The comparative study on the performance of bamboo fiber and sugarcane bagasse fiber as modifiers in asphalt concrete production

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ABSTRACT

Highway pavement structures are expected to be adequately strong and durable for their design life which can be achieved only when the pavements are properly designed, constructed, maintained, and managed. In Ethiopia, most of the asphalt pavement is suffering from fatigue, creep, and rutting in long term. These stresses may be occurred due to the shortage in the mechanistic properties of either the binder or the asphalt mixtures as well as due to the increase in traffic loads. Failures of some roads can be attributed to the poor design of the asphalt mixes and materials being used. The properties and dosage of additive materials in hot mix asphalt affect the overall performance of pavement structure. Hence, modifying the properties of asphalt is necessary to enhance the performance of HMA. This study aims to investigate the performance of bamboo fiber and sugarcane bagasse fiber on the mechanical properties of Hot Mix Asphalt production. This research was conducted by using an experimental research design method and Non-Probability sampling techniques were adopted to collect samples. A sample preparation method of asphalt mixture specimens for asphalt mix design was performed based on AASHTO, ASTM and EN Standard specifications. The tests required were aggregate tests, a Bitumen test, Marshall test, and performance tests such Indirect Tensile Strength test and Rutting Test (RT) were conducted to evaluate a comparative study on the performance of bamboo fiber and sugarcane bagasse fiber as a modified Hot Mix Asphalt production. The preparing HMA mixes using crushed stone coarse aggregate, Fine aggregate, Mineral fillers 60/70 Bitumen, and by using bamboo and sugar cane bagasse fiber as additives were used to compare the results at a varying bitumen content of 4.5, 5.5, 5.6% bitumen. The Asphalt additives were used in the range from 0.2% to 0.5% of the total weight of the sample. Then, finally, the results of the laboratory were compared to standards of specifications. The optimum both fibers content obtained at 0.3% and OAC & OMF (5.2% & 4%) respectively, suggests that using both BF & SCBF fibers in asphalt concrete mixture improves the performance of asphalt pavements to resist external loads. Both fibers at 0.3% content better modify asphalt marshal stability, ITS of HMA, and Rutting resistance of AC. Finally, based on this study it was proved that the performance and properties of Asphalt concrete are affected by Fiber type and its content.

1. Introduction

A real flexible pavement provides 'elastically' behavior under the applied traffic load during its design life. It is constructed with an asphalt (bitumen) surface treatment or a relatively thin surface of HMA over one or more unbound base courses laying (placed) on compacted subgrade soil. Generally, flexible pavement structure is constructed from different layers, such as wearing course (asphalt concrete), base course, sub-base, and sub-grade layers from top to bottom. The AC layer is made up of a densely graded bitumen mix that has been compacted to form the pavement surface. When there was a high axial load to be expected during the design period, high-strength asphalt concrete pavements were constructed. In addition to this, a higher grade AC is used in areas where hot weathers condition is expected, whilst the lower grade AC is utilized in areas where colder climates are expected [1, 2, 3, 4]. Both cohesion and internal friction contribute to the stability of an AC mixture. Moreover, the gradation of the aggregate, the density of the mix, and the amount of asphalt used during mix design modify the cohesion and internal friction. A granular material or crushed stone is used for base or subbase materials, whereas the subgrade layer is commonly constructed from well-compacted soil [5]. The property of asphaltic concrete was assumed to be Visco-elastic. However, the asphaltic concrete may have a

