Journal of Civil Engineering, Science and Technology

Volume 15, Issue 1, April 2024, 50-68

RECYCLING OF ASPHALT PAVEMENT AGGREGATES AND WASTE PLASTIC BOTTLES IN ADDITION TO HOT-MIX ASPHALT PRODUCTION: ADEQUATE RECYCLING RATE

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Date received: 22/06/2023 Date accepted: 09/10/2023

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DOI: 10.33736/jcest.5781.2024

Abstract — This study focused on the recycling of asphalt pavement aggregates and waste plastic bottles (WPB) in addition to hot-mix asphalt (HMA) production. To achieve this objective, non-probable sampling methods were used to gather samples from the study locations. Crushed stone aggregate (CSA), bitumen, mineral filler, reclaimed asphalt pavement aggregate (RAPA), and WPB were the ingredients employed based on the requirements in the standard specification for asphalt concrete production. Initially, the Marshall Stability Test was then carried out using CSA with 6% and bitumen levels of 4.0, 4.5, 5.0, 5.5, and 6% by weight of the total mix to ascertain what the bitumen content should be with RAPA with replacement rates of 10, 20, and 30% and that of WPB with 2, 6, 8, 10, 12, and 14%. In the Marshall Stability Test, which consisted of three trials of 195 samples and 60 mix designs, 45 were for the control mix and 150 for the replacement proportion. In the Marshall Stability Test, the ideal value for CSA was 5.1%; for RAPA, 5.1%; and for WPB, 7.7, 5.5, 5.4, 5.0, 5.5, and 5.4% optimum bituminous content (OBC). 20% RAPA and 10% WPB by weight of OBC in the stability-modified asphalt mix satisfies Ethiopian Road Authority (ERA) and American Society for Testing and Material (ASTM) specifications for all qualities tested. Finally, for improved asphalt mix performance, a combined 70% CSA, 20% RAPA, and 10% WPB should be used in asphalt mixes at 5.0% OBC. These experimental Marshal Stability Test findings satisfy the necessary specifications of ERA and ASTM for all tests used in HMA production. Thus, this proportion is strongly advised.

Keywords: asphalt binder course, hot mix asphalt, performance, RAPA, waste plastic bottle

1.0 INTRODUCTION

One of the most important factors for the rapid development of a country is transportation as it plays a major role in the country's economic development. The most widely used mode of transportation in Ethiopia is the roads, which deserves due consideration from a quality and cost perspective since their construction and maintenance necessitate vast amounts of capital, resources, and materials. Over the past few years, the reuse of waste materials has become more common in this industry because one of the biggest challenges is integrating materials with low embodied energy. Waste materials in pavement construction have attracted much attention due to their ability to consume waste materials without compromising quality [1]. The U.S. government promotes sustainable materials and technologies to extend pavement production [2]. But in Ethiopia, especially in Arba Minch, RAPA wastes are dampened in free spaces and WPBs are thrown away into garbage or under ditches and gorges. This study used RAPA and WPB materials by considering the physical and mechanical requirements demanded in HMA production; however, they were used to reduce the environmental impact of conventional prime materials. Thus in asphalt pavements, the use of waste materials as a modifier results in improved performance [3]. RAPA and WPB materials have been promoted to reduce natural resources, substituting aggregates partially or entirely in newly designed mixtures. The most common method (conventional recycled hot mix) involves a process in which RAP is combined with virgin aggregate and asphalt cement in a central mixing plant to produce hot mix paving mixtures. WPB is combined with RAPA, virgin aggregate, and asphalt cement in a central mixing plant to produce hot mix paving mixtures.

Using RAP methods minimizes maintenance and rehabilitation costs and environmental impacts as recycled asphalt pavement is used which reduces waste generation [4]. A lot of RAPA garbage is produced, especially in large, historic cities like Arba Minch, where it is a common practice to replace old roads with new ones. As a result, there is a substantial buildup of garbage that must be disposed of. However, because of its overpopulation, there is limited space to transport and dampen these RAPA materials. Therefore, these RAPA wastes are disposed of improperly and illegally, which leads to environmental degradation, which can harm the social health and wellness of the community.

One of the legitimate methods for reducing costs and addressing environmental issues associated with the construction of transport infrastructure is to use recycled materials and wastes such as RAPA and WPB wastes. But the saturation of RAPA causes many imminent problems, including land encroachment, overconsumption, and pollution in Ethiopia. The Ethiopian government has banned or restricted quarrying in many areas of Ethiopia to protect the environment, leading to sourcing materials used for highway engineering. Recycling RAPA into road materials is a promising way to address these issues, with significant environmental and economic benefits. The RAPA is milled, excavated, or crushed from existing asphalt pavements or returned from job sites [5][6], which is then blended with fresh asphalt mixture and other additives such as rejuvenators. Compared with natural aggregates (NA), RAP is covered with a lot of cement mortar and micro cracks. RAP shows significant characteristics of low strength, high void age, small bulk density, and large water absorption [7]. Their mechanical properties [8][9], durability and stability [10][11], and the effect of the specimen compaction method have been comprehensively studied [12]. To improve the properties of these RAPA mixtures, WPB additives were used as an option. Separation technology is used for RAPA compositions for accurate and efficient utilization.

Throughout our daily lives, plastics have become ubiquitous commodities. Since 1950, plastic production has grown from 2 million metric tons to 322 million metric tons [13]. In 2017, plastic production reached 8.3 billion metric tons. The lack of awareness of recycled plastics is a major concern for municipal solid waste (MSW). In 2018, plastic waste generation was approximately 35.7 million tons in the United States. Among all waste plastics, 8.7% can be recycled, while 75.6% and 15.7% are landfilled and combusted for energy recovery, respectively [14]. Being a form of polymer and a petroleum-based product, plastics present a unique opportunity for research into recovered waste plastic as an ingredient to hot mix asphalt (HMA). Utilizing recycled waste plastics in HMA can conserve resources while managing waste plastic pollution. One of the most recycled goods in the USA is HMA. As stated by Naskar et al., [15] polymer-made additives have been proven to be effective in many aspects for modifying the properties of the bitumen material in road pavement. This further contributes to the increase in the life span of the road. The WPB increases asphalt's resistance to temperature variations and aids in preventing rutting when compared to standard [16]. The inclusion of WPB blends showed notable improvements to the performance of an asphalt mixture, decreasing cracking, stiffening mixes at high temperatures, minimizing rutting, improving blend quality, enhancing mixes' resistance to oxidation, and decreasing asphalt thickness and life costs [17]. Hot mix asphalt (HMA) mixtures are considered a promising approach to reusing waste plastics in large volumes. Hence, waste plastics are investigated as potential modifiers for asphalt binders or substitutes for aggregates to achieve sustainable pavements. Lots of physical methods, including the physical property of aggregate, RAPA, and WPB, have already achieved effective separation of the physical property of aggregate, RAPA, and WPB.

In this study, the hot-mix asphalt production method involved incorporating bitumen at percentages of 4.0, 4.5, 5.0, 5.5, and 6% by weight of the total mixture. Recycled Asphalt Pavement (RAPA) was used as a substitute with rates of 10%, 20%, and 30%, while Waste Plastic Binder (WPB) was included at 2%, 6%, 8%, 10%, 12%, and 14%. The RAPA content was varied across four ratios: 0%, 10%, 20%, and 30%, while considering seven proportions of WPB (0, 2, 4, 6, 8, 10, 12, and 14). Reclaimed asphalt pavement (RAP) is the term given to removed and/or reprocessed pavement materials containing asphalt and aggregates. These materials are generated when asphalt pavements are removed for reconstruction, resurfacing, or to obtain access to buried utilities. When properly crushed and screened, RAP consists of high-quality, well-graded aggregates coated with asphalt cement. The process of making WPB materials involves gathering WPB from various waste sites, packing, eliminating semi-particles, cleaning, drying, shredding, screening, and blending with a Crushed stone Aggregate (CSA) and RAPA to meet performance standard requirements. This enhances the stability, strength, and other desired properties of bituminous mixes in small amounts. Initially, the Standard Test Methods procedure was employed to investigate the physical properties of bituminous and aggregates (Natural Aggregate, RAPA, and WPB). Subsequently, the Standard Marshall Test was used to determine the properties of Natural Aggregate, RAPA, and WPB, as well as to identify the ideal asphalt dosage. Consequently, the incorporation of WPB and RAPA in asphalt production presents a viable solution to the significant issue of waste disposal in Arba Minch.

