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*Research Article*

# The Influence of Coffee Husk Ash as a Filler on the Performance of Bituminous Concrete Mix

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Utilization of agricultural waste by-products in road construction has become a common practice in developing countries. The present study investigates the effect of coffee husk ash compared to basaltic stone dust on the performance of bituminous concrete mixes for road construction. Based on the Marshall mix design, a total of thirty (30) asphalt concrete specimens were prepared with basaltic stone dust and coffee husk ash as a filler with bitumen content between 4.0% and 6.0% at varying increments of 0.5%, and the Marshall stability test was performed on full mixes to determine the optimum asphalt content of the mixtures. From the test results, it is seen that specimens made with coffee husk ash and basaltic stone dust are found to have satisfactory Marshall properties, and moisture susceptibility shows that mixes using CHA filler provide better resistance to moisture effects than mixtures using BSD filler. When compared to BSD, the CHA shows an 8.43% increase in OBC. From the laboratory results, it has been shown that specimens made with coffee husk ash and basaltic stone dust are found to satisfy Marshall parameters and indirect tensile strength of bituminous concrete mixes when the coffee husk ash exhibits better performance than basaltic stone dust, which indicates that the CHA shows an increase of 35.80% compared to basaltic stone dust. The research findings indicated that the TSR of the paving mixes using basaltic stone dust was 94.58% and that using coffee husk ash was 105.03%, where both fillers satisfy the minimum limiting value of 80%. Overall, using coffee husk ash as a filler in hot mix asphalt concrete helps to solve a significant agricultural waste disposal issue while also being environmentally friendly.

## 1. Introduction

The majority of the world's road network is made up of flexible pavements, which use bituminous concrete mixtures as their wearing course. Hot-mix asphalt (HMA) concrete is a combination of aggregates (both coarse and fine), filler, and asphalt as a binder. While asphalt offers the binding action (glue of the mixture) and durability to asphalt mixes, different-sized aggregates give stability by acting as the structural skeleton of the pavement to withstand traffic loads. The mineral aggregates (both coarse and fine) in asphalt paving mixtures encompass approximately 90% of the volume of HMA. The properties of aggregates have a direct and significant effect on the performance of bituminous concrete pavements [1]. Asphalt concrete is the most commonly used pavement material due to its exceptional service performance in providing driving comfort, stability, durability, and water resistance [2, 3].

Highways are very expensive structures, so it is essential that the materials used in their construction meet the necessary standards. Flexible pavements are made with a 20-year project life in mind. The load distributions that would be present on these structures should thus also be computed and taken into account throughout the design process. Studies aimed at extending the lifespan and performance of roads are among the current study subjects. By using various additive materials, it is intended to improve the functionality and lifespan of roads [4].

Asphalt mixes contain filler, which affects how well they hold up under certain strains. The finest portion of aggregate that passes through a specific sieve no. 200 (0.075 mm sieve) can be referred to as filler. Filler can make up to 12% of the weight of asphalt mixtures. Wastes can be used for the production of new products or can be utilized as fillers. Nowadays the production waste materials from industries, agriculture lands, and other areas have been increased for the development of civilization. The generation of waste materials causes many deflections and is the main reason for environmental pollution. To overcome this problem, the wastes are recycled in many areas, such as construction of buildings and transportation areas. The mostly used fillers in bituminous mix are basaltic stone dust, cement, and lime. There are some other filler materials like brick dust, stone dust, concrete dust, limestone dust, fly ash or pond ash, marble dust, rice husk ash, corn cob ash, and egg shells, short-fibered asbestos that are finer than a 0.075 mm size sieve that can be used in the bituminous mixes.

Coffee husk ash (CHA) is a by-product of burning rice husks. Coffee husk is widely used throughout Ethiopia as a result of the region's considerable coffee growing. These Ethiopian countries profit from the optimum tropical temperature and fertile land that make for the best coffee-growing conditions. The husk of the coffee is taken off during the farming process before it is sold and consumed. Ethiopia has produced more paddy coffee. During the processing of coffee, approximately 192,000 metric tons (192 million kg) of coffee husk residue are produced, which is 50% of the total coffee production annually. Although the solid waste (coffee husks) is added to animal feed, the majority of it, about 134,400 metric tons (134.4 million kg), is dumped, filled in, and burned underground [5].

Utilizing waste materials is something that is becoming more and more popular today. The development and use of waste as supplemental cementitious materials have become increasingly popular in the construction sector. Common pozzolanic agents from industry and agriculture by-products, like fly ash and RHA, are developing into active research areas because using them not only results in a diversified product quality of the blended cement concrete but also in cost savings and adverse effects on the environment [6–9]. As per [9], the experimental results showed that the Marshall properties of the specimens constructed with nontraditional fillers (such as slag and rice husk ash) are nearly identical to those of conventional fillers (e.g., stone dust). Slag and stone dust both have the same optimal asphalt content (5.5%), but rice husk ash (5.83%) has a little higher value.

According to [10], the marshal properties of brick dust as a filler in bituminous mixtures, are practically exactly the same as those of traditional fillers, such as cement and lime. The findings demonstrated that bituminous mixtures including brick dust as a filler exhibited their greatest stability at a certain bitumen content, with an increasing trend up to that amount and then gradually declining. According to [11], the number of trucks and automobiles using the road is growing, which increases the loading on the asphalt surface of the road. This frequent loading caused issues such as irreversible deformation, cracking, fatigue, and sliding. Numerous studies have been carried out to identify the best waste products that may be used to increase the resistance to rutting and fatigue cracking caused by filler hardening and filler adherence to aggregate. The purpose of this study is to look into how CBA affects an asphalt mixture's engineering qualities. The asphalt mixture was supplemented with CBA in various amounts (0%, 2%, 4%, and 6%). The asphalt had a penetration grade of 60–70%. Marshall stability, indirect tensile strength, resilient modulus, dynamic creep, and image analysis were used to assess the performance of the samples. According to the data, the addition of CBA had a considerable impact. The findings indicate that the best results for density, stability, stiffness, and flow are obtained with a CBA addition of 2–4%, while the best outcomes for indirect tensile strength, dynamic creep, and resilient modulus are obtained with a CBA addition of 6%. Therefore, it can be said that the presence of CBA can improve the effectiveness of asphalt mix. Mineral filler is often added to asphalt mixtures to stiffen the asphalt binder and boost the mixture's strength. For open gradations like porous asphalt, which is notorious for having low strength and durability due to its open structure and extensive air voids, this is essential. Specific mastic properties that affect the mixture's strength are produced by the interactions between the filler and the asphalt binder. As per [12], the study examined the effects of various filler types on the rheological properties of asphalt-filler mastics for porous asphalt using the frequency sweep and multiple stress creep recovery (MSCR) tests. Hydrated lime, cement, and diatomite with a 2% composition were utilized to create the asphalt-filler mastic. When compared to those of hydrated lime and cement fillers, diatomite filler's properties were studied. The indirect tensile strength (ITS) test conducted by [13] revealed that the strength of the asphalt mixture increases with increased filler content. This result is consistent with the findings of [14], according to which a higher filler content increases the tensile strength of a mixture. Because of this increased tensile strength, mixes containing filler can withstand higher tensile stresses before failing [15].

