Hindawi
Advances in Civil Engineering
Volume 2022, Article ID 7491279, 14 pages
https://doi.org/10.1155/2022/7491279

Research Article

Laboratory Performance Evaluation of Hot Mix Asphalt Mixture Using Belessa Kaolin as a Filler with Superpave Aggregate Gradation

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Received 12 July 2022; Revised 20 October 2022; Accepted 31 October 2022; Published 7 November 2022

Academic Editor: Vasant Matsagar

Mineral fillers and different aggregate gradations have a great effect on the mechanical property of asphalt concrete pavements. In this research, the effect of nonconventional material so-called Belessa kaolin and Superpave gradation on marshal properties, moisture susceptibilities, and permanent deformation in asphalt mixtures was investigated. The chemical composition of Belessa kaolin shows that the total content of silicon dioxide (SiO_2), iron oxide (Fe_2O_3), and aluminum oxide (Al_2O_3) was 63%, 24.1%, and 2.84%, respectively. The physical properties of Belessa kaolin were conducted on specific gravity, and the plastic index was 2.62 and 3.24, respectively. Based on the study area characteristics and temperature, a bitumen grade of 60/70 penetration is selected. Hot mix asphalt (HMA) specimens were prepared from three different Superpave gradations with conventional filler crushed stone dust (CSD) of different proportions (5.0, 6.0, and 7.0%) and five different bitumen contents (4, 4.5, 5, 5.5 and 6%). A hot mix asphalt with 5.0% of CSD was selected as the control mix based on Ethiopian Road Authority (ERA) standard specifications. The conventional filler was replaced by Belessa kaolin at different replacement rates (0, 10, 20, 30, 40, and 50%) on the basis of the control mix with 5% CSD and 5.1% optimum bitumen content (OBC). The replacement rate of 30% of Belessa kaolin provides better marshal properties and resistance to moisture susceptibility. The results of the experiments indicated that the use of Belessa kaolin on HMA has fulfilled the criteria specified on the specification as a filler with Superpave aggregate gradation up to 30% replacement of conventional filler in HMA.

1. Introduction

Nowadays, natural assets have been impressively diminished due to the development of mining industries and increment within the utilization of mined materials [1]. In order to spare the cost speculation and to amplify the service life of asphalt pavement, the utilization of a modified asphalt mix can meet the needs of the users. To protect natural resources, a number of studies have been carried out to demonstrate the ease of use of diverse common and elective materials in concrete and asphalt pavements such as lime, cement, steel slag, waste rubber, waste polyethylene, recycled concrete, and asphalt aggregate, as well as construction and demolition waste [2–5]. The quality of the pavement surface is affected by the content and type of component materials used to prepare the asphalt mix [6–9]. The performance of hot mix asphalt is basically a function of the characteristics of its components: bitumen, filler, and aggregate. Fillers are fine materials of different sorts, most of them pass the 0.075 mm sieve, and their incorporation in bituminous and nonbituminous binders and in aggregate mixtures confers special characteristics to these mixtures [10]. Fillers play a major role in the preparation of asphalt, in terms of the composition of the blends and their physical and mechanical properties [11]. A higher percentage of very fine filler may harden the mixture excessively, making it troublesome to work with and resulting in a crack-susceptible mixture [12]. Fillers influence the workability, moisture sensitivity, stiffness, and aging characteristics of hot mix asphalt. In order to improve pavement performance and durability, it is vital to produce a good mix [13]. Therefore, understanding the impact of fillers on the asphalt concrete mix is fundamental. The use of locally available materials in road construction is a key part of road construction [14]. One of the most promising filler materials in HMA from the point of view of locally available and introduced nonconventional filler is kaolin. Kaolin could be a subgroup of clay minerals having polytypes to be specific to kaolinite, dickite, and nacrite and a polymorph called halloysite [15]. It is commonly distinguished as white and delicate clay that shows versatility with the composition of fine-grained plate-like particles. It is produced from the change of anhydrous aluminate silicates in feldspar wealthy rocks like a rock through weathering or aqueous forms [16]. Such portrayal infers that kaolin is appropriate to be utilized as a natural pozzolan Pozzolanic materials, of natural or artificial origin, contain a high percentage of amorphous silica and a high specific surface in order to generate a pozzolanic reaction [17]. Kaolin events are for the most part common and detailed on all the landmasses within the world except Antarctica [18]. The United States of America is the most ranked country with a deposit of kaolin. Japan, Germany, Belgium-Luxembourg, Finland, China, and Italy are the biggest producers of kaolin, respectively. The biggest producers in other regions of the world are Canada for North America, Egypt for Africa, Argentina for South America, and Australia for Oceania [19]. There are plenty of deposits and occurrences of kaolin in different African countries. Most kaolin deposits and occurrences were located in Southern and West Africa, and the least number being North Africa. In East Africa, Eritrea, Ethiopia, Kenya, and Uganda, each had a minimum of eight stores and events of kaolin [18]. Topographical works from the past demonstrated the presence of kaolin in numerous territories inside Ethiopia. Some of which namely, Kombolcha, near Harar, Debre tabor, Kerker, Belesa, and many occurrences in Tigray are worth mentioning [20].