Numerous studies revealed that pavements using RAPA fared comparably to those using standard combinations [18]. Using these hazardous and non-biodegradable wastes as a binder can aid in minimizing environmental issues caused by improper WPB and RAPA disposal as well as the mining of asphalt pavement materials for road building. They can behave as aggregate substitutes, aggregate coatings, or binder modifiers in the asphalt mix depending on their physical properties and improve the performance of the modified asphalt mixtures [19]. This study attempted to utilize the adequate recycling rate of RAPA and WPB wastes accumulated in Arba Minch to use fully or partially as a wearing course aiming to conserve natural stone aggregate and minimize the cost of road construction and at the same time removing and recycling the unnecessary accumulation of RAPA and WPB wastes and preserve the environment. This study evaluated CSA, WPB, and RAP combination at the effects of adding 4 to 6% CSA, 10 to 30% RAPA, and 14% WPB as an aggregate cover to provide an objective picture of an experimental performance evaluation of HMA concrete incorporating RAPA and WPB. The OBC refers to the amount of asphalt binder that balances different desirable mixture properties for each combination of aggregate type, aggregate grade, additive type, additive dosage, and binder type. Asphalt is typically determined by the optimum binder content of HMA in a particular mix design and the binder content was used to evaluate mix properties. In a typical mix design method, the optimum binder content of a particular asphalt mixture and binder types is determined from the relationships between the combination of volumetric and strength properties and variations in binder contents. This paper presents an alternative approach to OBC determination by developing a general model of volumetric and strength behavior for given materials (RAPA, WPB, and binder content) and the parameters investigated. In this approach, the required criteria for selecting OBC were first determined for each condition by a Marshall Stability Test.

2.0 MATERIALS AND METHODS

2.1. Materials

To perform this study, various sorts of data such as bitumen, filler, and aggregate collection are the main data sources. Interviews with knowledgeable material engineers and lab personnel who have investigated the impact of asphalt-on-asphalt production performance were used to collect secondary data. Recyclable materials such as plastic and RAPA were collected at the point of disposal in many areas of Arba Minch and placed in separate waste disposal bins and places. Following the separation of the WPB and RAPA from the other recycled items, the other products were used. A variety of quantitative data types, including aggregate, filler, RAP, WPB, and bitumen, were gathered to achieve the research's goal.

The materials used for this study were bitumen grades (60/70), extracted RAPA, crushed stone aggregate, crushed stone dust, and crushed WPB. All aggregates, RAP, and bitumen were sampled from the stock and crusher sites prepared for asphalt works on the road projects. For the Marshall Stability Test, mixed designs and specimens were prepared from those materials to achieve the goals of the study. Out of the samples, 15 were used as a control mix, and 50 were used for the replacement proportion. The Marshall Stability Test results were used to determine the maximum allowable replacement percentage, and their performance tests, including moisture susceptibility and rutting, were compared with the standard specification requirement.

To collect the data required for this research strategy, non-probable purpose sampling techniques were used.

- Coarse and fine crushed stone aggregates
- Penetration grade 60/70 bitumen,
- Filler (crushed stone dust),
- (Coarse and fine) Reclaimed Asphalt Pavement Aggregate
- Ground-up waste plastic bottles

2.2. Study Design

A study design based on non-probable sampling techniques was adopted to collect representative samples from study areas such as crushed stone aggregate, bitumen, mineral filler, RARA, and WPB used in HMA production as illustrated in Figure 1. The study was conducted using an experimental research method. In general, identifying the optimum percentage of RAPA and WPB to be added in HMA production, a specification created for a typical HMA manufacturing qualifies as experimentation. A literature review of various prior research on the effects of RAPA and WPB on rutting and moisture susceptibility in HMA was done.

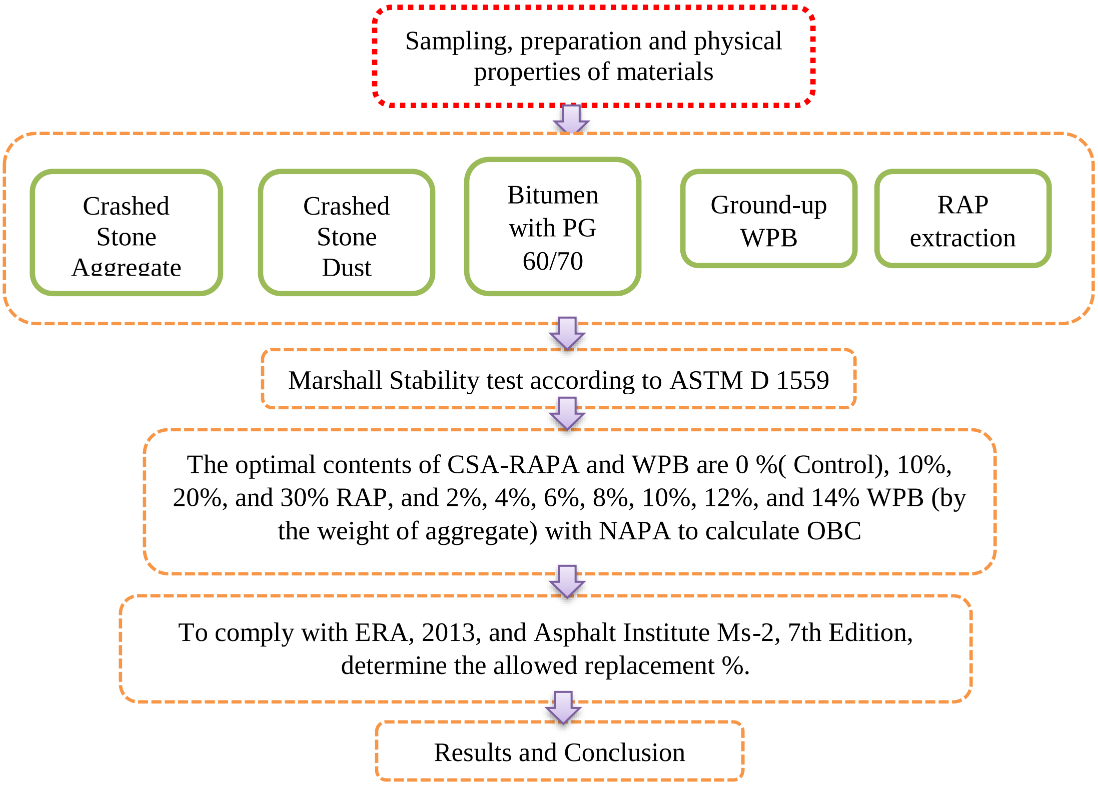

Figure 1 Study design

2.3. Sample Size

The sample was recruited using the tests that adhered to the requirements and standards for the bitumen laboratory test. For each test, quartering and weighing were used as sample techniques. Laboratory tests were utilized to assess the strengths of ordinary bitumen and asphalt samples, according to the study's findings. The sample size of a test was calculated using the ERA, ASTM, and AASHTO standards and regulations.

2.3.1. Aggregate test

The determination and assessment of aggregate tests were conducted based on establishing the aggregate's physical properties. This was followed by determining additional descriptive physical properties of the aggregate, and finally, carrying out blending calculations to achieve the mix design for the aggregate gradation.

The estimation of the aggregate physical properties included tests for toughness and abrasion. These tests involved conducting an LAA (Los Angeles Abrasion) and ACV (Aggregate Crushing Value) test to determine the resistance of small-size coarse aggregate to abrasion and impact degradation.