Based on previous literature, it is clear that filler is an important component of bituminous concrete mixtures. In this study, the aim is to evaluate the influence of coffee husk ash as a filler on the performance of bituminous concrete mixtures and indirect tensile strength compared with conventional filler (basaltic stone dust).

## 2. Materials and Methods

*2.1. Experimental Methods.* In this study, the effects of coffee husk ash (CHA) as a filler in comparison to basaltic stone dust (BSD) filler on the properties of bituminous concrete mix are examined using coarse aggregate (13–19 mm), intermediate aggregate (5–13 mm and 3–5 mm), and fine aggregate (0–3 mm) as aggregate. There are two stages to the entire laboratory experiment. Basic test methods are used in the first stage to evaluate the physical characteristics of bitumen, mineral filler, and aggregate. Additionally, the CHA and BSD mineral fillers' physical and chemical compositions are investigated. In the second stage, the foremost function of this laboratory work is to investigate the optimum bitumen content of a bituminous mix with different types of bitumen contents of 4.0%, 4.5%, 5.0%, 5.5%, and 6% for each type of filler used. These tests were performed in the First Highway Engineering Asphalt Plant Testing Laboratory of the Institute of Technology at Bahir Dar University. In order to perform the laboratory work, Marshall specimens were prepared and tested in accordance with ASTM D 6926-04 [16].

### 2.2. Materials

*2.2.1. Aggregates.* In this study, basaltic rock stones obtained from the first highway engineering (FH Eng.) asphalt plant were used. Different sizes of aggregates, viz., 13–19 mm, 5–13 mm, 3–5 mm, and 0–3 mm, were used for the preparation of bituminous mixes. The quality of the aggregate plays a great role in the performance and service life of flexible pavement structures. The physical properties of aggregate were tested before putting them to use. These tests include determining properties of aggregates such as specific gravity, particle shape, strength, and water absorption of the aggregates. Table 1 shows the mix composition and sieve analysis of aggregates according to AASHTO T27 and T37 [17]. The physical requirements of aggregates should meet the desired specifications as specified by American and European standards [18–23], as given in Table 2.

*2.2.2. Mineral Fillers.* The porosity of the asphalt mixture, which fillers greatly contribute to, helps to solve problems like permanent deformation, cracking, fatigue, and skidding that can occur on bituminous pavements. Numerous studies have been conducted to identify the suitable waste materials that can be utilized to increase filler adhesion to aggregate and resistance to rutting and fatigue cracking brought on by filler hardening [11]. Mineral fillers are often described as substances that pass through the No. 200 (0.075 mm) standard sieve. According to various investigations, at least 70% of this material passes the No. 200 (75 mm) screen when it comes to the grain size of mineral fillers. In the present study, two types of fillers were used for the preparation of specimens, such as basaltic stone dust (BSD) and coffee husk ash (CHA), which passed through the No. 200 sieve.

The coffee husk utilized in this study was gathered from the coffee industry and burned in a furnace at 550°C for four hours to reduce it to ash, with the leftover ash being used as coffee husk-ash mineral filler. Therefore, it must perform better as a professional, utilizing these solid waste materials (coffee husks) by using a furnace to convert them to ash and using them as an alternative filler material in the manufacturing of hot mix asphalt mixture and improving some of the mechanical attributes of hot mix asphalt mixture. Basaltic stone dust (BSD) is a conventional filler material gathered from the First Highway Engineering (FH Eng.) PLC quarry site. Table 3 displays the physical parameters of the filler material that was used in accordance with the standard specification ASTM D242 [24].

*2.2.3. Chemical Composition of Fillers and Their Composite Analysis.* Table 4 displays the chemical compositions of the traditional filler made of basaltic stone dust and the unconventional filler made of coffee husk ash, an agricultural waste product. The total of ($SiO_2 + Al_2O_3 + Fe_2O_3$) must be more than or equal to 70% to meet ASTM C618 requirements. After burning coffee husk, which is thought to have strong reactivity and pozzolanic properties, ash is created. Basaltic stone dust and coffee husk ash both have high $SiO_2$ levels (58.05% and 60.00%, respectively), which are indicative of their strong mechanical strength, stability, impermeability, and durability properties. The chemical properties of the employed filler materials are shown in Table 4.

*2.2.4. Asphalt Binder.* The asphalt utilized in this study was bitumen of grades 60/70 that was obtained from the FH Engineering Asphalt Plant Testing Laboratory of the Institute of Technology at Bahir Dar University. 60/70 PG bitumen is commonly used in Ethiopian road construction operations because it is temperature and weather resistant. The test results were compared to the requirements set by American and Ethiopian standards. Table 5 displays the physical parameters of the bitumen material that was used in accordance with the standard specification of AASHTO [25–29] are given in Table 5.

