB Mix. The stability and flow test results of all modified asphalt are more valuable than unmodified asphalt. The detailed property comparison between WPB-modified asphalt with standard mix is shown in Tables 10–12.

The modified asphalt mix has a little rise in OBC, VA, VMA, and bulk density instead of 5.5% OBC and VFB, but a minor drop in flow percent, stability, and bulk density of 5.5% OBC. WPB produces a rougher surface texture for aggregate particles in a modified asphalt mix because of

Table 13: Summary stripping value test.

Test method	Test: name	Test result (%)	Recommended value (%)	Remark
AASHTO T 182-84 (CSA)	Control	93.67	≥95	Not comply
AASHTO T 182-84 (CSA + RAPA)	10% RAPA	95	≥95	Comply
	20% RAPA	94	≥95	Not comply
	30% RAPA	97.3	≥95	Comply
AASHTO T 182-84 (CSA + RAPA + WPB)	2% WPB	95.3	≥95	Comply
	4% WPB	96	≥95	Comply
	6% WPB	96.2	≥95	Comply
	8% WPB	96.7	≥95	Comply
	10% WPB	95	≥95	Comply
	12% WPB	97.7	≥95	Comply
	14% WPB	98	≥95	Comply

the improved adhesion between bitumen and WPB-coated aggregates, stability would benefit the improved asphalt mix's fatigue and rutting resistance, resulting in a more durable asphalt surface, demonstrating that the modified asphalt mix with 10% WPB satisfies all ERA requirements for all of the qualities tested.

While the Gmb, VFB, VA, and VMA of the asphalt mix changed with 7.0% WPB by OBC weight is greater, the remaining characteristics of the modified mix are still lower and within the acceptable range for the standards. The corrected asphalt mix has a slight decrease in stability, flow, and percent, and the Gmb of 5.5 WPB OBC is almost comparable in both asphalt mixes, while the Gmb of 5.4, 5.0, 5.5, and 5.4 OBC remains the same. WPB makes aggregate particles in modified asphalt mix have a rougher surface texture because bitumen and WPB-coated aggregates adhere to one another more effectively. This increases the stability, fatigue resistance, and rutting resistance of the asphalt mix, resulting in a more durable asphalt surface. Table 11 demonstrates compliance with ERA standards for the amended asphalt mix containing 10% WPB by weight of OBC.

3.5. Performance Tests

3.5.1. Effects of RAPA and WPB on Moisture Susceptibility of HMA. Effects of RAPA and WPB on HMA's moisture susceptibility evaluation of HMA's moisture damage is based on a comparison of the mixtures of various properties both before and after conditioning with moisture. The mixes' susceptibility to moisture is forecast using the TSR. In this investigation, a total of 66 samples were made with a varied percentage of 0% (control mix), 10%, 20%, and 30% (RAPA), and 2%, 4%, 6%, 8%, 10%, 12%, and 14% by weight of aggregate utilizing the optimal bitumen content of each replacement is shown in Table 13.

Using 20% RAPA and optimum chosen and basting with optimal bituminous test with Marshall stability does not satisfy the standard specification on moisture susceptibility test, so it needs improvement. According to the results of the striping value test, 20% RAPA is more susceptible to moisture damage even if water absorption rates for 10% and 30% RAPA are higher. This could be explained by the mineral makeup of RAPA or limestone, as one of its numerous minerals is quartz, which is recognized for being a mineral that is more attracted to water than asphalt. Other minerals with strong dipole moments, such as silica and silicate, are attracted to water because it is a polar molecule. However, the nonpolar nature of limestone minerals like carbonate allows them to keep their adhesive force to the bitumen binder. Which combination will be more resistant to stripping will be determined by this investigation, which is crucial. The aforementioned discussion leads to the conclusion that bituminous mixtures containing 20% RAPA show inclinations to strip more than 10% RAP, 30% RAP, CSD, and WPB. However, it has proved to be weak in terms of strength and unable to support the load when utilizing a bituminous mixture containing 20% RAPA. Therefore, it is advised to employ several types of aggregates in future studies to determine the optimal aggregate to resist stripping and at the same time handle heavy loads. Aggregates including basalt, diabase, and sandstone are stronger and more permeable than those with a 20% RAPA content.