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plastic or elastically behavior under the application of load. The asphaltic concrete sample (specimen) will collapse with the fracture tensile stress (load) at high strain rate and low-temperature conditions. However, the asphaltic concrete will collapse by plastic flow at low strain rate and high-temperature conditions. Another possible way of failure mode of asphalt concrete is through micro-cracking at an intermediate strain rate and low climatic conditions [6]. Permanent deformation in HMA is caused by a deformation flow rather than a volume change. The deformation caused by the influence of temperature and also the rate of loading-dependent Visco-elasto-plastic behavior leads to rutting [7]. The strength and stiffness of HMA are significantly influenced by weather conditions, volume of traffic loading, and asphalt binder (bitumen). The effects of asphalt binder mainly depend upon the time-temperature shift function is rather small and could be disregarded. Therefore, a unique time-temperature shift function can be applied for various (different) penetration-graded asphalt binders [8]. Asphaltic concrete is well known it mainly depends upon both strain rate and climate conditions. The temperature effects should be considered in countries that have hot weather conditions, whereas the capability of pavements may be adversely affected by high daytime temperatures. Therefore, it is very important to understand the influence of weather conditions on the response of asphalt concrete [9]. AC is a well-graded blend of (92-96 percent) coarse crushed stone (0.5–1.5 percent), filler (4–8 percent), 60/70 bitumen content (3–5 percent) and stabilizing additives (0.3–0.5%). Asphalt concrete is usually the most common type of HMA constructed in the tropical area [10]. Fine-graded mixtures appear to have higher resistance to collapse under the application of moisture than coarse-graded mixtures for both HMA and WMA due to the different structures of air void content distribution in the mixes. Coarse-graded mixes have high interconnected voids, and thus water can easily enter the voids but cannot freely discharge from them. Therefore, Coarse-graded mixes have lower permanent deformation than fine-graded mixtures for both HMA and WMA. This could be due to a higher percentage of coarse aggregates creating stone-on-stone interconnected between coarser aggregates of particles, and hence reducing rutting failure of pavements [11]. The filler materials can fill the void in the mix and maximize the density of the asphalt mixture. Also, act as a tiny roller during the compaction process undertaken. If the filler material has a large adequate diameter and a regular shape, it will act as a friction-lubricate agent. The relationship between different types of filler and voids of mineral aggregates directly influences the workability of the mixture [12]. Hot mix asphalt must be designed to resist various pavement failures such as; Cracking, Plastic deformation, and Loss of surfacing aggregate [10].

The higher performance of HMA requires tolerance to deformation due to traffic load, temperature, and cracking. Also specifically, grinding, weather resistance treatment such as rotting and cracking under low climatic conditions. Even under the slow movement of heavyweight traffic load, sustainability is excellent in the performance of asphalt pavement [13]. The most common types of fibers are used in hot mix asphalt are synthetics fibers and natural's, the synthetic fibers are high initial cost since it is the products of industries and whereas natural fibers are inexpensive due to naturally available in India [14, 15]. The dense graded hot mix asphalt with bottom ash (as a fine aggregate), fly ash (as mineral filler), and sial fiber acts as an additive to enhance the engineering properties and performance of the bituminous paving mix design. Four various percentages of sial fiber 0.25%, 0.5%, 0.75%, and 1.0% by weight of the mix and various lengths of fibers (10, 15, and 20 mm). The test results indicate that the use of sial fiber content up to 0.5% with a fiber length of 10mm maximizes the Marshall Stability, whereas air voids and Marshall Flow was reduced; moreover the indirect tensile strength increased due to the addition of emulsion coated fiber [16]. Adding Palm fiber to Asphalt concrete mixes improved the performance and characteristics of the mixes. Also, it was indicated that adding 0.20% of palm fiber content by total mix weight was considered the most suitable percentage, by reducing air void and marshal flow of the mix. It also enhances the stability of Asphalt concrete mix at all compaction blows used in this experimental work. The addition of palm fiber to the asphalt mix increases its density, compaction energy, and strength of asphalt mix. It is also observed that with an increase in fiber content up to 0.20%, air void and flow value reduces, whereas Marshall Stability maximized by compared with that of the conventional mixture. It is further observed the use of fiber content of 0.30% increases the resistance to moisture-induced damages as determined in terms of the indirect tensile strength and retained tensile strength ratio. The increase in fiber length from 0.50cm up to 1.50cm caused the Marshall stability was increase and its retained tensile strength ratio to increase whereas the increase in fiber length of more than 1.5 cm led to difficulties in the process of mixing the fibers with the mixture. Using natural fibers as a modifier in the production of hot mix asphalt, it is possible to obtain excellent performance and engineering properties of the mixture [17].