### 2.3. Marshall Mix Design and Sample Preparation of the Mix.

The Marshall Mix design procedures have been specified by the American Society for Testing and Materials and published as ASTM D1559 [30] and AASHTO T245 [31]. It consists of a specimen produced at 100 mm in diameter, compacted with an impact Marshall compactor, using a Marshall apparatus for stability and flow determination as well as for volumetric property determination (air voids, voids in the mineral aggregate (VMA), and voids filled with asphalt (bitumen) (VFA). Marshall stability and flow cannot be employed in analytical pavement design calculations because they are empirical features. According to ASTM-specified limit values for the Marshall mix design criteria, which include the number of compactions, minimum stability value, flow value, air voids, voids filled with asphalt, and voids in mineral aggregate, they are 75, 8 kN, 2–4 mm, 3–5%, 65–75%, and based on nominal maximum aggregate size (in this study, minimum 13%), respectively, for a heavy traffic road. The needed mass of binder is added to the hot mixer after the appropriate mass of aggregate has been added. In order to evaluate the ideal bitumen percentage for each type of filler used, samples for bituminous concrete mixes were made in accordance with ASTM D1559 [30], ranging from 4.0% to 6.0%, utilizing increments of 0.5% by the total weight of the AC mix. The bituminous concrete's Marshall stability, flow values, and volumetric characteristics were assessed using a total of 30 samples. The mixture is poured into the Marshall mold (64 mm high and 100 mm in diameter) and compacted with a standard hammer device weighing 4.5 kg and designed to drop from a height of 457 mm with 75 blows in each face.

Table 1: Aggregates gradation and specification criteria as per ASTM D3515 for nominal size 19 mm.

| Sieve size (mm) | Percentage passing (%) | % used | Weight (gm) | AASHTO T27 and T37 [17] specification |
|---|---|---|---|---|
| 19 | 100.00 | 0.00 | 0.00 | 100 |
| 12.5 | 93.10 | 6.90 | 82.80 | 90–100 |
| 4.75 | 63.00 | 30.10 | 361.20 | 44–74 |
| 2.36 | 43.20 | 19.80 | 237.60 | 28–58 |
| 0.3 | 11.40 | 31.80 | 381.60 | 5–21 |
| 0.075 | 3.40 | 8.00 | 96.00 | 2–10 |
| Filler | 0.00 | 3.40 | 40.80 | |
| Total | | 100.00 | 1200.00 | |

Table 2: Physical requirements for aggregates as per specifications.

| Test property | Test method | | Test results | | | | Recommended values |
|---|---|---|---|---|---|---|---|
| | AASHTO | CEN EN | 13–19 mm | 5–13 mm | 3–5 mm | 0–3 mm | |
| Bulk dry S. G | | | 2.694 | 2.718 | 2.716 | 2.747 | — |
| Bulk SSD S. G | T 85-91 [18] | | 2.740 | 2.770 | 2.769 | 2.801 | — |
| Apparent SG | | | 2.813 | 2.859 | 2.866 | 2.904 | — |
| Water absorption, % | | 1097-6 [19] | 1.570 | 1.870 | 1.926 | 1.968 | 2% max |
| Sand equivalent, % | T 176-86 [20] | | 76.4 | — | — | — | 40% min |
| Flakiness index | | 933-3 [21] | 22 | — | — | — | 45% max |
| ACV, %AX | | 933-5 [22] | 12 | — | — | — | 25% max |
| LAA, % | T 96 [23] | | 14 | — | — | — | 30% max |

Table 3: Physical properties of used filler materials.

| Sieve size (mm) | Percentage passing | | Standard specification (ASTM D242 [19]) |
|---|---|---|---|
| | BSD | CHA | |
| 2.36 | 100.00 | 100.00 | 100 |
| 0.30 | 99.98 | 100.00 | 95–100 |
| 0.075 | 94.40 | 100.00 | 70–100 |
| Sp. Gravity | 2.91 | 2.72 | — |

Table 4: Chemical compositions of BSD and CHA.

| Chemical constituents | Contents (%) | | Specifications (ASTM C618) |
|---|---|---|---|
| | BSD | CHA | |
| Silicon dioxide ($SiO_2$) | 58.05 | 60.00 | |
| Aluminum oxide ($Al_2O_3$) | 10.41 | 7.48 | |
| Iron oxide ($Fe_2O_3$) | 11.29 | 3.00 | |
| Calcium oxide (CaO) | 7.63 | 9.52 | |
| Magnesium oxide (MgO) | 4.32 | 4.08 | |
| Sodium oxide ($Na_2O$) | 1.92 | 0.08 | |
| Potassium oxide ($K_2O$) | 3.93 | 2.00 | |
| $SiO_2 + Al_2O_3 + Fe_2O_3$ | 79.75 | 73.07 | Min. 70% |

*2.4. Combined Gradation of Mineral Aggregates.* Any form of roadwork mix design should take the aggregate's gradation into consideration. It has an impact on a bituminous concrete mix's essential characteristics. The performance of a pavement is largely dependent on the right choice of aggregate gradation made during the initial stage of bituminous mix design. According to a clause of the American Standard Specification, the gradation of 19 mm nominal size aggregate bituminous concrete (BC) was chosen for this study. The combined grading of coarse aggregate (13–15 mm), intermediate aggregate (5–13 mm, 3–5 mm), and fine aggregate (0–3 mm), evaluated in accordance with ASTM D1559, should comply with the ASTM-specified limits listed in Table 1. In order to prevent gap grading, the combined grade must fall within the lower and upper limits shown in Figure 1. According to ASTM D3515 requirements, the combined aggregate's maximum gradation for use in the asphalt binder course was chosen.