3.5.2. Indirect Tensile Strength Test Results. For high-temperature rutting, midtemperature cracking, and moisture damage resistance characterization, respectively, mechanical tests such as wheel tracking (WTT) and ITS in dry and wet circumstances were used. The outcomes demonstrated that, with the exception of the control combination (i.e., C), the RAP-blended mixes with and without RAs generated with the OBCs could pass the rutting and moisture damage resistance criteria while their cracking resistance was below the acceptable threshold. Even though the RAP blended mixtures' cracking resistance increased when the RAs were added, RAP blends still require an increase in OBC to satisfy the required cracking resistance [28]. Finally, significant performance differences between the analyzed combinations' behaviors that were difficult to discern from ITS and ITSM tests could be observed thanks to fatigue investigations. Because of this, it is advised to incorporate fatigue testing into the mix design process along with traditional ITS processes to enhance mix optimization. While extremely helpful for characterizing the mechanical behavior of mixtures, the stiffness modulus alone cannot provide the thorough

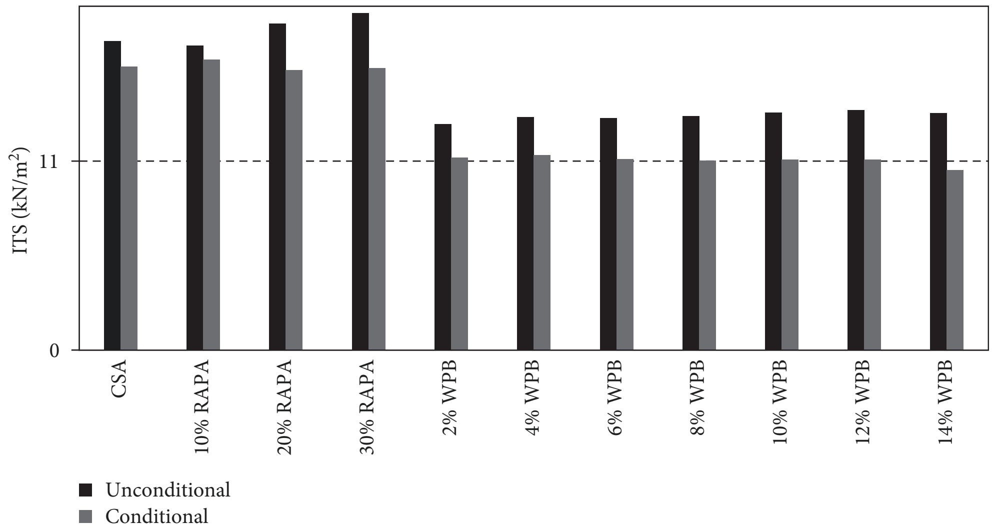

Figure 14: Unconditioned and conditioned ITS test results of percentage of CSD, RAPA, and WPB.

evaluation provided by fatigue tests [29]. The effects of adding aggregate to a standard mixture and the variations in ITS results between conditioned and unconditioned samples are shown in Figure 14. The dry and wet samples' CSA values were 18 and 16.5 kPa, respectively. For the two scenarios (conditioned and unconditioned), ITS values rise along with RAPA until they reach the ideal replacement proportion of 20%, and CSA values are larger. Results from the CSA and the mix created with replacement of 0%, 20%, and 30% were 19.2, 19.0, 18.9, 16.9, 16.3, and 16.2 kPa for the unconditioned and conditioned, respectively.