In HMA mixture, gradation is considered as the cornerstone property of aggregate which needs careful attention due to its effect on mix properties and performance of HMA mixtures, including air void, stability, stiffness, durability, permeability, workability, fatigue resistance, frictional resistance, and resistance to moisture damage [21]. Different methods of asphalt pavement design are being introduced to enhance the performance of roads [22]. Superpave mix introduces a different gradation system from the Marshall mix design. Superpave aggregate gradation is characterized by the introduction of the restrict zone to aggregate gradation. As the study carried out on the assessment of the effects of Superpave aggregate gradation on Marshall method design parameters of wearing course, the Superpave specified gradation could be used as a guide to select aggregate gradation for wearing course in Marshall mix design without significant effect [23]. One of the failures of asphalt pavements before their service life is due to the quality of construction materials and defects in the mix design. Among them, the quality of filler material has a great effect on the failures of pavements. The one reason behind this problem is selection of poor filler materials type and content for hot mix asphalt concrete mixture. Mineral fillers are the major reasons for an increment of the stiffness of the hot mix asphalt mortar mix and improvement of the rutting resistance of asphalt pavements. Filler type and content have a considerable effect on the bituminous mixture making it act as much stiffer, and thereby affecting the HMA pavement performance including its fracture behavior [24]. Subsequently, the application of new filler materials should be examined to reduce the presence of poor Marshall properties and performance in the asphalt concrete mix. Strong, durable, resistive to fatigue and permanent deformation, environment-friendly, and economical pavement construction can be achieved through the application of new filler materials in aggregate gradation. Hence, a good design of bituminous mixes shall be studied in laboratories for the provision of a strong pavement structure that fulfills the contentious transportation demand of the people. This can be done using naturally found material such as Kaolin as filler material in hot mix asphalt aggregate mixing gradation. The particle size distribution, or gradation of aggregates, is the most critical figure that influences the full performance of the asphalt pavement material. Gradation is one of the most affecting components for Marshall properties of hot mix asphalts, so it is required to choose the best aggregate gradations. The best gradation is characterized by the proper packing of fine particles between coarser particles, which reduces the void space between particles [25]. Currently, the actual usage of Belessa kaolin is very limited and has not been recognized as an alternative filler in local pavement construction. Also, the usage of Belessa kaolin dust filler in the HMA mixture, particularly with different aggregate gradation and percentages, is not examined. Thus, based on the above research gap, the investigation was made by preparing laboratory samples with different percentages of the conventional filler that would be replaced with the Belessa kaolin and the Marshall stability, flow, volumetric properties, and performance parameters such as moisture susceptibility, rutting evaluated by the Marshall method of mixture design with conventional engineering properties. Therefore, this study was undertaken through laboratory tests to evaluate the properties of the bituminous mixture using Belessa kaolin filler combined with Superpave aggregate gradation.

2. Materials and Methods Used

2.1. Material Required. Nonprobable purposive sampling techniques were adopted to collect materials used for conducting this research method.

(i) Crushed stone aggregate (coarse, fine)
(ii) Bitumen (60/70 penetration grade)
(iii) Mineral filler (crushed stone dust and Belessa kaolin dust)

2.2. Research Design. The Marshall mix design and Superpave aggregate gradation method were 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 performance parameters are performed based on British Standards (BS). The standard Marshall specimens were prepared by applying 75 blows on each face according to the American Society for Testing and Materials (ASTMD 6926) with five different bitumen contents (4.0%–6.0%) at 0.5% increments by weight of total mixes `and different conventional filler contents (5.0, 6.0, and 7.0%). From this, Marshall specimens in each filler content prepared of the 15 samples, and each of them weighed 1,200 grams in weight. The prepared mixes containing 5.0, 6.0, and 7.0% crushed stone dust filler were used for determining the OBC and optimum filler content. Belessa kaolin was used to replace conventionally used crushed stone dust at 0, 10, 20, 30, 40, and 50% by weight of optimum crushed stone dust filler. The detailed research design procedure was illustrated in Figure 1.