*2.5. Marshall Stability Test.* The construction and evaluation of bituminous mixtures can be done using the Marshall Test, a simple and extensively used laboratory test that has been employed by countries all over the world, including Ethiopia. The stability of the test specimen will possess the highest load resistance when heated to 60°C. A 0.1 mm deformation upon breaking is used to express the flow. According to ASTM D6927-06 [32], the test has primarily been used in this study to evaluate the various mixtures at different bitumen levels, and the parameters considered are stability, flow value, and volumetric properties of the mix. The test should be designed in 0.5 percent increments with at least two binder contents below the optimum. The ideal bitumen content was chosen to have the highest levels of

Table 5: Physical properties of the 60/70 penetration bitumen grade.

| Property | Units | Test method (AASHTO) | Test results | ERA limits as per specification |
|---|---|---|---|---|
| Penetration value (25°C) | 0.1 mm | T 49 [20] | 66.50 | 60–70 |
| Ductility test | Cm | T 51 [21] | Full scale | Min 75 |
| Softening point test | °C | T 53 [22] | 48.9° | 42–51 |
| Solubility | % | T 44 [23] | Full scale | Min 75 |
| Specific gravity | -- | T 228 [11] | 1.02 | 1.05 |

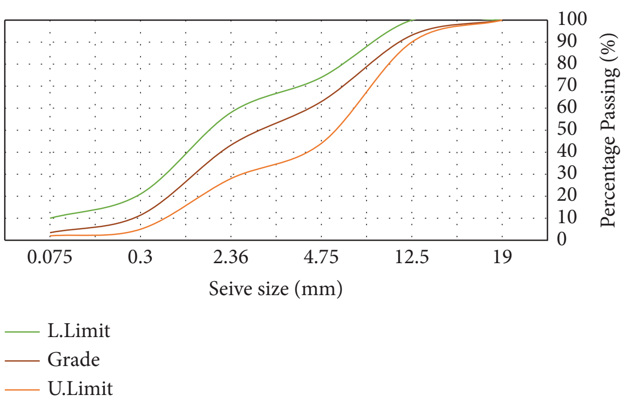


Figure 1: Combined aggregate gradation of the mixture.

stability, unit weight, and median permissible limits for percentage air voids. The optimum bitumen content (OBC) is determined by taking the average of the bitumen concentration for these three characteristics.

*2.6. Indirect Tensile Strength and Tensile Strength Ratio Test.* According to ASTM D6931 [33], the ultimate load of failure of a specimen subjected to a continuous rate of deformation of 51 mm per min on its diameter axis is used to determine the indirect tensile strength (ITS). Using the indirect tensile strength (ITS) test, the low-temperature cracking resistance of an asphalt mixture is evaluated. The ITS test is performed at 25°C on mixtures of basaltic stone dust and coffee husk ash, according to ASTM D6931. The conditioned set and the unconditioned set are two independent sets of the conditioned specimens that are cured at 60°C for 24 hours prior to testing. According to ASTM D 4867 [34]and AASHTO T-283 [35] standards, the asphalt mixture should exhibit a minimum tensile strength ratio (TSR) value of 80% to satisfy the moisture damage requirements. To calculate the ITS of an asphalt mixture, the maximum load at failure value is inserted in equation (1). A higher TSR for an asphalt mixture means better moisture resistance, and the opposite is also true. Tensile strength ratio (TSR) calculation evaluates an asphalt mixture's resistance to moisture damage as shown in the following:

$$TS\,(kPa) = \frac{2 \times \mathbf{P}}{\boldsymbol{\pi} \times \mathbf{t} \times \mathbf{d}}, \tag{1}$$

$$TSR\,(\%) = \frac{\mathbf{Avg.ITS_{cs}}}{\mathbf{Avg.ITS_{us}}}. \tag{2}$$

In where, $P$ = peak load, in kilo newton; $t$ = sample thickness, in mm; $d$ = sample diameter, in mm; Avg. ITScs = average tensile strength of a conditioned set, in kPa; Avg. ITSus = average tensile strength of an unconditioned set, in kPa.

## 3. Results and Discussion

*3.1. Marshall Stability.* The Marshall properties of each specimen, such as stability, flow, bulk density ($\rho$b), or bulk specific gravity (Gmb), the percentage of air voids (Va), the percentage of voids in the mineral aggregate (VMA), and the percentage of voids filled with asphalt (bitumen) (VFA), are the parameters obtained from the Marshall stability. The Marshall stability of the mix is defined as the maximum load carried by the test specimen at a standard test temperature of 60°C [9, 36]. To determine the optimum bitumen content, a total of thirty (30) asphalt concrete specimens were prepared with basaltic stone dust and coffee husk ash as fillers, with bitumen contents ranging between 4.0% and 6.0% at varying increments of 0.5%. Three samples were prepared for each bitumen content. According to [37] Marshall design criteria for heavy traffic, the minimum Marshall stability must be 8.00 kN at 60°C, the flow value must range between 2 mm and 4 mm, the percentage of air voids must range between 3% and 5%, the minimum VMA related to the nominal maximum particle size of 19 mm must be 13%, and the VFB must range between 65 and 75%. Tables 6 and 7 indicate the average Marshall properties of mixtures at their various bitumen contents for mixes with basaltic stone dust and coffee husk ash filler, respectively. The plots also show the variation of parameters with bitumen content for both types of fillers considered in this study, as shown in Figures 2 and 3. It has been observed that Marshall test results of mixtures with basaltic stone dust and coffee husk ash filler as filler and the corresponding values of Marshall properties such as Marshall stability, flow value, air voids, voids in mineral aggregates, voids filled with asphalt, and unit weight at different bitumen contents give satisfactory results, as suggested by the Asphalt Institute [37].

*3.2. Determination of the Optimum Bitumen Content.* The optimum bitumen content (OBC) was determined by the method of the National Asphalt Pavement Association (NAPA). First, find the bitumen content, which corresponds to the median air void content (4%) of the requirement. Second, determine the bitumen content corresponding to maximum stability, and third, determine the bitumen content corresponding to maximum bulk density. Therefore, the optimum bitumen content is the average of the above three bitumen contents corresponding to air void, stability, and bulk density. In this study, the two filler types with

Table 6: Laboratory mix design result with BSD.

| Bitumen (%) | ρ A (gm/cc) | VA (%) | VMA (%) | VFA (%) | Stability (kN) | Flow (mm) | Stability (kN) (after 24 h) |
|---|---|---|---|---|---|---|---|
| 4.0 | 2.389 | 10.01 | 17.97 | 44.30 | 9.67 | 2.22 | 8.44 |
| 4.5 | 2.398 | 9.71 | 17.71 | 45.19 | 10.15 | 2.37 | 9.26 |
| 5.0 | 2.403 | 4.56 | 17.95 | 74.61 | 10.20 | 2.41 | 9.56 |
| 5.5 | 2.406 | 4.12 | 18.27 | 77.44 | 10.97 | 2.34 | 10.75 |
| 6.0 | 2.408 | 3.83 | 18.64 | 79.44 | 9.97 | 2.62 | 9.81 |
| Standard values | | 3–5 | Min 13 | 65–75 | Min 8 | 2–4 | Min 8 |