For more details on how to increase mixtures' tensile strength (conditioned and unconditioned) relative to the CSA mixture by 0%, 20%, and 30% of RAPA and 2% up to 14% of WPB by 2% increments, respectively, and how to decrease the risk of moisture by increasing the TSR relative to the CSA mixture, Figure 14 shows how the ITS values rise in both of the scenarios where RAPA and WPB increase, achieving their ideal replacement proportions of 20% and 12%, respectively, and having larger values for the CSA conditioned values were 12.1, 11.9, 11.7, 11.5, 11.3, 11.1, and 10.4 kPa.

3.5.3. Tensile Strength Ratios (TSR). The CSA has a TSR value of 91.75 kPa, the highest value, whereas the mix including 12% WPB has a TSR value of 75.73 and 85.75 kPa, respectively. Mixtures containing RAPA and WPB are much more likely to sustain moisture damage than mixes including CSA, and the risk of moisture damage rises as RAPA and WPB concentration increases. All the mixes have higher resistance than RAPA + 12 WPB and RAPA + 14 WPB, which have 79.48 and 75.73 kPa, respectively, despite the TSR values exceeding the advised standard penetration of 80%. Thus, employing RAPA and WPB together increases the tensile strength of mixes for both conditioned and unconditioned materials by 0%, 20%, and 30% of RAPA and by 2%–14% of WPB by 2% increment, respectively, compared to the CSA combination and lowering the risk of wetness by raising the TSR from the default combination to 75.73%. The excessive hardness of the modified asphalt, however, reduces the workability of the mixtures and the amount of asphalt that coats aggregate grains, making them weak and easily permeable by water, as shown in Figure 15.

The Marshall properties' performance tests for moisture susceptibility and rutting compression were conducted using the highest RAPA and WPB% possible to produce the results for Marshall stability, as shown in the ERA and MS-2, sixth edition [30]. RAPA from 0% to 30% and WPB from 0% to 10% mixed with CSA satisfied these requirements, but WPB of 12% and 14% mixed with CSA did not.

3.5.4. Rutting Test. The most important aspect of asphalt's performance is its resistance to rutting. In this study, resistance to rutting was evaluated for the control and modified mixing performance in conjunction with the Marshall stability test. A crucial instrument for determining the rutting performance of asphalt mixtures is the wheel tracking test (WTT) [31]. Predictions of rutting, fatigue, moisture susceptibility, and stripping can be made using laboratory wheel-tracking devices. These devices are used in simulative tests to measure the qualities of HMA by rolling a small loaded wheel device over a prepared HMA specimen repeatedly. The test specimen's performance is then correlated to actual in-service pavement performance. In this study, the resistance to rutting WTT was tested on CSA of the highest permissible RAPA replacement and WPB. One advantage of the truck wheel is that it can simulate the field more accurately by predicting the rutting depth at different temperatures. The ability of asphalt mixtures to resist persistent deformation at high temperatures must be evaluated in nations with warm climates, such as Arba Minch. Figure 16 displays the outcomes of every CSA laboratory test. In terms of resistance to rutting, WPB-treated asphalt with a blend of 70% CSA + 20% RAPA + 10% WPB outperformed, while a blend lagged a blend of 20% RAPA and 80% CSA. Less rut was observed when the control mix was introduced to the