The natural fiber reinforced polymers (NFRP) indicate a significant confinement effect on maximizing compressive strength and improving the ductility of concrete. The improvements in strength and ductility increase with an increase in the amount of NFRP’s plies. The compressive strength of confined concrete increases significantly up to 42%, 25%, and 28% for Jute-, Hemp-, and Cotton NFRP, respectively. To promote a sustainable society, using alternative FRPs made of natural fibers such as Natural FRP (NFRP) are very important for developing countries since they are relatively inexpensive and available in local areas [18]. The shear strength of deep RC beams when strengthened with externally bonded synthetic fiber-reinforced polymer composites, an idea to improve the FRP composites to be more eco-friendly material is now considered. This issue has ignited engineers to investigate alternatives materials that do not disturb the condition of the environment at economical prices such as natural fiber reinforced polymer composites as the reinforcement substitute for some of the conventional materials. Therefore, using the NFRP composites in the production of concrete is very important for concrete strengthening is one of the most decent options to achieve sustainable construction [19]. The efficiency of natural FRP composites significantly relies on the adhesion between fiber and matrix because it is used as a stress transfer from the matrix to the fiber. Jute cellulose fibers are naturally hydrophilic, so they absorb moisture when exposed to air. This leads to degradation of the fiber-matrix adhesion, which in turn decreases the mechanical properties of the composites. Before making molding natural FRP composites, fiber treatment is very important to enhance their mechanical properties [20]. Bamboo fiber is a naturally available, renewable, environmentally friendly material; it has low density, low price, and suitable mechanical properties. Due to this advantage, researchers are motivated to use it as an additive in HMA materials to conserve the environment and enhance the performance of the asphalt mix [21]. SCBF is left over after the crushing and extraction of juice from the sugarcane. Utilization of SCBF in SMA mixtures can prevent excessive binder drain down, provide durable, quality pavement and reduce the excessive volume of agricultural solid waste [22]. Improving the performance of the asphalt concrete pavements is essential in order to prevent or reduce pavement defects. Therefore, research worldwide conducted an experimental investigation to enhance the physical and mechanical properties of HMA using several additives (Polymer, Glass Fiber, Lime, Rubber, etc.). Also, the evaluation of pavement responses is the most concern of asphalt paving studies. The previous studies concluded that using additives in HMA improved pavement performance. Therefore, searching for an alternative new additive is still continuous. In this study bamboo and sugar cane fiber as an asphalt additive were added separately to investigate the property of asphalt concrete.

1.1. Statement of problem

Sugarcane bagasse is a waste product of sugar industries that is produced worldwide by approximately 540 million metric tons per year; From this globally ranked three producing countries are located in
Latin America are Brazil produces 181 million metric tons per year, Mexico produced 15 million metric tons per year and Colombia produced 7 million metric ton per year [23]. According to the report shown by the UN; between the academic years 2010 and 2013, Ethiopia produced about 4108 thousand metric tons of sugarcane bagasse fiber [24]. Due to the demand for sugar is increasing nationally or globally, hence the production capacity of sugarcane bagasse fiber also increasing, this may cause environmental inconvenience, such as the generation of a huge amount of bagasse. Production of one metric ton of sugarcane produces about 280 kg of bagasse [25]. Some of this bagasse is may use for producing steam and electricity within the plant and the remaining large-volume amount of bagasse is still known not used for other purposes [26]. In addition to natural waste, natural fibers like Bamboo fiber have the advantages like biodegradability, renewable, economically viable, environmentally friendly, and relatively high mechanical properties make them more acceptable [27]. Bamboo fiber is a regenerated cellulose fiber made from the starchy pulp of bamboo plants processed from bamboo culms [28]. The utilization of these natural fibers and waste in the construction industry will lead a long way in realizing the dreams of most developing countries of scouting for inexpensive and easily available construction materials. The increase in road traffic during resent time due to introduction of new technology or industries and increasing human life standards. Due to this, its road network is transporting heavy traffic volumes. When accompanied by hot temperatures during the summer these road networks become collapse prematurely due to permanent deformation [29]. Due to the increase in traffic loads, environmental condition effects, and other factors on the Ethiopian highways network. That leads to a shortage in the long-term performance of the paving sections (pavement failures). Pavement failures are mainly the causes of increases in the maintenance costs, increased accident rates, increased travel time, affect the safety of road users as well as politically affecting the government. Generally, pavement failures may affect the development of one’s country. Hence it is necessary to investigate new asphalt additives and the properties of bitumen and hot-mix asphalt mixtures can be improved to meet the basic requirements.