Table 7: Laboratory mix design result with CHA.

| Bitumen (%) | ρ A (gm/cc) | VA (%) | VMA (%) | VFA (%) | Stability (kN) | Flow (mm) | Stability (kN) (after 24 h) |
|---|---|---|---|---|---|---|---|
| 4.0 | 2.13 | 12.39 | 18.97 | 34.70 | 10.91 | 2.77 | 9.67 |
| 4.5 | 2.23 | 7.79 | 15.76 | 50.59 | 11.95 | 3.08 | 11.06 |
| 5.0 | 2.25 | 6.31 | 15.46 | 59.17 | 13.98 | 3.17 | 13.54 |
| 5.5 | 2.27 | 4.44 | 14.83 | 70.04 | 14.54 | 3.37 | 15.32 |
| 6.0 | 2.28 | 3.43 | 14.97 | 77.11 | 13.87 | 3.60 | 13.84 |
| Standard values | | 3–5 | Min 13 | 65–75 | Min 8 | 2–4 | Min 8 |

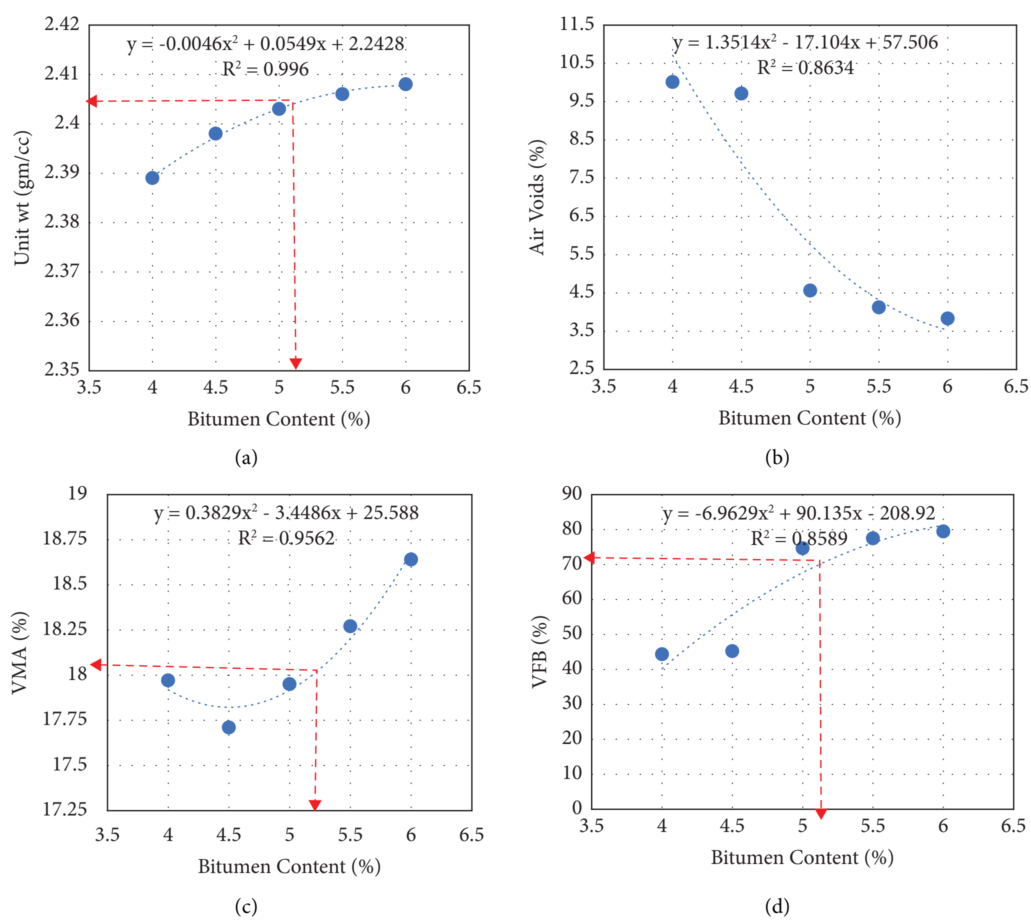


Figure 2: Continued.

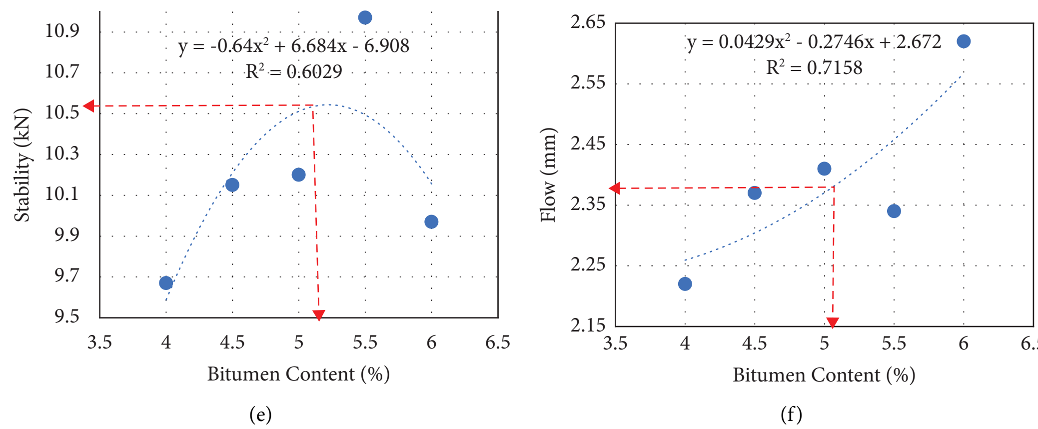


Figure 2: Typical graphs of Marshall properties with basaltic stone dust (a–f). (a) Bitumen content vs. unit wt. (b) Bitumen content vs. VA, (c) bitumen content vs. VMA, (d) bitumen content vs. VFA, (e) bitumen content vs. stability, and (f) bitumen content vs. flow.