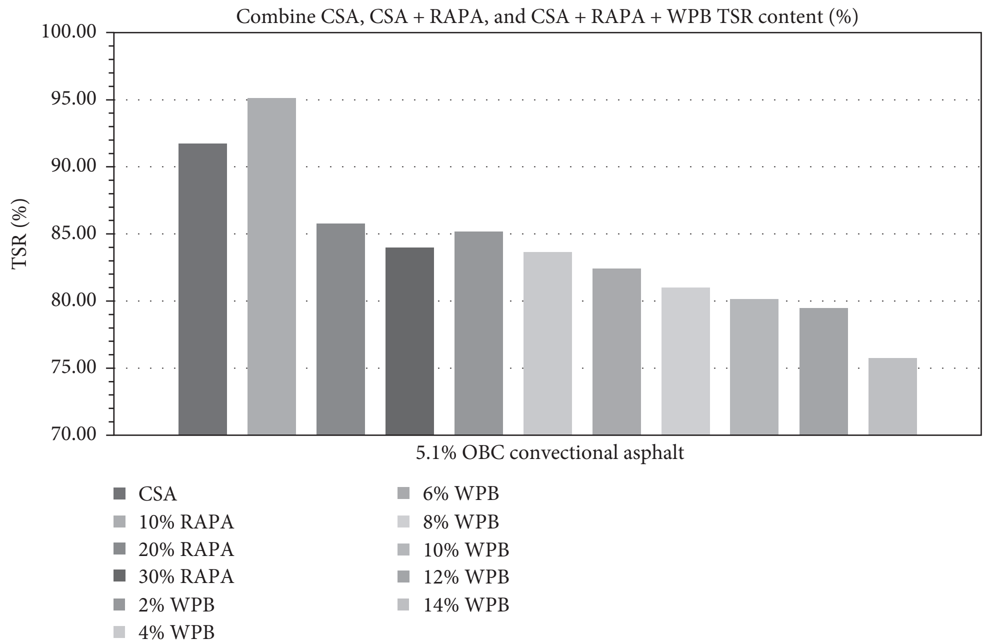

Figure 15: Combine percentage of TSR of HMA with CSA, RAPA, and WPB.

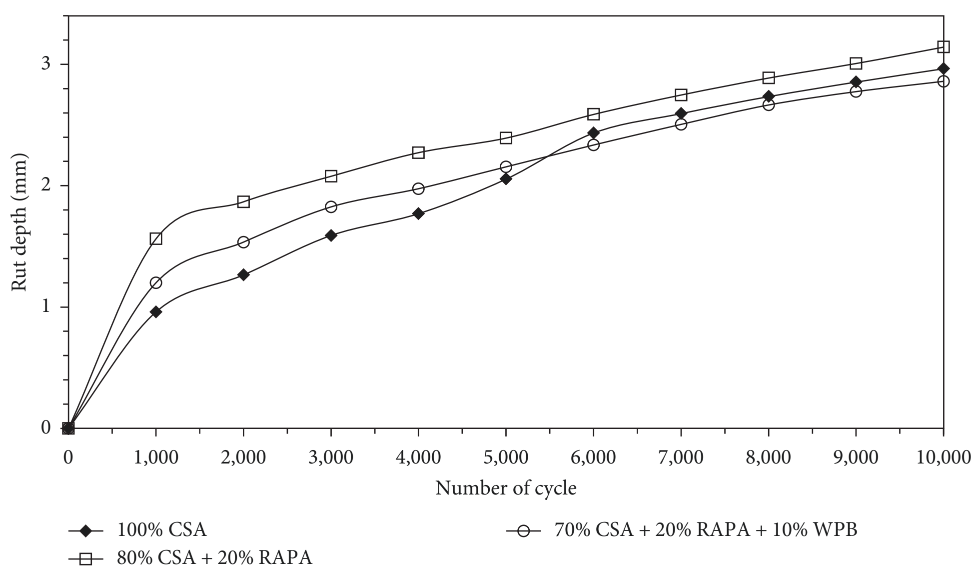

Figure 16: Results of the wheel tracking test for control, RAPA, and WPB rutting.

sample blended mix at 60°C in place of previously crushed material. However, the average rutting depth was unaltered. The diagram also demonstrated that deformation rates decrease as rutting depth rises.