The Los Angeles Abrasion (LAA) test, performed using equipment, evaluated the ability of coarse aggregate smaller than 37.5mm (1-1/2 inches) and retained on a 1.7mm sieve to resist abrasion. The original weight sample was subtracted from the weight retained on the 1.7mm (No.12) sieve. As a percentage of the original sample weight, the values regarded as the wear percentage of clarity and deleterious materials, particle shape and surface texture were computed. Other additional descriptive physical properties of the aggregate were also identified. Additional tests are performed on aggregate that passed step one to fully characterize it.

2.3.2. Aggregate gradation and size

In the experiment, the distribution of aggregates' particle sizes was determined by sieving both fine and coarse aggregates. To define the physical and mechanical properties of aggregates, many laboratory tests were conducted, including sieve analysis of coarse and fine aggregates (AASHTO T 27), specific gravity (AASHTO T 85), water absorption (AASHTO T 85), Los Angeles abrasion (AASHTO T 96), and soundness loss (AASHTO T 104).

The computations were based on the overall sample weight. Percentages were calculated, and the amount retained as well as the amount that is finer through each sieve were determined. Additionally, comparisons were made for each sieve size regarding coarse and fine particles, and measurements were taken for specific gravity and absorption. The bulk, apparent, and effective specific gravities of coarse and fine aggregates, as well as their absorption were determined. Water is drawn into and tends to fill the permeable pores of a porous solid body through absorption. Due to the significance of asphalt cement absorption in asphalt mixtures, the effective specific gravity was calculated. Therefore, coarse aggregate refers to the aggregate that is mostly 4.75mm sieved and contains only as much finer material as allowed by the specification.

2.3.3. Filler and reclaimed asphalt pavement aggregate test

The detail description of the required test for filler and reclaimed asphalt pavement are shown in Table 1.

Table 1 Filler and Reclaimed Asphalt Pavement Aggregate Test

Test Type	Sample Test
Filler test	– Sieve Analysis (AASHTO T 27)
	– Specific gravity (AASHTO T 85)
Reclaimed asphalt pavement aggregate test	– Extraction of bitumen from RAPA (AASHTO T164/ASTM D2172)
	– Sieve Analysis (AASHTO T 27)
	– Moisture Content of RAPA AASHTO T 265
	– Maximum Theoretical Specific Gravity (Gmm) of RAP AASHTO T209
	– Bulk Specific gravity of RAPA (AASHTO T 85)
	– Water absorption (AASHTO T 85)
	– Los Angles abrasion (AASHTO T 96)
	– Soundness (AASTO T 104)
	– Mix Proportioning of RAPA & Virgin Materials
	– Virgin aggregate and RAPA proportioning
	– Estimation of approximate asphalt bitumen demand of combined aggregate
	– Estimation of New Asphalt bitumen in the mix
	– Laboratory Batch Preparation
	– Mixing and Compaction of Test Specimens (ASTM C-337)
	– Moisture Sensitivity
	– Blending of RAPA

2.3.4. Bitumen extraction from RAPA (AASHTO T164/ASTM D2172)

The extraction test is the cornerstone of RAPA preparation for partial virgin aggregate and bitumen replacement. This technique addresses the quantification of bitumen in asphalt-mixed paving mixtures and pavement samples. Therefore, four RAPA samples were extracted in line with AASHTO T164/ASTM D2172 with the exception that the solvent was changed to benzene because trichloroethylene was not readily accessible.

2.3.5. Mix proportioning of RAPA and virgin material

The RAPA and CSA were proportioned and combined to meet the desired specification requirement as shown in Table 2. There are a few extra procedures to consider in this process of HMA design with RAPA materials compared to traditional HMA design. To show how to proceed with material proportioning and mixing, the steps below were modified from Asphalt Institute's MS-2 (1995). The recovered bitumen's properties have not been established, the investigation was restricted to partial substitution up to 30%, and understanding the characteristics of the original bitumen may not be necessary.

Table 2 Mix Proportioning of RAPA, Virgin Material, and WPB

Test Type	Test Detail
Aggregate Blending	– Determine the asphalt content of RAPA aggregate – Determine graduation of RAPA and virgin aggregate – Calculate the combined aggregate in a recycled mix – Approximate asphalt demand of combined aggregate
Grade selection /RAPA%/	– Percept of new asphalt added to the recycled mix – Select the grade of new asphalt
WPB test	– Cleaning, washing, and removing inessential post links – Waste plastic bottle properties – Shredding – Sieve Analysis (AASHTO T 27) – Specific gravity (AASHTO T 85) – Blending of WPB

In this study, WPB (used for locally available water bottles) was used as an additive. WPB was collected, washed, and cleaned in hot water for 3–4 hours, and then dried.

2.3.6. Bitumen test

Rheology is the study of how matter moves and changes shape. In this case, HMA primarily consisted of asphalt. The way asphalt binder flows and deforms substantially affects how well a pavement performs. Rutting and bleeding may be more likely to occur on HMA pavements with high flow and deformation.

The properties of bitumen were determined based on specific gravity (ASTM D 70). The dimensions of the container used for the penetration test were 75 mm x 55 mm (ASTM D5-95, 0.1 mm). Additionally, tests were conducted for ductility (ASTM D113-86), flash and fire point (ASTM D92-90), and softening point (ASTM D36-2002). Meanwhile, the aggregate with bitumen test included assessing conventional binder properties such as viscosity, as well as sample preparation, which involves compaction.

Five mixes, each having three material samples produced during the original trial and varying amounts of asphalt binder, were combined to create the fifteen specimens used in this investigation. Following that, the ideal asphalt binder content was chosen by analyzing each sample blend's Marshall Properties. The experimental blends of asphalt content must range between 4 and 6% for this concept to be successful. Therefore, determining the ideal asphalt composition was the first step in the sample preparation.

2.3.7. Compaction with Marshall Hammer

Each sample was heated to the predicted compaction temperature and compacted using a Marshall Hammer, a machine that exerts pressure on a sample through a tamper foot. Some hammers are operated manually, while others are mechanical. The Marshall Hammer used in this test was automatic since it was performed at AMU.

2.3.8. Marshal stability and flow test

In this method, the resistance to deformation of a compacted cylindrical specimen of a bituminous mixture is measured when the specimen is loaded diametrically at a deformation rate. According to ERA and AASHTO standards, the standard Marshall method is utilized for the design and field control of HMA (Hot Mix Asphalt) mixtures containing aggregates with a maximum size of up to 25mm. Initial mix design samples were prepared that covered a range of bitumen contents and were then subjected to a level of compaction that was related to the expected traffic, in terms of equivalent standard axles, to be carried in the design life of the HMA layer(s). The bulk density, void in air (VA), stability, and deformation characteristics were included under load to determine the properties of compacted samples. The mix was reformulated when the mix properties did not meet the specified mix design criteria, and the tests were repeated until an acceptable design was established as illustrated in Table 3.

Table 3 Marshal Stability and Flow Test

Marshal Stability and Flow Test	Description
Stability and bitumen content relationship	– This test was done to determine the Marshall stability of the bituminous mixture as per ASTM D 1559 in the maximum load required to produce a failure of the specimen when a load is applied at a constant rate of 50 mm/min.
Flow and bitumen content relationship	– The flow refers to the vertical deformation when the maximum load is reached. In flow, different bitumen contents represent a flow of asphalt mix with a flow vs. bitumen content graph.
Density and Air voids	– Bulk density – bitumen content relationship – Bulk density is the actual density of the compacted mix. Bulk density for different bitumen contents is expected to represent the bulk density results of the asphalt mix. – The theoretical maximum specific gravity of mix (Gmm) – The proportion of the mass of an equivalent volume of gas-free distilled water at a specific temperature (often 25°C) to that of a given volume of void less (VA = 0) HMA. – Air voids (VA %) – bitumen content relationship – VA % is the percentage of VA by volume in a specimen or compacted asphalt mix. VA % expected results for different bitumen contents are to represent maximum VA content value as bitumen content on VA proportion vs. bitumen content diagram. – Voids in mineral aggregates (VMA%)– bitumen content relationship – VMA is the percentage of void volume in the aggregates before adding bitumen or the sum of the percentage of voids filled with bitumen and the percentage of air voids remaining in the asphalt mix after compaction. It represents the results for different bitumen contents of max VMA content from VMA proportion vs. bitumen content. – Voids filled with bitumen content (VFB%) – bitumen content relationship – VFB is the percentage of VMA filled with bitumen [20]. The relationship between voids filled with bitumen percentage (VFB%) and different bitumen contents was analysed to determine the voids filled bitumen proportion versus bitumen content in the asphalt mix.