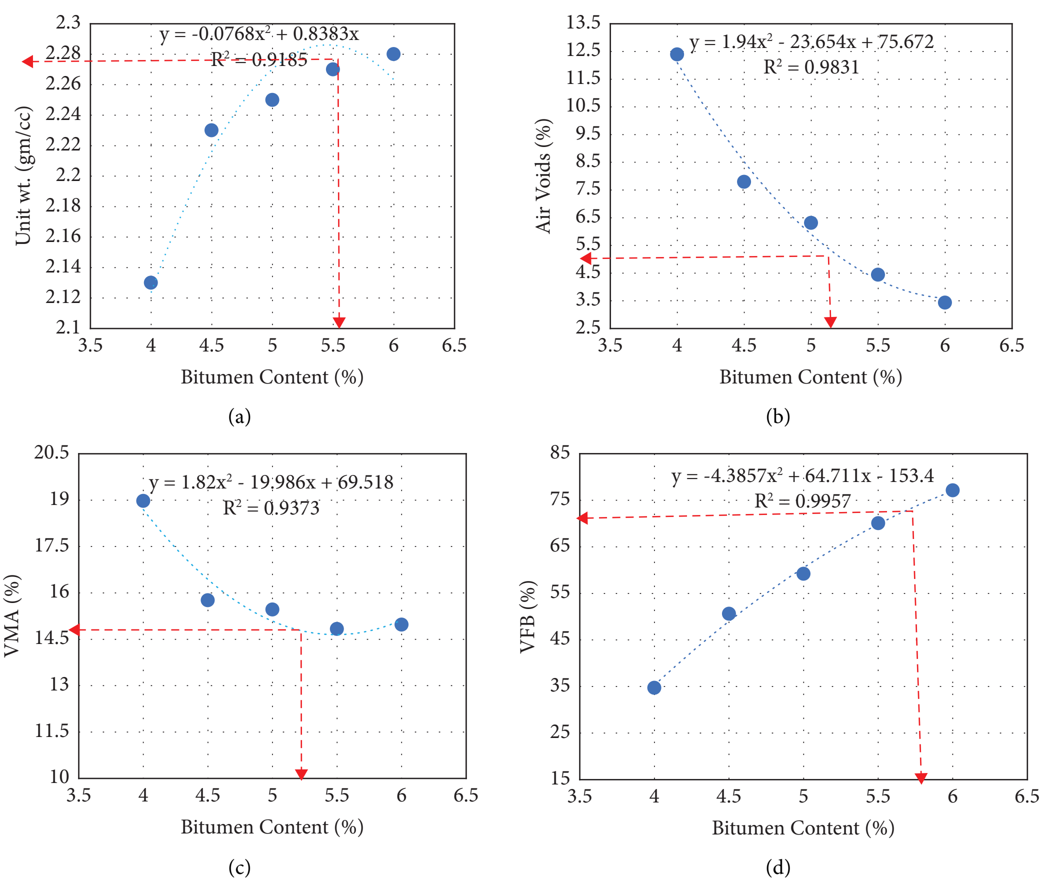


Figure 3: Continued.

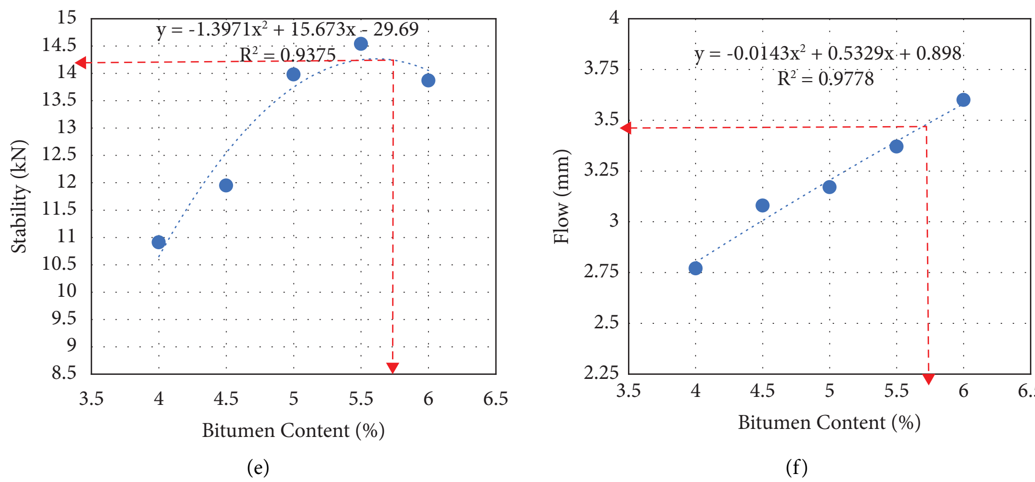


Figure 3: Typical graphs of Marshall properties with coffee husk ash (a–f). (a) Bitumen content vs. unit wt. (b) Bitumen content vs. VA, (c) bitumen content vs. VMA, (d) bitumen content vs. VFB, (e) bitumen content vs. stability, and (f) bitumen content vs. flow.

bitumen content are then used to determine the values for Marshall stability, flow value, unit weight, air voids, voids in mineral aggregates, and voids filled with asphalt in the mix, as plotted in Figures 2 and 3. The obtained value is compared against the specified value for that property, and if all are within the specified range, the bitumen content at 4% air voids is the optimum bitumen content. Based on the outcome, the optimum bitumen content is 5.10% and 5.30% for basaltic stone dust and coffee husk ash mineral filler, respectively, at 4% air voids. The BSD shows reduced OBC by 3.77% compared to CHA. Table 8 lists the volumetric parameters VA, VMA, VFB, stability, and flow that satisfy the required limits for both mixes.