2. Material and methods

The materials and methods used in this research work are described in the following subsection. A summary of this research methodology has been demonstrated in Figure 1.

![Study Methodology Flow chart](image-url)
2.1. Materials

Different materials were collected from the different available areas for the preparation of hot mix asphalt mixtures. These materials are used in the mixtures include: coarse aggregate, fine aggregate, crushed stone fillers, and bitumen as an asphalt binder. Aggregate samples for the proposed HMA mix design are obtained from ERCC (Ethiopian road Construction Corporation) quarry located at Deneba site 81 km far from Jimma town. The crushed stone dust is also brought from the same source as aggregate. The properties of selected aggregate and conventional filler are summarized in Table 1.

Coarse & fine aggregate and mineral filler are blended to get adopted gradation by trial and error method. The last trial is blending 55% of coarse aggregate, 41% of fine aggregate, and 4.0% of mineral filler. The graphical and tabular description of aggregate gradation is given in Figure 2.

A bitumen 60/70 penetration grade is also obtained from ERCC, the same project site. Asphalt binding is tested according to AASHTO standards. The properties of the Asphalt cement binder are presented in Table 2 and Figure 4.

2.2. Sample preparation

The Marshall Mix design and Superpave aggregate gradation method was used to prepare the specimens. The Marshall Design method was used to investigate the stability and flow value of the mixtures as well as to determine the volumetric properties of the marshal mix design. The standard Marshall specimens were prepared by applying 75 blows on each face according to ASTM D6926 with five different bitumen content (4%–6%) at 0.5% increments by weight of total mixes and different conventional filler content (4%, and 5.0%). For this, 10 samples were prepared,

| Property | AASHTO Designation No. | C.A size 2 | C.A size 1 | F.A | Filler Material | Ethiopian Spec.(ERA) |
|----------|------------------------|------------|------------|-----|----------------|---------------------|
| Los Angeles Abrasion | AASHTO (T96) | 25.2% | 21.4% | - | - | <30% |
| Flakiness Index | BS 812 Part 105 | 27.3% | 25.7% | - | - | <35% |
| Aggregate Crushing Value | BS 812 Part 110 | 20.7% | 18.4% | - | - | <25% |
| Aggregate impact value | BS 812 Part 110 | 15.3% | 13.7% | - | - | <25% |
| Water absorption | AASHTO T 85 | 0.331 | 0.427 | 0.540 | - | <2% |
| Bulk (S.G) | AASHTO T85 | 2.660 | 2.650 | 2.500 | - | - |
| Saturated and Dry Surface (S.G) | AASHTO T85 | 2.650 | 2.660 | 2.580 | - | - |
| Apparent (S.G) | AASHTO T85 | 2.670 | 2.680 | 2.650 | 2.650 | - |
| Plasticity Index | ASTM D-854 | - | - | - | NP | <4 |

Table 1. Physical properties of aggregates.