Ultimately, the Marshall stability and flow, density, and void analysis data were integrated to determine the optimal asphalt binder content. The process described below led to the optimal amount of asphalt binder.

2.3.8.1. Determination of optimum content

The Gmm (ASTM D2041) of the loose material containing 4.5% and 5.0% of bitumen, i.e., the two bitumen contents nearest to the optimum determination was needed. The experimental works were started by determining the optimum asphalt content using the Marshall Mix Design method and with a compaction effort of 75 blows. According to the standard 75-blow Marshal design method designated [21], 15 samples of 1200 gm. in weight were proposed to be prepared using five different BC (from 4 - 6% with 0.5 % incremental).

The OBC for the proposed mix is the average of three values of bitumen which include:

1. Bitumen content at the highest stability (% Mb)$_{\text{Stability}}$
2. Bitumen content at the highest value of bulk density (% Mb)$_{\text{bulk density}}$
3. Bitumen content at the median of allowed percentages of VA (VA = 3-5%) (% Mb)

The properties of the asphalt mix, including stability, flow, voids in air. and bulk density, obtained using the OBC (Optimum Binder Content), were utilized. Graphs were plotted to compare asphalt binder content and density. Generally, as the amount of asphalt in the mixture increases, the density initially rises to a peak before starting to fall. When compared to peak stability, peak density typically occurs at higher asphalt binder contents. One of two trends ought to be followed here: with more asphalt binder present, stability rises to a peak before falling. Asphalt binder content increases and causes a decline in stability, which does not peak. Several recycled HMA formulations follow this pattern typically. Asphalt binder content should increase as the asphalt binder content increases. Asphalt binder content in comparison to air voids the percentage of air voids should decrease as the asphalt binder content increases. The percent VMA should decrease as asphalt binder content increases, reaching a minimum, and then increase again. The percentage of VFA increases as the asphalt binder content increases.

The most important thing to do is to determine the best binder content is to follow the critical steps outlined below.

I. Calculate the asphalt binder content that corresponds to the specification's median 4% air void content, maximum stability, and maximum density. The best asphalt binder content is the average of the three values.
II. Using the plots, determine the properties at this OBC. If all of these values are within specification, the preceding optimum asphalt binder content is satisfactory. If any of these properties are outside the specified range, the mixture should be redesigned by changing the filler content.

2.3.9. Aggregate with bitumen and RAPA test

2.3.9.1. Preparation of asphalt mix modified with RAPA

There are many different methods for the utilization of RAPA in the asphalt mix. In this study, the aim of adding RAPA to the asphalt mix was to provide an aggregate coating material and not to enhance bitumen properties as bitumen modifiers. After obtaining OBC, 15 samples were needed to prepare at OBC to evaluate the effect of adding RAPA and WPB to asphalt mixture samples by considering proportions of RAPA (4, 4.5, 5, 5.5, and 6% by the weight of OBC) for 10%, 20% and 30% RAPA. The estimation of approximate asphalt bitumen demand for combined aggregates is determined using an empirical formula that calculates the approximate asphalt demand based on the initial design bitumen content (DBC). However, there are discrepancies between the initial values and the actual values observed in practice. The bitumen content for crushed concrete aggregate was initially determined to be 6.5 when F=2 was used, while the DBC for natural aggregate was 5.1 when F=0.7 was used. These initial values differ significantly from those observed in practical applications. As a result, the approximate bitumen demand of the combined aggregates was estimated by substituting the percentage pass values. The estimated asphalt demand served as a foundation for a series of trial mix designs. The asphalt content of the trial mix was varied in 0.5 increments on either side of the calculated approximate asphalt demand, with asphalt contents ranging from 4% to 6% being prepared.

Estimation of New Asphalt bitumen in the mix based on the amount of new asphalt that must be added to the trial mixes of the recycled mixture was expressed by the weight of the total mix and was calculated using the formula; the results were summarized by substituting the values in the calculation. Calculating the laboratory batch for a particular mix was the last step in aggregate analysis. Getting the laboratory aggregate blend as near to the finished asphalt plant aggregate blend as possible is the aim of batching. Each specimen from each fraction was weighed separately for this purpose, producing a batch of compacted specimens. For a specimen of this height, a normal-weight aggregate typically weighs around 1200 grams.

Sample preparation, including compaction, of test specimens using aggregate fraction and asphalt contents was carried out. The trial batches were heated until the temperature reached 150-160°C and then mixed. Finally, 75 blows of compaction at both faces continued according to the step outlined for the Marshall Method of mix by Stability – RAPA content relationship, Flow – RAPA content relationship, Air voids (VA) – RAPA content relationship, Voids in mineral aggregates (VMA) – RAPA content relationship and Optimum modifier content.

The asphalt mix with OBC met the RAPA maximum stability, maximum bulk density, and VA % within the allowed range of specifications. The Optimum RAPA content is determined as the average of the previous three RAPA contents.

2.3.9.2. Comparison of control mix with RAPA modified mix

According to ERA and Asphalt Institute criteria, it is also necessary to compare the mechanical characteristics of RAPA-modified asphalt mix at the optimal RAPA content and properties of the traditional asphalt mix minimum and maximum allowable limits.

2.3.9.3. Required RAPA quantity

This research has attempted to partially replace the bitumen with RAPA and WPB as much as bitumen, RAPA, and WPB mix which have the quality that satisfies the standards of tests like penetration, softening point, and ductility tests. Subsequently, the optimum bitumen content is determined through a trial mix design using the Marshall Mix method, followed by the selection of the job mix formula and assessment of volumetric properties.

2.3.10. Aggregate with bitumen, RAPA, and WPB test

There were 21 samples prepared at OBC to evaluate the effect of adding WPB to asphalt mixture samples by considering ten proportions of WPB (% by the weight of OBC). The mechanical properties of the asphalt mix using different percentages of WPB were assessed, including the relationships between Stability and WPB content, Flow and WPB content, Air voids (VA) and WPB content, and Voids in Mineral Aggregates (VMA) and WPB content. Additionally, the optimum modifier content, maximum stability, maximum bulk density, and VA % within the allowed range of specifications were determined.

The Optimum WPB content is the average of the previous three WPB contents.

- Comparison of control mix with WPB and RAP modified mix
- Required WPB quantity

2.4. Standards and Specifications

An ordinary aggregate assessment for utilizing Marshall Blend Plan strategies incorporates essential steps to estimate the aggregate physical properties which involves running various tests to determine properties for aggregate, filler, RAP, and WPB. The several tests conducted based on standard specifications, such as those detailed in Tables 4, Table 5, and Table 6 were carried out to determine the engineering qualities of the materials used in this study.

Table 4 Characteristics of CSA, RAPA, and WPB Engineering Quality Tests and Procedures

Material	Test conducted	Test method
RAPA	Extraction by centrifuge method	AASHTO T 85
WPB	Grinding	----
	Amount of water absorbed (%)	AASHTO T 85
	Moisture Level	AASHTO T 85
	Lose weight from coarse aggregate	ASTM C-337
Test for CSD and RAPA aggregates	Aggregate Crushing Value (ACV) (%)	BS 812, Part 110
	Aggregate Impact Value (AIV) (%)	BS 812, Part 112
	Abrasion Value in Los Angeles (%)	AASHTO T 96
	Aggregate’s compacted weight.	ASTM C-337
Test for CSD, RAPA, and WPB in aggregate	Coarse Aggregate in Gmb	AASHTO T 85
	Coarse Aggregate from GB (SSD Basis)	AASHTO T 85
	Coarse Aggregate in Gmm	AASHTO T209
	Blending	ASTMD 3515

Table 5 Bitumen Tests and Procedures

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°)	ASTMD36-2002
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 6 Testing Techniques for Mineral Filler

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

3.0 RESULTS AND DISCUSSION

3.1. Aggregate Quality and Physical Property Test Result

The results of the aggregate quality test were based on the ERA 2013 standard specification. Detailed physical properties are shown in Table 7.