*3.3. Influence of CHA on Engineering Properties of Asphalt Mixture.* In Figure 2(a) through 2(f), the relationship between filler content and Marshall properties of mixtures using basaltic stone dust as filler is shown. It has been shown that the maximum stability (10.97 kN) is obtained at 5.5% asphalt content; the values of unit weight, VFA, and VMA are increased by increasing the filler content; the values of flows are increased by increasing the filler content; and the air void is decreased by increasing the filler content. The relationship between filler content and Marshall properties of mixtures for coffee husk ash as filler is depicted in Figure 3(a) through 3(f). It has been shown that the maximum stability (14.54 kN) is obtained at 5.5% asphalt content; the values of flow, VFA, and unit weight are increased by increasing the filler content; the values of air void and VMA are decreased by increasing the filler content in a range of 4% to 6% at an interval of 0.5% asphalt content. The results of this study have shown that the use of coffee husk ash and basaltic stone dust as fillers at 5.5% have the maximum stability. The asphalt concrete mix engineering properties using basaltic stone dust and coffee husk ash as mineral fillers are shown in Table 8. The results show that specimens made with nonconventional filler (coffee husk ash) are found to have satisfactory Marshall engineering properties as per the American Association of State Highway and Transportation Officials' specification limits, which are met by the two values of Marshall properties, which are almost the same as the conventional filler (basaltic stone dust) values. The Marshall quotient of the coffee husk ash is 4.2, which complies with the demands of the highway authorities' minimum ratio of 2.0 and maximum ratio of 5.0. It can be shown that maximum Marshall stability is observed with coffee husk ash, followed by basaltic stone dust filler materials. The optimum bitumen content of basaltic stone dust is 5.10%, and that of coffee husk ash filler materials is 5.53%. The findings of the Marshall stability for stability and flow values are shown in Figures 3(e) and 3(f), respectively. The relationship between stability and flow values with respect to asphalt content is directly proportional ($R2 = 0.94$ and $R2 = 0.98$), which indicates a strong relationship between stability and flow values with asphalt content. This investigation indicates that as the stability and flow values increase, the filler content of the bitumen also increases, according to [9]. The coffee husk ash exhibits an increase of 35.7 percent compared to the conventional filler (basaltic stone dust). CHA shows an increased flow value of 44.73% over basaltic stone dust, both of which exhibit flow values within the range (2–4 mm) specified by the specifications. The current results show that coffee husk ash has good filler properties since the mixture with coffee husk ash produced better outcomes than basaltic stone dust. Coffee husk ash is extremely effective at strengthening the chemical connections between the aggregates and the binder in asphalt mixtures due to its chemical activity, which results in a strong physical-chemical interaction with the asphalt binder.

*3.4. Indirect Tensile Strength and Tensile Strength Ratio Test.* Figures 4 and 5 for both filler types show the values of the results of the indirect tensile strength and tensile strength ratio. The mixes that contain coffee husk ash in an unconditioned state have the highest tensile strength values, as shown. The ITS of conditioned mixes revealed similar

Table 8: Marshall properties of specimen mix with the two filler materials at OAC.

| Mix type | Marshall parameters | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | OBC (%) | UW (g/cc) | AV (%) | VMA (%) | VFA (%) | Stability (kN) | Flow (mm) | Marshall Quotient (kN/mm) |
| BSD | 5.10 | 2.404 | 4.70 | 18.05 | 70.12 | 10.53 | 2.37 | 4.44 |
| CHA | 5.53 | 2.275 | 4.97 | 14.65 | 72.25 | 14.30 | 3.43 | 4.17 |
| Standards | — | — | 3–5 | Min 13 | 65–75 | Min 8 | 2–4 | 2–5 |

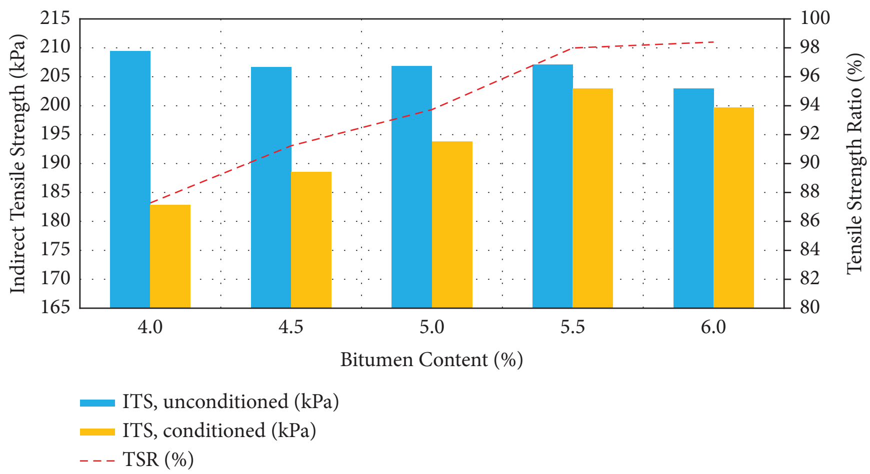


Figure 4: Indirect tensile strength and tensile strength ratio test results for BSD.

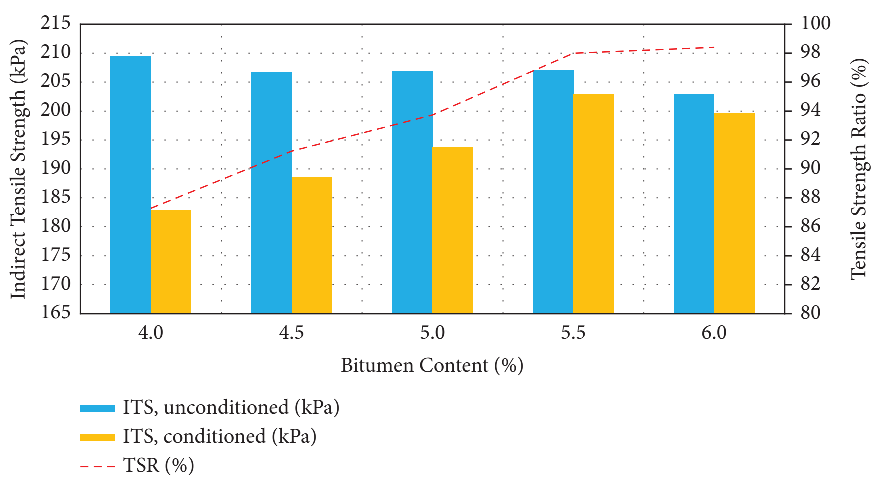


Figure 5: Indirect tensile strength and tensile strength ratio test results for CHA.