(1) Comparison of CSA HMA vs. HMA with RAPA. Using a small-size instrument, proportional rut depth (PRD) is the proportionate rut depth for the material being tested at 10,000 cycles. The mean PRD of two or more specimens, rounded to ±0.1%, represents the proportionate rut depth for the material being tested at *N* cycles. Results of the wheel track test are presented as mean PRD vs. the quantity of loaded wheel passes [32–34]. PRD values show rutting resistance as control, RAPA, and WPB content in the mix increase in the examination of the results that follow. After 10,000 wheel passes, the combinations with the lower contents of control, RAPA, and WPB aggregates display the depth of the rut. The PRD values for the control group were 5.41, which was lower in the case of RAPA. RAPA's PRD readings were 2.705. These findings differed from those of past trials on the effectiveness of HMA with RAPA conducted by other researchers. However, when contrasting the PRD of the different HMA mixtures, the findings varied depending on whether CSA or aggregate modified with RAPA was used. This shows that 80% CSA + 20% RAPA has better rut depth (mm) vs. many cycle values than that of 100% CSA, as Figure 16 illustrates above.

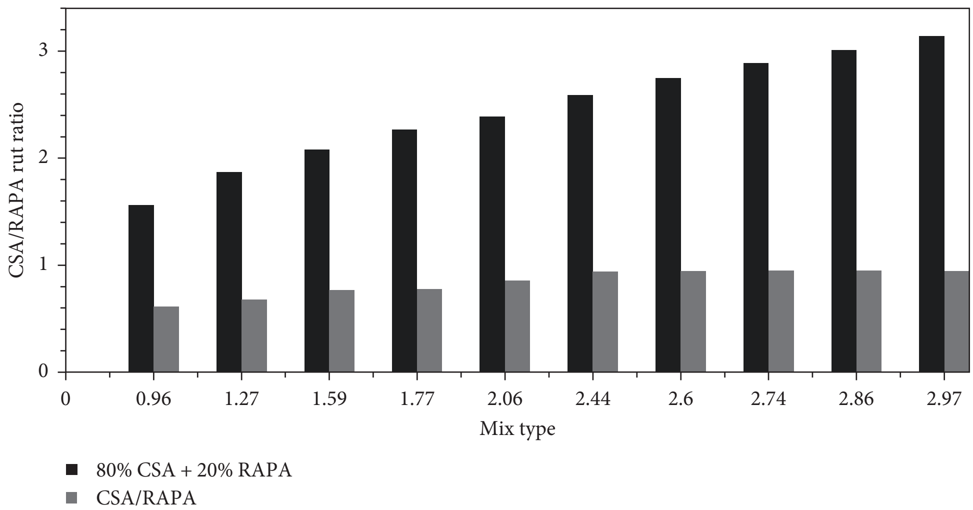

Figure 17: Displays the CSA/RAPA rut ratios for each mixture; a ratio larger than 1 denotes more rutting occurs during the rutting experiment.

Using the WTT for control, RAPA, and WPB, Figure 16 shows the deformation as the loading cycle increases. There is a direct correlation between the deformation of CSA and RAPA specimens with loading, and the deformation of RAPA specimens increases more with increasing loading than that of CSA specimens. This is because when compacted samples have water in them; asphalt and aggregate no longer bond together. The CSA one rutted more when loaded because it became soft and easy to crumble.

(2) Evaluation of Convectional HMA CSA vs. WPB. In the case of the compacted HMA including CSA, the use of conventional or modified WPB binder exhibited different PRD values. The WPB had a slightly higher PRD value. Comparing the two mixes used in the study, the control mix's average PRD was 5.41, while the WPB's was 5.72. However, after comparing the PRD of the various HMA combinations, it was discovered that the outcomes changed based on whether virgin aggregate or aggregate containing RAPA and WPB content was employed. This shows that 70% CSA + 20% RAPA + 10% WPB has better rut depth (mm) vs. many cycle values than that of 100% CSA from 0 to 550 numbers of cycles and vice versa, as shown in Figure 16.

The rut depth versus the loading result of wheel trucker loading testers of control, RAPA, and WPB rutting is shown in Figure 16. Both the CSA and WPB specimen rut depth increases as loading increases, but the WPB samples rut more in every loading from 0 up to 5,250 than the CSA samples, and then the CSA samples rut more in every loading from 5,250 to 10,000.