| Property | AASHTO Designation No. | Result | Ethiopian Specification |
|----------|------------------------|--------|------------------------|
| Penetration at 25°C, 0.1mm | AASHTO T 49 | 65.12 | 60–70 |
| Flash point, | AASHTO T 48 | 290°C | Min. 232 |
| Softening point, 25°C | AASHTO T 53 | 51.8 | >46 |
| Ductility,25°C | AASHTO T 51 | 92.6 | Min.75 |
| Specific Gravity at 250°C (kg/m3) | AASHTO T228-06 | 1.03 | - |

Table 2. Asphalt cement properties.
and each of them was weighed 1,200gm in weight. The prepared Mixes containing 4.0%, and 5.0% crushed stone dust filler were used for the determination of OBC and optimum filler content. After the determination of OBC, three Marshall Specimens at different percentages (0.2, 0.3, 0.4, and 0.5%) of additives were prepared. A total 24 specimens are required to determine the effect of modifiers on volumetric properties of control mixes prepared at OBC. Finally, the performance parameters are performed based on BS standards. Some volumetric properties of the asphalt mixture prepared at OAC (5.2%) before modification are summarized in Table 5.

3. Result and discussions

3.1. Effect of BF and SCBF on stability

Figure 5 and 6 demonstrate the effect of fibers and their contents on Marshal Stability. Both considered modifiers have the same trend in their effect on stability by content, i.e., as BF and SCBF content in the mixes increase, Marshal Stability also increases up to maximum then decreases. It is observed that the Marshall stability becomes higher as the amount BF and SCBF content increases from 0.2 up to 0.3% and then decreases as BF and SCBF content increases. This increases stability because the addition of BF and SCBF to the mixture may lead to making the HMA act as an extra viscous binder thus increasing the Marshal stability. Increasing the amount of fiber in the binder above the optimum value will reduce contact between aggregate, leading to a reduction in instability. Therefore, the optimum BF and SCBF percentage to be added to obtain maximum stability is 0.30%.

As it is plainly illustrated in Figure 7, the marshal stability for both modifiers has the same attitude in which BF and SCBF were the highest and more stable than the control mix (OBC). The stability of the modified mixtures using BF and SCBF is improved by 20.82% and 11.4% respectively. Accordingly, BF is the best additive in order to improve the stability of asphalt mixtures.

3.2. Effect of BF and SCBF on flow

As it is simply demonstrated in Figures 8 and 9, the values of Marshal Flow obtained from the experimental prepared mixes using both types of fibers, meet the Marshal criteria (2–4mm). For mixes prepared using 0.2%, 0.3%, 0.4%, and 0.5% of BF and SCBF, the flow values gained were increased by(3.2, 7.8, 6.9, and 6.6 %) and (0.3, 4.6, 6.63, and 4.03 %) at the optimum binder content respectively. This initial increment may be due to BF and SCBF reinforced HMA that enhanced stability and flow. The further increasing of the content of BF and SCBF beyond the optimum percentage decreased flow value by making the mixture more flexible. This leads to making the modified mixes capable to resist the tendency to deformation under traffic loads.

Figure 10 shows the effect of various types of additives used on the property flow on asphalt mixtures as compacted at OAC and their optimum additive content. Results indicate that the BF and SCBF addition increased the flow value of the control mix by 7.8% and 4.61% respectively. Accordingly, SCBF is considered the best additive relative to BF but both modifiers are within the accepted specification.

3.3. Effect of BF and SCBF on unit weight

The effect of BF, SCBF and their contents on the unit weight of compacted mixes is elucidated in Figures 11 and 12. The study plainly shows that the unit weight value is decreased by 0.17, 0.52, 0.86, and 1.4 % for addition of Bamboo fiber dosage 0.2, 0.3, 0.4, and 0.5 % respectively. Similarly, unit weight of SCBF modified HMA was decreased by 0.43, 0.65, 0.99, and 1.25 % for addition of SCBF content 0.2, 0.3, 0.4, and 0.5 % respectively. It noted that all values of the unit weight of the modified mixtures are less than the value of the control mix. This decrease in unit weight may be due to the increment of voids with the addition of BF in the HMA mix which makes the mix lighter than the control mix.