tendencies. Based on those findings, it appears that conditioned samples have a lower ITS than unconditioned samples. This observation shows that the mixtures deteriorated and that moisture conditioning significantly lowered the tensile strength of the mixtures. ITS is higher in samples made with coffee husk ash than in those made with basaltic stone dust. As a result, samples containing coffee husk ash show better resistance to moisture damage than samples made of basaltic stone dust. TSR values for combinations with coffee husk ash are somewhat higher than those for basaltic stone dust filler. In AASHTO T283, a minimum TSR value requirement of 80% was set for Superpave mix designs. Results show that all mixes have TSR values greater than 80%, suggesting that basaltic stone dust and coffee husk ash may help increase moisture resistance. As revealed in Table 9, the TSR values of the bituminous concrete mix using basaltic stone dust and coffee husk ash are 98.40%, and 105.36%, respectively, which satisfy the limiting value of 80%. According to [38], the TSR values were observed in the samples prepared with hydrated lime, cement, and diatomite at 88.80%, 90.60%, and 91.90%, respectively, which satisfied the minimum requirements of the specification. In this study, the results show and the previous literature indicates that filler is an important ingredient in asphalt concrete mixtures, all of which are within the specified range as per American standards. Tables 9 and 10 show the indirect

Table 9: Indirect tensile strength results for basaltic stone dust as a filler.

| Bitumen (%) | Load (kN) | | Area (mm$^2$) ($\pi^* t^* d$) | Indirect tensile strength (kPa) | | TSR (%) |
|---|---|---|---|---|---|---|
| | Standard | Conditioned | | Unconditioned | Conditioned | |
| 4.0 | 9.67 | 8.44 | 29.393 | 209.44 | 182.80 | 87.28 |
| 4.5 | 10.15 | 9.26 | 31.265 | 206.67 | 188.55 | 91.23 |
| 5.0 | 10.2 | 9.56 | 31.401 | 206.79 | 193.82 | 93.73 |
| 5.5 | 10.97 | 10.75 | 33.716 | 207.13 | 202.98 | 97.99 |
| 6.0 | 9.97 | 9.81 | 31.279 | 202.92 | 199.66 | 98.40 |

Table 10: Indirect tensile strength results for coffee husk ash as a filler.

| Bitumen (%) | Load (kN) | | Area (mm$^2$) | Indirect tensile strength (kPa) | | TSR (%) |
|---|---|---|---|---|---|---|
| | Standard | Conditioned | | Unconditioned | Conditioned | |
| 4.0 | 10.91 | 9.67 | 29.411 | 236.15 | 209.31 | 88.63 |
| 4.5 | 11.95 | 11.06 | 31.787 | 239.33 | 221.51 | 92.55 |
| 5.0 | 13.98 | 13.54 | 35.213 | 252.75 | 244.79 | 96.85 |
| 5.5 | 14.54 | 15.32 | 32.565 | 284.25 | 299.49 | 105.36 |
| 6.0 | 13.87 | 13.84 | 32.04 | 275.59 | 274.99 | 99.78 |

tensile strength values of various bitumen contents and the moisture susceptibility value of the tensile strength ratio values, respectively.

## 4. Conclusion

According to the results of this study, evaluate the influences of coffee husk ash (CHA) on the engineering properties of bituminous concrete mixtures compared with the conventional filler (basaltic stone dust). The following conclusions have been drawn from the various laboratory results:

(1) The optimum bitumen content was found to be 5.53%, which can provide a coffee husk ash filler in the bituminous concrete mixture. For an OBC of 5.53%, the stability value, the flow value, and the VFA were 14.30 kN, 3.43 mm, and 72.25%, respectively, and all these properties satisfy the limits specified as per AASHTO and ERA for the bituminous concrete (BC) mix.

(2) The substitution of BSD by CHA has significantly increased the stability value. The coffee husk ash (CHA) increases the stability by 35.8 percent compared to the basaltic stone dust (BSD) mixture. However, both these mixes yield stability values above the minimum required value of 8 kN, according to AASHTO specifications. And also, the volumetric parameters such as VA, VMA, and VFB satisfy the required criteria as per AASHTO specifications.

(3) The Marshall quotient (MQ) represents the stability of bituminous concrete mixtures against unit deformation, expressed in kN per mm unit. The results of this study show that both BSD and CHA have MQ values of 4.44 kN/mm and 4.20 kN/mm within the range (2–5 kN/mm) specified by the AASHTO specification.

(4) The results of the study showed that the tensile strength ratio (TSR) of the bituminous concrete mixture made with basaltic stone dust filler was 94.58% and that made with coffee husk ash filler was 105.03%, both of which met the specifications' minimal limiting value of 80%. The results of the indirect tensile strength tests showed that the tensile strength ratio values increased as the filler content increased. Since a high TSR indicates a thicker mix, which reduces the tendency for water to percolate into the asphalt mix and result in moisture-related issues, it follows that the effect of moisture damage decreases as moisture resistance increase.

## Abbreviations

| | |
|---|---|
| BSD: | Basaltic stone dust |
| CHA: | Coffee husk ash |
| AASHTO: | American Association of State Highway and Transportation Officials |
| ASTM: | American Society for Testing and Materials |
| ERA: | Ethiopian Road Authority |
| OAC: | Optimum asphalt content |
| OBC: | Optimum bitumen content |
| TSR: | Tensile strength ratio |
| HMA: | Hot mix asphalt |
| RHA: | Rice husk ash |
| CBA: | Coal bottom ash |
| PLC: | Private limited company |
| FH: | First highway |
| PG: | Penetration grade |
| VA: | Air voids |
| VMA: | Voids in mineral aggregates |
| VFA: | Voids filled with asphalt |
| AC: | Asphalt concrete |
| BC: | Bitumen concrete |
| ITS: | Indirect tensile strength |
| NAPA: | National Asphalt Pavement Association. |

## Data Availability

The data that support the findings of this study are available from the corresponding author upon request.

## Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

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