(3) Comparison of WPB Modified HMA and RAPA. However, when comparing the PRD of the other HMA mixes, results varied between CSA in HMA and WPB-modified HMA, depending on the use of CSA or aggregate containing RAPA and WPB content. There was a noticeable decrease in the WPB value as compared to the PRD value of HMA with RAPA when using the 10% WPB-modified binder. This shows that 80% CSA + 20% RAPA has better rut depth (mm) vs. some cycle values than that of 70% CSA + 20% RAPA + 10% WPB, as shown in Figure 16.

For the WTT for control, RAPA, and WPB rutting, Figure 16 shows the deformation as the loading cycle increases. As loading increases, the RAPA and WPB specimens deform more, but the RAPA samples deform more than the WPB samples. The link between asphalt and aggregate is lost because the compacted samples show water. When loaded, it creates more rutting than the CSA one since it becomes brittle and easier to collapse.

Figure further demonstrates that mixture convectional HMA CSA vs. WPB samples were more deformed than mixture type CSA HMA vs. HMA with RAPA samples. Concerning the aggregate performance test, this demonstrates that combination convectional HMA CSA vs. WPB samples were more water sensitive than CSA HMA vs. HMA with RAPA. The aggregate of CSA HMA vs. HMA with RAPA water absorption was slightly higher and had a coarser gradation, compared to the aggregate of convectional HMA CSA vs. WPB. Additionally, mix type CSA HMA vs. HMA with RAPA has slightly higher asphalt content than mix convectional HMA CSA vs. WPB which aids the mix to resist moisture damage for a little while longer.

The rut ratio of CSA/RAPA and 80% CSA + 20% RAPA for the various laboratory core samples were normalized and plotted in Figure 17, this shows that the values for each mixture; a ratio larger than 1 denotes more rutting occurs during the rutting experiment. Some similarity in trends was observed, but it is clear that the CSA/RAPA and 80% CSA + 20% RAPA tests provide different rutting measures overall.

The rut ratio of CSA/WPB and 80% CSA + 20% RAPA for the various laboratory core samples were normalized and plotted in Figure 18, this shows that the values for each mixture; a ratio larger than 1 denotes more rutting occurs during the rutting experiment. CSA/RAPA rut ratio values for the individual mixes ranged from a high of 2.97 to a low of 0.96 (Figure 18). The medium rut ratio values produced the lowest average rut ratio values (1.5) of CSA/RAPA which was not unexpected since the rut ratio value of 80% CSA + 20% RAPA approached the maximum line.

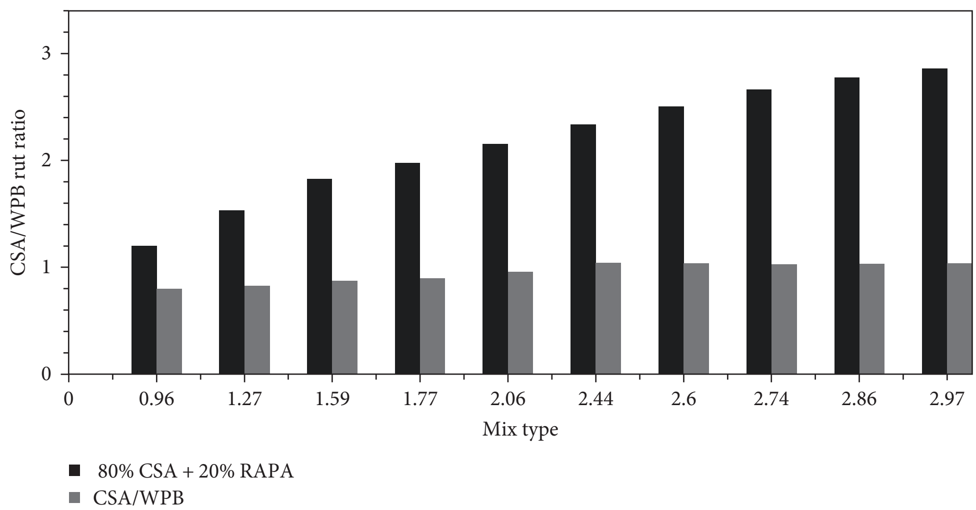

FIGURE 18: Displays the CSA/WPB rut ratios for each mixture; a ratio larger than 1 denotes more rutting occurs during the rutting experiment.