Figure 13 indicates the effect of additives used on the unit weight values of asphalt mixtures at OAC. Furthermore; the addition BF and SCBF was decreases unit weight (gm/mm³) by 0.52% and 0.65% respectively. Hence, the unit weight for both modifiers has the same attitude in which BF was the highest and a little bit less weight than the control mix (OBC). However, both types of fibers are still within the accepted specification limits. Accordingly, BF is considered the best additive relative to SCBF. And BF is denser than that of SCBF.
3.4. Effect of BF and SCBF on AV

The effect of BF, SCBF, and their contents on the AV (%) of compacted mixes is elucidated in Figures 14 and 15. As it is plainly demonstrated in Figure 14 both considered modifiers have the same trend in their effect on air void by content, i.e., as BF and SCBF content in the mixes increase, AV also increases continuously. For mixes prepared using 0.2%, 0.3%, 0.4%, and 0.5% of BF and SCBF, the AV values gained were increased by (4.3, 5.54, 8.9, and 19) % and (5.54, 6.75, 815.2, and 17.83) % at the optimum binder content respectively. The values of AV% increase by an increase in SCBF percentages due to decreased in Bulk unit weight of asphalt mix with increased SCBF content.

As it is plainly illustrated in Figure 16, the AV% of the modified mixes is greater than the value of the control mix. However, the entirely obtained air voids percentages for all types of additives are still within the accepted specification limits. BF and SCBF increase AV percentage by 18.4% and 19.7% respectively. Accordingly, BF is considered the best additive relative to SCBF of additives on the AV% of asphalt mixes at OAC.

3.5. Effect of BF and SCBF on VMA

Figure 17 shows the VMA% at various values of BF at the OAC. The results indicate that the value of VMA% increased by (0.68, 2.7, 4.8, and 8.2) % by increasing Bamboo fiber content (0.2, 0.3, 0.4, and 0.5) %
**Figure 6.** Effect of SCBF on Marshall stability.

**Figure 7.** The marshal stability values before and after modification.

**Figure 8.** Effect of adding BF on flow.
Figure 9. Effect of SCBF on flow.

Figure 10. The marshal flow values before and after modification.

Figure 11. Effect of BF on Marshall unit weight.
Figure 12. Effect of SCBF on unit weight.

Figure 13. The Unit Weight of HMA before and after modification.

Figure 14. Effect of adding BF on AV
respectively. The maximum value of VMA% is obtained at 0.5% BF, while the minimum value occurs at 0.0%. Similarly, the value of VMA% increased by (2.04, 3.4, 5.4, and 6.8) % by increasing SCBF content (0.2, 0.3, 0.4, and 0.5) % respectively. as shown in Figure 18. The highest value of VMA% is obtained at 0.5% SCBF, while the lowest one has occurred at 0% SCBF.

Figure 19 show the effect of adding different types of additives on the Voids in Mineral Aggregates percentage (VMA %). Results indicate that
Figure 18. Effect of adding SCBF on VMA

Figure 19. The values of VMA before and after modification.

Figure 20. Effect of adding BF on VFB.
Figure 21. Effect of adding SCBF on VFB.

Figure 22. The values of VFB before and after modification.

Figure 23. Effect of BF on Marshall stiffness.
the VMA% value was increased by increasing the contents of both additives. The VMA% of the modified mixtures is greater than the value of the control mix. However, the entirely obtained air voids percentages for all types of additives are still within the accepted standard specification limits.