Table 7 Comparisons of Physical Attributes of Crushed Stone Aggregate (CSA) and RAPA for The Study

Tests	Characteristics	CSA	RAPA	Distinction
1	Water absorption percentage	0.68%	0.49%	-0.2%
2	Moisture levels	0.56%	0.56%	0%
3	Granular mass in Gmb	2.78	2.77	-0.01%
4	(SSD Basis) GMB Coarse Aggregate	2.8	2.78	-0.02
5	Granular mass in Gmm	2.84	2.8	-0.04
6	Crushing Value of Aggregates (ACV) (%)	8.786%	8.786%	0%
7	AIV (Aggregate Impact Value) (%)	10.124%	10.124%	0%
8	Abrasion Value for Los Angeles (%)	26.5%	26.7%	0.2%
9	Granular material compacted weight	2183 kg/m^3	2183 kg/m^3	0
10	Lose weight from granular material	2146 kg/m^3	2146 m^3	0

Comparisons of physical attributes of CSA and RAPA results in Table 7 showed that RAPA has a lower water absorption value, Gmb of Coarse Aggregate, Gmb Coarse Aggregate (SSD Basis), and Gmm of Coarse Aggregate than CSA but high Los Angeles Abrasion Value. They have the same ACV, AIV, compacted weight of coarse aggregate and lose weight from the coarse aggregate. This demonstrates that RAPA is weaker and more porous than CSD because a low specific gravity could be a sign of significant porosity, which would lead to inadequate strength and durability. Additionally, this study demonstrates that RAPA is less difficult than CSD. However, the aggregate crushing value is less than 10 and has an exceptionally strong aggregate. The Aggregate Impact Value was 10% to 20% and is in the strong category because of British Standard BS 812-110: 1990. In general, both are within the satisfactory categories because they have 26.5 and 26.7 which are laid 20 to 30 because of abrasion values. The outcome met the requirements of ERA/AASTHO and British Standard BS 812-110: 1990 for specification.

3.2. Aggregate Gradation for the Investigation

Following the determination of the physical properties of the aggregates and their gradation, a blending calculation was carried out based on standard requirements for gradation for the wearing course from Asphalt Institute Standards. The proportions of each aggregate type utilized on the sixth course of asphalt binder are shown in Table 8. The ASTM standard specification for grading the asphalt binder course, and the aggregate gradation curves were acceptable. As determined by ASTM D5315 gradation limits 2, the aggregate mix was graded in Table 8 and Figure 2.

Table 8 Graduation Value Combined for Aggregates

Size (mm) of the sieve.	34% binders	30% binders	34% binders	2% filler	Combined passing rate	A limit is specified According to ASTM D5315		
						Lower	Upper	Middle
	34	30	34	2	100	100	100	100
25	34	30	34	2	100	100	100	100
19	32.8	28.9	32.8	2	96.3	90	100	95
12.5	28.3	25	28.3	2	83.2	67	85	76
9.5	23.02	20.31	23.02	1.4	67.7	56	80	68
4.75	17.04	15.03	17.03	1.0	50.1	35	65	50
2.36	12.3	10.83	12.28	1	36.11	23	49	36
1.18	8.3	7.32	8.3	1	24.4	15	37	26
0.6	5	4.41	5	0.8	14.7	8	26	17
0.3	3.502	3.09	3.502	0.5	10.3	5	19	12
0.15	2.38	2.1	2.38	0.5	7	3	14	8.5
0.075	1.7	1.5	1.7	0.5	5	2	8	5

The result provided in Table 8 illustrates that although the blended aggregate mix's nominal size was 19 mm, its nominal maximum aggregate size was 25 mm. Grading the blend using these proportions reveals that it conformed to ASTM D5315 standards and fulfills specification limitations for all sieve sizes. The combined aggregate used has been made from the total same of the percent of 34, 34, 30 percent of aggregate, and 2 percent of fillers. The ultimate percentage of each aggregate material in the asphalt binder is depicted in the table above, and the intended aggregate gradation blending complied with ASTM D5315's standards for aggregate gradation. Figure 2 shows that two percentages of filler with aggregate were used to construct the ASTM D5315 aggregate gradations with Passing versus Discounted sieve.

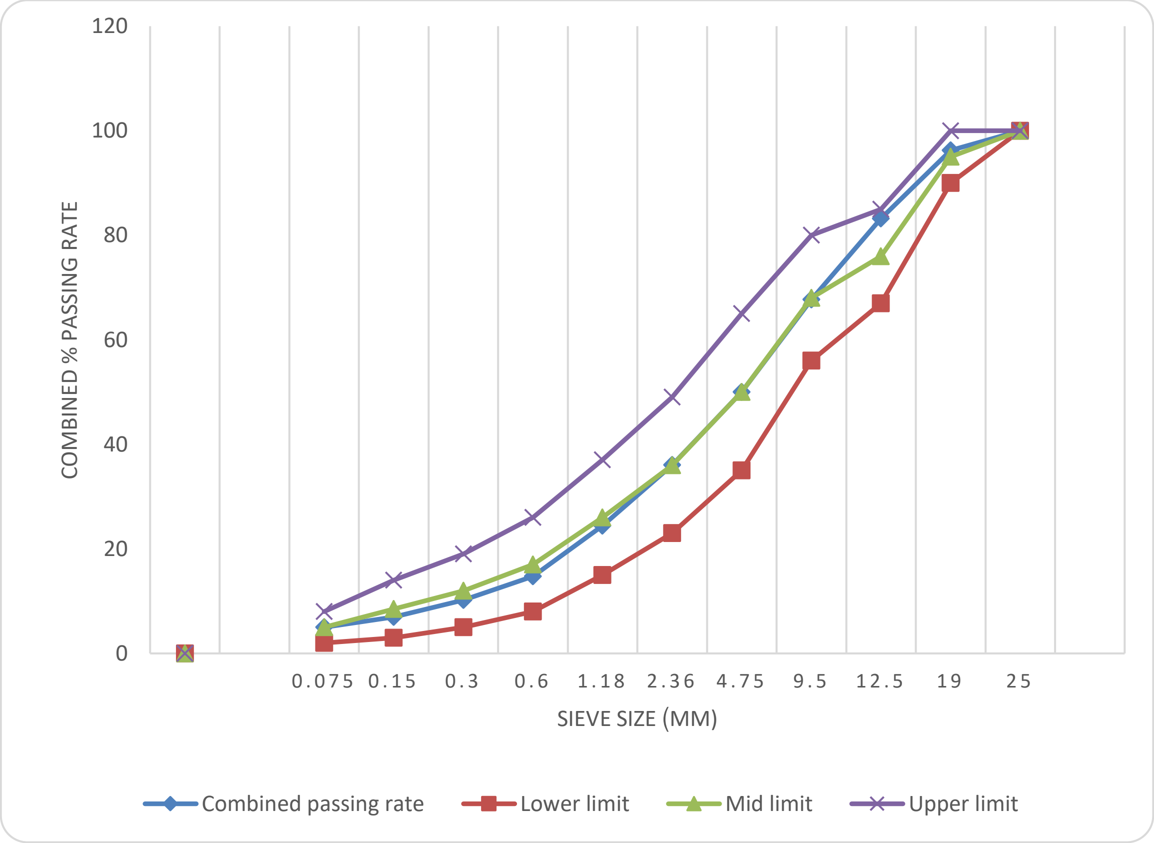

Figure 2 Sieves that pass versus those that are discounted

Due to limited resources, only three trials were carried out to check the properties of an asphalt mix by applying the criteria for gradation as mentioned in this paper. The results were quite encouraging as no major difference was observed between assumed and achieved properties as shown in Table 8 and Figure 2. The maximum size of aggregate and maximum passing percentage at sieve 0.075mm should be specified instead of specifying complete ranges for various sieve sizes. As illustrated in the graph, on the upper part, the curve reached more to the upper limit when sieves 9.5, 12.5, and 19 were used. When sieve 0.057, 0.15, 0.3, 0.6, 1.18, and 2.36 were used, it had a slit difference than a middle limit curve.