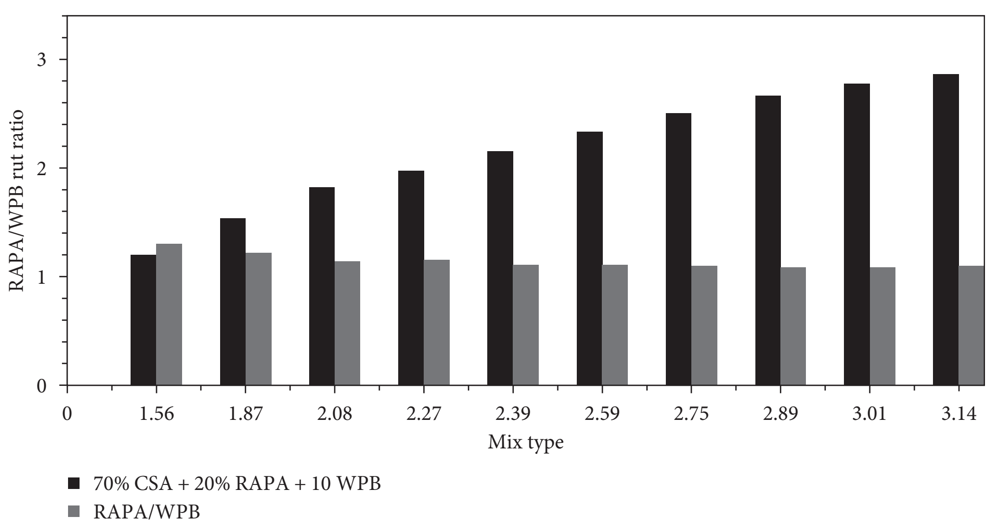

FIGURE 19: Displays the RAPA/WPB rut ratios for each mixture; a ratio greater than 1 denotes more rutting occurs during the rutting experiment.

Figure 19 shows the RAPA/WPB rut ratios for each mixture; a ratio greater than 1 denotes more rutting occurs during the rutting experiment showing that in the first stage RAPA/WPB value is higher than 70% CSA + 20% RAPA + WPB value and then decline and RAPA/WPB value is lower than 70% CSA + 20% RAPA + WPB value after 1.56. This shows that there is a higher increment on 80% CSA + 20% RAPA content than 70% CSA + 20% RAPA + WPB.

4. Conclusions and Recommendations

Based on this experimental performance assessment of HMA concrete incorporating RAPA and WPB in mix design properties, the engineering qualities, ideal proportion, and effects of CSA, bitumen, mineral filler, RAPA, and WPB used in HMA manufacture are established. Thus, using RAPA- and WPB-modified bitumen resulted in 7.39 tons, 7.22%, 7.39%, and 5.295%, respectively, a reduction in the cost of the components for the binder. By adding 20% RAPA and/or 10% WPB to the mixture, the amount of RAPA and WPB that accumulates in residential areas covers sea beads and clogs sewers is decreased. This will assist in resource conservation and reduce pollutants entering landfills and other garbage disposal facilities, which have a more detrimental impact on the environment. Also, CSA was mixed with RAPA and WPB materials bitumen's properties Marshall stability and performance tests of HMA were all investigated.