3.6. Effect of BF and SCBF on VFB

As shown in Figure 20 the value of VFB% is decreased by (1.4, 1.81, 1.94, and 4.3) % for increasing of Bamboo fiber content (0.2, 0.3, 0.4, and 0.5) % respectively. The values of VFB% are less than that of the unmodified mix for BF modifier. The decrements in VFB% occurs may be due to the presence of the fine particle of BF that penetrate the voids. Figure 21 of SCBF show that the value of VFB% is decreased by (1.7, 1.94, 3.75, and 4.31) % for SCBF content (0.2, 0.3, 0.4, and 0.5) % respectively. Generally, the value of VFB decreased with an increase in SCBF dosage. Figure 22 show the effect of adding different types of additives on the Voids Filled with Bitumen (VFB). Results indicate that the VFB value was increased for both types of additives.

3.7. Effect of BF and SCBF on Marshall Stiffness

Mix stiffness is defined as the Marshall stability divided by the flow value in KN/mm. Figure 23 shows the stiffness and BF content relationship at OAC. It shows that the mix stiffness increased by (3.2, and 12.1) % for Bamboo fiber content (0.2 and 0.3) %, respectively, and then it decreased by (7.1 and 25.3) % for Bamboo fiber content (0.4 and 0.5) % respectively. Figure 24 shows the value of stiffness and SCBF content relationship at OAC. It revealed that the mix stiffness increased by (1.1, and 7.5) % for SCBF content (0.2 and 0.3) %, respectively, and then it decreased by (18.5 and 28.1) % for SCBF content (0.4 and 0.5) % respectively. Generally, the mix stiffness increases as the BF and SCBF percentage increases up to 0.3% and after that, it decreases. Firstly; it increases in stiffness may be due to the gained stability; after that, the increase in BF increases the flow gradually making the overall stiffness decrease.

Figure 25 shows the significant change in asphalt mixtures stiffness values by adding both BF and SCBF additives to HMA. Results indicate that the values of stiffness increase with both types of additives. BF seems
to be the best additive that improves the stiffness of asphalt mixtures by about 12.1%.

3.8. Effect of BF and SCBF on indirect tensile strength (ITS)

The ITS test is carried out for both the control and modified specimens using optimum BF & SCBF contents (0.3%). A total of nine specimens are examined for this analysis. Figure 26 shows the significant change in asphalt mixture ITS values by adding both BF and SCBF additives to HMA. Results indicate that the values of ITS increase with both types of additives due to the fibers can highly reinforced asphalt mixtures together as well as resist the high tensile load. BF seems to be the best additive that improves ITS of asphalt mixtures by about 15%.

Figure 27 shows the significant change in water susceptibility of HMA mixtures ITS values by adding both BF and SCBF additives to HMA. Results indicate that the values of ITS decrease with both types of additives but all are within specification limits may be due to an increase in air void. BF seems to be the best additive in water damage resistance relative to SCBF additive.

The moisture susceptibility results indicate that the achieved compressive strength satisfies the minimum requirement of 80%, as indicated by the Superpave design method. Table 9 below shows the

Table 9. Index of tensile strength ratio.

| Specimen | Average S1 (MPa) | Average S2 (MPa) | Average TSR (%) |
|----------|-----------------|-----------------|-----------------|
| Control mix | 0.905 | 0.857 | 94.4 |
| BF | 1.04 | 0.850 | 81.7 |
| SCBF | 0.943 | 0.761 | 80.6 |

Table 10. Wheel track Test Results for Control and Modified Mixtures.

| Mix Name | WTS300 (mm/10^5 load cycles) | PRD (%) | Mean RD (mm) | Specification as per EN 13108 |
|----------|-------------------------------|---------|--------------|-------------------------------|
| Control | 0.013 | 4.1 | 2.165 | <5 | <3 |
| BF | 0.008 | 3.35 | 1.82 | <5 | <3 |
| SCBF | 0.007 | 3.75 | 2.025 | <5 | <3 |
3.9. Effect of BF and SCBF on wheel track (WT)

The WTT test is carried out for both the control and modified specimens using optimum BF & SCBF contents (0.3%). A total of six specimens are examined for this test. Table 10 shows both modifiers are within the specification limit and Figure 28 shows the relation between the three specimens and rutting depth.