3.3. Quality Test Results for Bitumen

Before beginning the mix design, a series of bitumen quality tests were carried out. The results are shown in Table 9.

Table 9 Physical Properties of Bitumen

Test	Specification	Results	ERA Spec.		ASTM spec.	
			Lower	**Upper**	**Lower**	**Upper**
Penetration (0.01 mm)	ASTM D5-06	67.27	60	70	60	70
Ductility (cm)	ASTM D113-86	143.6	100		100	
Softening point (C°)	ASTMD36-2002	48.4	42	51	42	51
Flashpoint (C°)	ASTM D92-02	279.3	232℃		232℃	
Fire point (C°)	ASTM D92-90	284.5				
Specific gravity (g/cm)	ASTM D70	1.02	0.97	1.06	1.01	1.06

This test establishes that the firmness or softness of the bitumen used in pavements satisfied the ASTM D5-95 standard and as indicated in Table 9, the penetration value gradually decreased to 67. The minimum penetration value was 60.67 mm and the maximum value was 75.33 in this study.

The value is the ductility of a bituminous material as indicated in Table 9. The binders had high ductility and good bitumen qualities on the road surface and adhered well to aggregates. There were five samplings with similar convectional bitumen and each of them showed a different value as a result of temperature at 250c of the water in which the sample is socked. The value of a sample showed a result of above 100cm and taken 143.6cm.

The bleeding explains both the slick condition in rainy weather and increased friction for operating autos. Both of these detrimental conditions are significantly reduced by the bitumen blend. The bitumen mix's softening point steadily increased and the values were determined, as shown in Table 9. The softening point value eventually fell to 48.4. In this study, the minimum softening point value was 45.67 mm and the maximum value was 51.33 mm.

All results, including penetrability, ductility, softening point, flash point, and specific gravity, are shown in the illustrative results section of Table 9, which summarizes the bitumen’s properties per ASTM standards. Compared to the average or mid-range values of standards, the values determined for penetrability, softening point, and specific gravity were higher.

3.4. Properties of Mineral Filler Made from Crushed Stone Dust

Using the water Pycnometer method, laboratory tests were done to determine the apparent specific gravity and plasticity index indicated in Table 10.

Table 10 The Filler Material’s Physical Characteristics

S/N	Test description	Test method	Result	ERA 2002
1	Apparent specific gravity (kg/m3)	ASTM D-854	2.783	N/A
2	Plasticity Index (PI)	ASTMD-423	NP	≤ 4
3	% passing 0.6 mm sieve	ASTM D-242	100	100
4	% passing 0.3 mm sieve	ASTM D-242	97.8	95-100
5	% passing 0.075 mm sieve	ASTM D-242	91.2	70-100

From the physical characteristics, it is observed that CSD is a grey color fine aggregate consisting of medium to fine sand-size particles and of angular shape with rough surface texture. Plasticity characteristics and their deformation can be better explained with the Index Properties of the Plasticity Index (IP) from the consistency data. It is non-plastic and incompressible. The results of the material 0.6 mm sieve, 0.3 mm sieve, and 0.075 mm sieve of CSD have been taken at various percentages of crusher dust and subjected to apparent specific gravity and consistency limits such as liquid limit, plastic limit, and plasticity index, etc. as per IS:2720 and the results are shown in Table 10.

3.5. A Study of Asphalt Mixture Properties

3.5.1 Results of the conventional asphalt mix's Marshall test

3.5.1.1 Finding the ideal bitumen content for a convectional asphalt mix (0% RAPA & 0% WPB)

The OBC of the mix was calculated as the average of four bitumen content values based on NAPA, which are: Maximum stability of bitumen content of 5, Bitumen content at the greatest value of bulk density of 5.1, Bitumen content at the median of authorized percentages of VA of 5.1, and median of allowed percentages of VFB of 5.2. By taking the average of these values, the OBC is 5.1 for the Convectional asphalt mix as shown in Table 8.

3.5.1.2 Optimum modifier content

The OBC is a set of control mixes that offer the best mechanical character of an asphalt mixture as shown in Table 11.

Table 11 Optimum Bitumen Content

RAP content	Stability	Bulk density	Air void	VFB	OBC
10%	5	5.5	5.5	5	5.25
20%	5	5	5.5	5	5.13
30%	5.5	5	5.5	5	5.25

Based on this, 20% RAPA is the minimal OBC, indicating that RAPA could be lower as shown in Figure 3. Because of limitations, RAPA's benefit could not be significant. But in contrast, the OBC of 10% RAPA & 20% RAPA maintained the same result at 5.3 & 5.1, while at 30% RAP, there was a slight improvement from 5.5 to 5.3. It was determined that waste plastic reduces the requirement by at least 10% of the minimum ideal concentration. However, it has drawbacks, and recycled plastics can be insignificant.

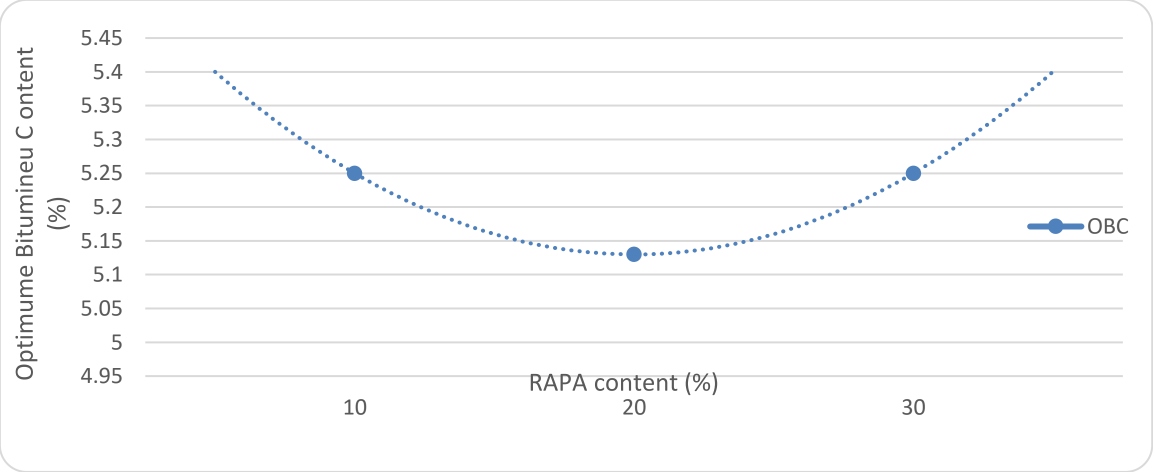

Figure 3 Optimum bitumen content vs. RAPA content

The Volumetric and Marshall Properties for 10%, 20%, and 30% RAPA substituted HMA, respectively, are presented in Figure 3 and Table 12. As this is the aim of the study, the first step is to examine and evaluate the test results for each partially substituted mix in light of the parameters that have been specified. The trend of specification parameters was compared and discussed across the mixes created for this research, as a further method of deciphering test data and observing RAPA's impact on HMA. Therefore, a graphical analysis of the relationships between stability, flow, and the percentage of voids filled with bitumen (VFB), voids in the air (VA), and voids in mineral aggregates (VMA) and bitumen content was provided. At using 10% RAPA the (% Mb) Stability, (% Mb) bulk density, and (% Mb) voids in the air were high and declined up to 20%RAPA then increasing and reaching 5.25 and more due to the highest value of the (% Mb) Stability, (% Mb) bulk density, and (% Mb) voids in the air. This shows that all of the calculated and measured mix properties at this asphalt content were evaluated by comparing them to the specification criteria. From Figure 3, it can be seen that the OBC need generally decreased with the quality of the RAPA aggregate being used. This could be a result of the RAPA content's poor strength, porosity, and quantity.