4.1. Conclusions. After evaluating the asphalt quality using RAPA and WPB as aggregate binders in comparison to a standard mix in laboratories using ASTM, AASHTO, and BS standard test methods to conclude. RAPA and WPB can be used to improve the quality and performance of asphalt mix as well as for sustainable management, according to this research and compared to international Asphalt Institute (ASTMA) and local ERA specifications. Asphalt mix modified with RAPA and WPB exhibited higher air voids, VMA, and bulk density than a mix that did not contain the additives. This increase in air voids, VMA, and bulk density can be explained to be a result of the high density of added RAPA/WPB material compared to an untreated mix. With bitumen contents of 4%, 4.5%, 5.0%, 5.5%, and 6.0% by weight of the total mix, maximum stability was achieved, with 5.1% of OBC among the aggregate gradations, to calculate the OBC of aggregate gradation sizes with 6% mineral filler. Using the NAPA approach, it was possible to calculate the RAPAs and WPBS OBC for each replacement percentage of 10%, 20%, and 30% as well as 2%, 4%, 6%, 8%, 10%, 12%, and 14% with five different bitumen contents of 4%, 4.5%, 5%, 5.5%, and 6% by weight of the whole mix. With optimum RAPA and WPB, all the Marshall properties met, satisfied, and implemented the ERA flexible pavement design manual, and the OBC is found to be 5.1% in CSA. The mixtures containing reclaimed asphalt pavement aggregate and waste plastic bottles (10%, 20%, 30%, and 10% RAPA, and WPB by OBC weight) have approximately 13 kg 10.7 kg of RAPA and WPB of higher stability value compared to the conventional asphalt mix of 9.8 kg. The effects of RAPA and WPB on rutting and moisture susceptibility in hot-mix asphalt were investigated. Then shows an increase in softening point but a decrease in ductility, specific gravity, and penetration as modifier content is increased. This is an indication of an increase in rutting resistance and a decrease in temperature susceptibility. The specified percentages (CSA 5.1%, RAPA 5.1%, and WPB have 5.0% by OBC weight) for better asphalt mix performance with the experimental value of TSR, PRD, and mean rut depth on 20% RAPA replacement was 85.76% and 6.83%, 3.415 mm, respectively. Finally, the Marshall stability and performance test results reveal that up to 30% replacement of aggregate is 20% RAPA and 10% WPB in HMA production satisfies the standard specification of the ERA flexible pavement design manual.

The abovementioned discussion leads to the conclusion that bituminous mixtures containing 20% RAPA show inclinations to strip more than 10% RAPA, 30% RAP, CSD, and WPB. However, it has proved to be weak in terms of strength and unable to support the load when utilizing a bituminous mixture containing 20% RAPA. Therefore, due to performance tests especially moisture susceptibility the OBC obtained from 20% RAP, it is advised to employ several types of aggregates in future studies to determine the optimal aggregate to resist stripping and at the same time handle heavy loads. Additionally, the most important performance indicator for asphalt is its resistance to rutting, which determines whether the RAPA material stiffens the mix that passes the rutting test. In a similar vein, adding WPB stiffens the mixture. As a result, the rutting test must be employed as a crucial test for such a combination to conclude the potential usage of RAPA and WPB for the production of sustainable asphalt pavements.

4.2. Recommendation. Because of the relative compatibility and enhancement, it provides convectional bitumen, disposable RAPA, and WPB-modified bitumen are recommended for road construction in this study. Based on the Marshall test, an optimum modifier concentration of 5.1% convectional, 20% RAPA, and 10% WPB by weight of OBC in the hot-mix asphaltic wearing course is indicated. Conducting performance-based testing (such as a colorimeter device supposed for visual inspection, rheological, and fatigue) is advised for future studies, taking into account various elements and indirect expenses such as disposal costs, construction costs, and maintenance and rehabilitation costs. It is advised to employ several types of aggregates in future studies to determine the optimal aggregate to resist stripping and at the same time handle heavy loads. Aggregates including basalt, diabase, and sandstone are stronger and more permeable than those with a 20% RAPA content. As a performance test, the WTT is not very common in Ethiopia. The amount of rut depth required by the asphalt mixtures suggested for further studies in Ethiopia should be determined by a separate study.

Data Availability

All 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.

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