Figure 28 shows the significant change in asphalt mixtures’ rutting depth values by adding both BF and SCBF additives to HMA. Results indicate that the resistance of rutting depth increase with both types of additives due to the fibers can highly reinforced asphalt mixtures together as well as resist the tensile load. BF seems to be the best additive that improves the rutting resistance of asphalt mixtures by about 16%.

Figure 29 shows the significant change in asphalt mixtures’ rutting depth values by adding both BF and SCBF additives to HMA. Results indicate that the values of rutting depth decrease with both types of additives. BF seems to be the best additive that improves the rutting resistance of asphalt mixtures by about 16%.

4. Conclusions and recommendations

4.1. Conclusions

The potential use and performance of BF and SCBF in hot mix asphalt were investigated through Marshall Mix design and performance-based experiment. From the analysis of the laboratory test data, the following conclusions can be made:

❖ All values of physical properties of aggregates and mineral filler are within standard specification limits and fulfill the requirements, and hence they are suitable for the production of Asphalt concrete (or HMA).
❖ The mixture of HMA-0.3%BF and HMA-0.3% SCBF have a low bulk density, high air void, high void in mineral aggregate, high stability,
and higher flow than the control mix but all marshal properties are within the ERA specification.

- The Addition of 0.3% BF in the HMA mixture increases Marshall Stability by about 20.82% and the Flow by 7.8%, Marshall Stiffness by 12.1%, AV by 5%, and VMA by 2.7%, and VFB is decreased by about 1.8%. It also increases the ITS value from 0.905 to 1.04 N/mm² and enhances the rutting resistance (rutting depth decreased) by 16%.

- Adding 0.3% SCBF to HMA mixture increases Marshall Stability by 11.4% and flow by 4.61%. Increases the mixture stiffness, AV and VMA by about 7.5%, 6.7%, and 3.4% respectively while VFB was decreased by about 1.9%. It also improves the ITS value by 4.2% and enhances the rutting resistance (rutting depth decreased) by 6.5%.

- Both additives decrease the rutting depth significantly, i.e., the BF has decreased the rutting depth from 2.165mm to 1.822mm while SCBF decreases the rutting depth from 2.165mm to 2.025mm.

- Both additives increase the indirect tensile strength significantly, except BF has the best BF increases the indirect tensile strength from 0.905MPa to 1.04MPa while the addition of SCBF increases the indirect tensile strength from 0.905MPa to 0.943MPa.

- Therefore, the Results indicated that BF is considered the best modifier based on its performance on stability, Indirect Tensile Strength, Marshall Stiffness, and Rutting depth.

4.2. Recommendations

Based on the outcomes of the study, it is strongly recommended to:

- As BF and SCBF have shown satisfactory results when used in HMA. Therefore to utilize the full extent of fibers, other natural fibers and waste fibers are also taken into consideration and their effects on HMA should be tested and studied.

- In this study only 60/70 bitumen penetration grade was considered as a coating medium for both fibers, therefore the effect of other types of bitumen penetration grade, AC, and emulsions such as rapid setting emulsion (RS) and medium setting (MS) emulsion are taken into account and subsequent tests should be performed for future study.

- Furthermore, the performance of fibers with different mineral fillers such as cement and lime cannot be overlooked. Lime as an anti-stripping agent, cement as a stabilizing agent, and other non-conventional fillers can be used as potential mineral fillers for HMA mix, and subsequent tests may be performed as a part of the future scope.

- The researcher suggests that further experiments be conducted on BF and SCBF, such as chemical compositions and properties including the leaching test, which are not covered in this study.

- Future researchers can use BF to improve the properties of asphalt mixtures in different temperatures as warm asphalt as well as using different fiber lengths and Asphalt content.

Declarations

Author contribution statement

Kemal Umer Ahmed: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.
Anteneh Geremew, Abubekir Jemal: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data included in article/publication/supplementary material/referenced in article.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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