Table 12 Different Percentages of RAPA Make Up the OBC of HMA

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

3.5.1.3. How RAPA Affects the Marshall Quotient

Divide stability (kN) by flow to get the Marshall quotient (MQ), which gauges a material's resistance to permanent deformation in use (mm). The findings of the Marshall Stability and Flow tests showed that the asphalt that had been treated performed better than asphalt that had not been amended. The Marshall Quotient (MQ) test, however, showed that mixes with a 30% RAPA performance fell short of other blends that were regarded as equivalent in this study as shown in Figure 4.

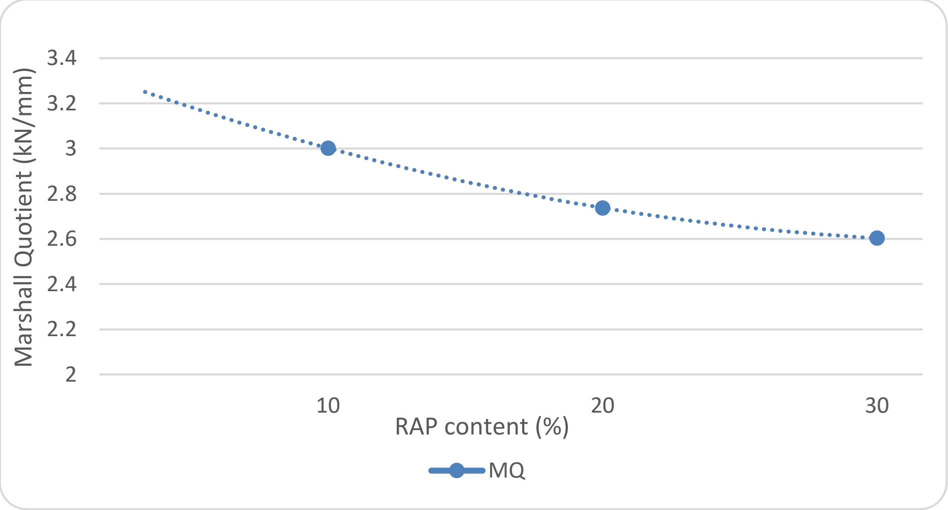

Figure 4 How RAPA affects the Marshall Quotient

Figure 4 illustrates a variation of Marshall Quotient (MQ) with a change in the dosage of CSA for the mixtures containing RAPA asphalt binder. When the amount of RAPA was increased, the magnitude of MQ reduced by up to 30% (the lowest MQ reached). However, as the RAPA content exceeded 30%, the magnitude of MQ decreased. The amount of RAPA in the asphalt mixture varied depending on its weight, ranging from 10% to 30% by weight. When these additives were combined in the right way, the mix was more resistant to deformation than when they were combined in other ways. According to the results of the study done by [22], the Marshall Stability increased by 7.22% using an asphalt mixture containing 20% RAPA at the ideal binder level of 5%. Similarly, the Marshal stability increased with the combined application of 20% RAPA and 80% CSA in the current study. The percentage of RAPA that satisfies the highest required magnitude of stability is considered an optimum amount. Accordingly, the 20% by weight of RAPA was identified as the optimum amount.

3.5.1.4. Identifying the bitumen content

The asphalt mixes were tested to ensure their OBC had mechanical properties as shown in detail in Table 13 and Figure 5. Marshall Properties of Bituminous Mixture at OBC are shown in Table 14.

Table 13 Optimal Bitumen Content Determination

WPB content	Stability		bulk density		Air void		OBC
	Bit.	Max.	Bit.	Max.	Bit.	Min.	
6 %	4.6	9.5	5.8	2.41	6	4	5.46
8%	4.9	9.45	6	2.38	5.4	4	5.43
10%	4.4	9	5.5	2.36	5.2	4	5.03
12%	5.4	9.3	6	2.35	5.2	4	5.53
14%	5.25	10.5	6	2.38	4.9	4	5.38

If bitumen is concentrated at a minimum of 10 percent, waste plastic could reduce bitumen consumption. However, it has its limitations, and the value of used plastic may be negligible.

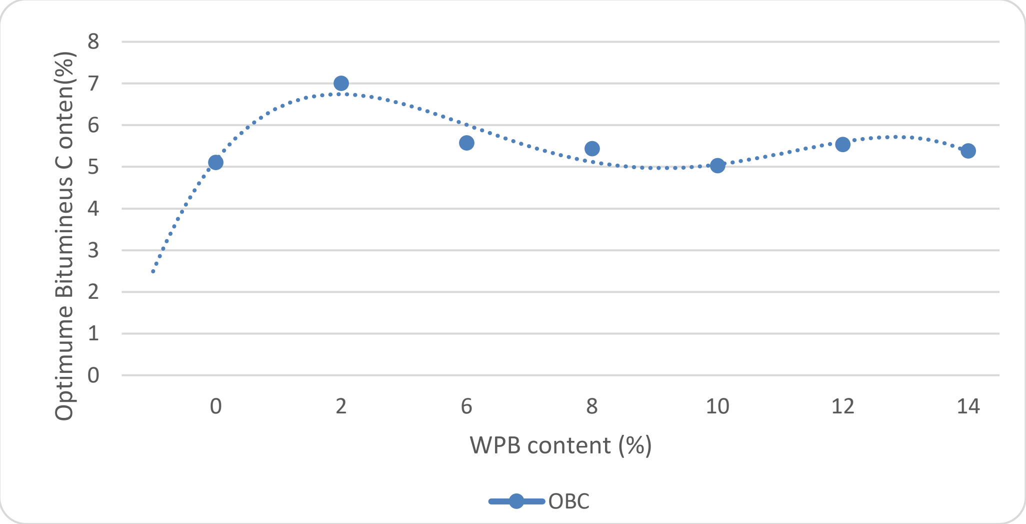

Figure 5 Optimum bitumen content vs. WPB

In Figure 5, the OBC climbed from 0% to 2% and then fell from 2% to 10%. It then showed an increase until it reached 10% to 14% of bitumen and WPB mix content. The OBC rose and the maximum value attained a peak at 7% before it dropped to 5% and then started to rise. The OBC grew, reaching its maximum with 2 percent WPB at 7% OBC, and its minimum with 0 percent at 5% OBC as discussed above.

This is because the higher adhesion created between bitumen and WPB-coated aggregates due to intermolecular bonding improved the strength of the asphalt mix, which in turn helps to increase the asphalt mix's durability and stability (ASTM) based on the WPB content. The stability climbed from 2% to 6% and then fell from 7% to 10%. It then showed an increase until it reached 10% to 14% of bitumen and WPB mix content. This study depicts how the stability point rose and the maximum value attained was 8.7 (kN) before it dropped to 8.6 (kN) and then started to rise. The stability point grew, reaching its maximum with 14 percent WPB at 9.3 (kN) on stability, and its minimum with 2 percent at 8.4 (kN) stability as discussed above. The WPB-modified asphalt mix had a lower bulk density (2.36 gm/cc) than regular asphalt mix. The bulk density fell as the WPB concentration increased, according to the usual tendency. At WPB content of 7%, the maximum bulk density was (2.37 gm/cc), whereas the minimum bulk density was (2.31 gm/cc) (14%). The low density of the added plastic material can be attributed to the decrease in bulk density. Figure 5 depicts the relationship between asphalt mix bulk density and WPB content which determined OBC Vs. WPB.

The VA content of modified asphalt mixtures was higher than that of regular asphalt mixtures. With increasing WPB content, the VA percent of partially replaced asphalt mixes grew continuously, peaking at 4.32 at 8% WPB. According to the curve depiction of the asphalt mix, the modified asphalt mixes have VA percent content within the required range. VA and WPB have a content relationship. Figure 5 shows VA and WPB content relation and shows Optimum bitumen content Vs. WPB. The horizontal and vertical arrows demonstrate that the optimum content based on 4% of air voids per NAPA standards is shown to use 10% of WPB.

The VMA percent of modified asphalt mixes was greater than the VMA percent of conventional asphalt mixes. Based on the VMA percent Vs. WPB content relationship, the VMA percent of modified asphalt mixes decreased as WPB content increased with bitumen content to a minimum value of VMA 16.96% with 5.2% of WPB content percent, and then increased with an increase in bitumen content of the asphalt mix. Figure 5 illustrates the highest VMA value obtained was 19.4% at 12% WPB content on Optimum bitumen content Vs. WPB. Therefore, it is concluded that waste plastic can lower the need for bitumen if the minimum optimal bitumen concentration is 10 percent. However, it has its limitations, and the value of used plastic may be negligible.

Table 14 Marshall Properties of Bituminous Mixture at OBC

WPB % (By OBC)	**sample**	**Bitumen % (By OBC)**	**Stability (Kg)**	**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

3.5.1.5 Effect of waste plastic bottles on Marshall Quotient

The findings of the Marshall Stability and Flow tests indicated that all modified asphalt was more valuable than regular asphalt. However, mixtures containing 6 percent waste plastic performed better than other examined mixtures in terms of the Marshall Quotient as shown in Figure 6.

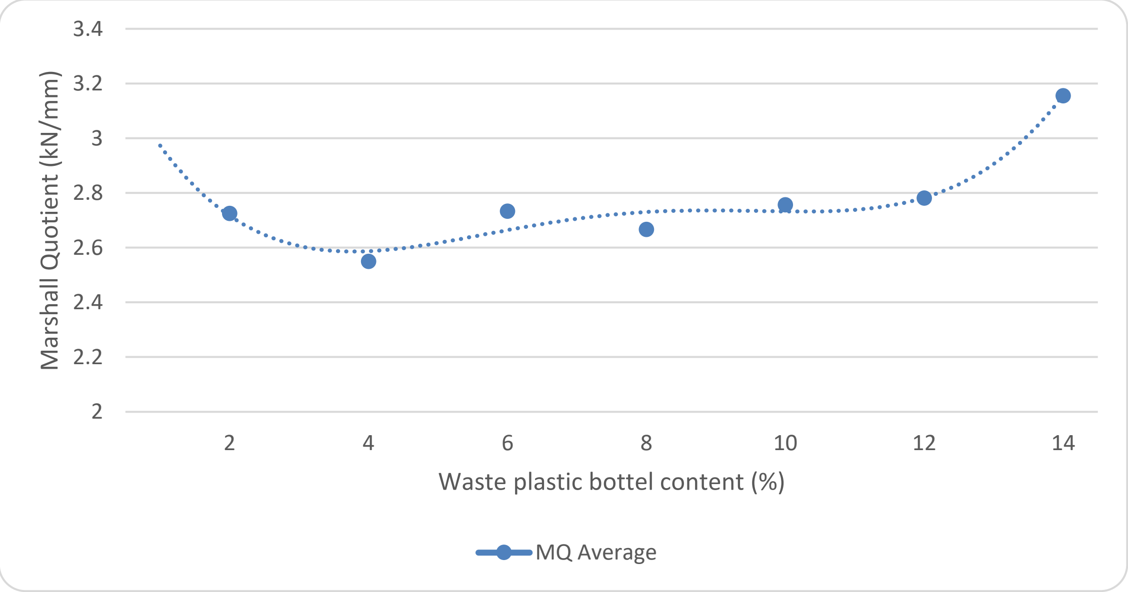

Figure 6 Effect of WPB content on Marshall Quotient

With a change in the dose of CSA and RAPA for combinations including WPB-modified asphalt binder, Figure 6 shows how the Marshall Quotient (MQ) can alter. The magnitude of MQ reduced with an increase in WPB content up to 4% (lowest MQ is reached) and subsequently increased. However, a further increase in the PET level above 4% results in a decrease in the magnitude of MQ. The modified asphalt binder (76% CSA, 20% RAPA, 4% WPB, and 5% by weight of WPB) was what made up the asphalt mixture. The key combination of these additives adds more than other combinations to the mix's resistance to plastic deformation. In the study conducted by [22], a mixture modified with 10% WPB at the optimum binder content of 5% improved Marshall Stability by 7.7%. Similarly, the Marshal stability increased with the combined application of 20% RAPA, 70% CSA, and 10%WPB in the current study. The percentage of WPB that satisfies the highest required magnitude of stability is considered an optimum amount.

Table 15 WPB Modified Asphalt Mix Properties Compared to Requirements

Property	**(5.4%) 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		

Other qualities of the modified mix were still within the acceptable range of the standards as shown in Table 15. The changed asphalt mix had a minor increase in OBC, air voids, VMA, and bulk density compared to 5.6 % OBC and air void filled in bitumen content, whereas has a minor decrease in stability, bulk density of 5.6 % OBC, and flow percent. As the enhanced adhesion between bitumen and WPB-coated aggregates, WPB offers a rougher surface texture for aggregate particles in a modified asphalt mix. Improved stability would have a favorable impact on the improved asphalt mix's fatigue and rutting resistance, resulting in a more durable asphalt surface [23] shows that the modified asphalt mix with 10% WPB by weight of OBC meets all of the requirements of the ERA and the Asphalt Institute for all of the qualities tested. The results were similar to other research done [20]. All WPB-modified asphalt mix properties are increased and higher except for stability. Other research was done by [15] on high OBC, stability at 5.1 OBC, flow & VFB except for 5.1 OBC, VA, and VMA, and lowest value of stability except for 5.1 OBC, flow & VFB of 5.1 OBC.

4.0 CONCLUSIONS AND RECOMMENDATION

Among the main objectives of this research was to recycle asphalt pavement aggregates and waste plastic bottles (WPB) in addition to hot-mix asphalt (HMA) production in Arba Minch for use as a wearing layer. Aside from the main objective, the study materials, such as crushed stone aggregates, RAPA, WPB, filler, and bitumen, were also tested in laboratories using ASTM, AASHTO, and BS standard test methods to illustrate their properties. Based on this study and compared to international asphalt institute specifications (ASTM) and local Ethiopian road authority specifications (ERA), RAPA and WPB can be used to determine the optimum percentage to be added to HMA production.

The following conclusions can be drawn based on the literature collected and reviewed, the laboratory test results, and the analysis and discussion part of the research.

- From the physical characteristics, it was observed that CSD is a grey color fine aggregate consisting of medium to fine sand-size particles and of angular shape with rough surface texture.
- Comparisons of physical attributes of CSA and RAPA results demonstrate that RAPA was weaker and more porous than CSD because a low specific gravity could be a sign of significant porosity, which would lead to inadequate strength and durability.
- The trend of specification parameters was compared and discussed across the mixes created for this journal, nevertheless, as a further method of deciphering test data and observing RAPA's impact on HMA.

- Based on the NAPA approach, the RAPA and WPB OBC were calculated for each of the following replacement percentages: 10%, 20%, and 30%, as well as 2%, 4%, 6%, 8%, 10%, 12%, and 14%.
- With optimum RAPA and WPB, all the Marshall properties were met, satisfied, and implemented. The ERA flexible pavement design manual OBC is found to be 5.1% in CSA, 5.1% in RAPA, and 5.0% in WPB for better asphalt mix performance. The experimental value of the Marshall Stability test results revealed that up to 30% replacement of aggregate is 20% RAPA and 10% WPB in HMA production, which satisfies the standard specification of the ERA flexible pavement design manual.
- The optimum amount of RAPA and WPB required for the asphalt binder and keeping the binder properties within the specification limit was 20% and 10% by weight. 10% WPB is used as a modifier binder. WPB is an optimum amount that significantly improves the critical properties of asphalt and is an integral part of pavement performance.
- The higher adhesion created between bitumen and WPB-coated aggregates due to intermolecular bonding improved the strength of the asphalt mix, which in turn helped to increase the asphalt mix's durability and stability (ASTM) based on the WPB content.
- The percentage of WPB that satisfies the highest required magnitude of stability is considered an optimum amount.
- Due to relative compatibility and enhancement convectional bitumen, disposable RAPA, and WPB-modified bitumen are recommended for road construction in this study.
- 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.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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