3. Results and Discussions

3.1. Mineral Filler. The impacts of filler on the mechanical properties of the hot mix asphalt mixture are exceptional as it is one of the crucial ingredients in the HMA mixture. Fillers, as one of the components in an HMA mixture, play a crucial part in deciding the performance and properties of HMA mixes, particularly its interlocking and binding impacts [26, 27]. In this study, crushed dust and Belessa kaolin which pass through No. 200 sieve size were used as mineral filler in the preparation of the HMA mixture. The physical properties, which are expected to be critical in affecting the HMA mix property such as plasticity index and specific gravity, were tested in the laboratory. In this study, crushed stone dust and Belessa kaolin were used as filler materials whose apparent specific gravity is 2.67 and 2.62, respectively, and both fillers passed 100% through sieve No. 200. The physical properties of crushed stone aggregate (CSD) and Belessa kaolin are illustrated in Table 1.

3.2. Chemical Properties of Belessa Kaolin. The chemical composition carried out on kaolin was shown in Table 2 and Figure 2. The results indicate the presence of important and suitable oxide composition for replacement. The combined percent composition of Al_2O_3, SiO_2, and Fe_2O_3 was more than 70%. This was adequate to meet the requirement of ASTM C618 standard for pozzolanic materials to use as a filler.

3.3. Aggregate Physical Properties. The material quality test is very crucial for the requirement of hot mix asphalt design. The physical properties test results of an aggregate must satisfy the minimum requirement of ERA 2013 flexible pavement specification limits [28]. The detailed physical properties of the aggregate used are shown in Table 3.

3.4. Physical Properties of Mineral Aggregates. The mineral aggregate used in this research is nonconventional (Belessa kaolin) and conventional filler (CSD). Different laboratory tests have been conducted to determine their suitability via tests such as gradation parameters, plasticity index, and apparent specific gravity. The physical properties of crushed stone dust are generally nonplastic. Table 4 illustrates the physical properties of each type of filler according to ASTMD-854 using the water pycnometer method.

Particle size distributions are the critical factors in assessing kaolin for HMA applications. Thus, the particle size distributions show that kaolin is rich in terms of clay size fractions (55% < 2 μm), while silt and sand are less abundant. The particle size of Belessa kaolin also contains acceptable critical points which are in agreement with the specifications as shown in Figure 3.

3.5. Properties of Asphalt Binder. Plenty of tests including specific gravity, ductility, penetration, flash, fire point, and softening point were conducted for the basic characterization of properties of penetration-grade asphalt. The test results are discussed in Table 5, which met the criteria with the requirement of ERA specification.

3.6. Aggregate Blending and Gradation of Mix Design. The aggregate blending and gradation are the most important parameters in the preparation of the hot mix asphalt mixtures. Superpave gradation was used to prepare the Marshall mix design. Superpave aggregate gradation differs from conventional aggregate gradation by the incorporation of restricted zone and control points set by the author of [29]. In this study, three below restrict zone (BRZ) gradations were chosen because particle distribution that passes below the restricted zone normally provides the most effective material for road carrying heavy traffic and for the severe site by OVERSEAS ROAD NOTE 19 [30]. In addition, a gradation below the restricted zone has better resistance provided by the coarser aggregate skeleton. For this study, three trial blends with different filler proportions were adopted. Available aggregate or used materials, coarse aggregate (9–25 mm), intermediate aggregate (4.75–9 mm), fine aggregate (0–4.75 mm), and filler were combined in order to determine the proper gradation within the allowable limits according to ASTM specifications using the mathematical trial method. The percentage proportion of each size of aggregates is to be determined and compared to the specification limits. Table 6 shows the mix type and blending proportions of the different aggregate sizes to produce the desired combined gradation for different filler contents of the asphalt binder course. Normally, in this research, gradation passing below a restricted zone or relatively coarse graded aggregate gradation with a nominal maximum aggregate size of 19 mm was selected as recommended by Asphalt Institute Specification [31]. The adopted aggregate blending proportion of three gradations is presented in Table 7. The blended aggregate gradations are designated as BRZ5, BRZ6, and BRZ7, which describe below the restricted zone of Superpave aggregate gradation with 5, 6, and 7% filler proportions.

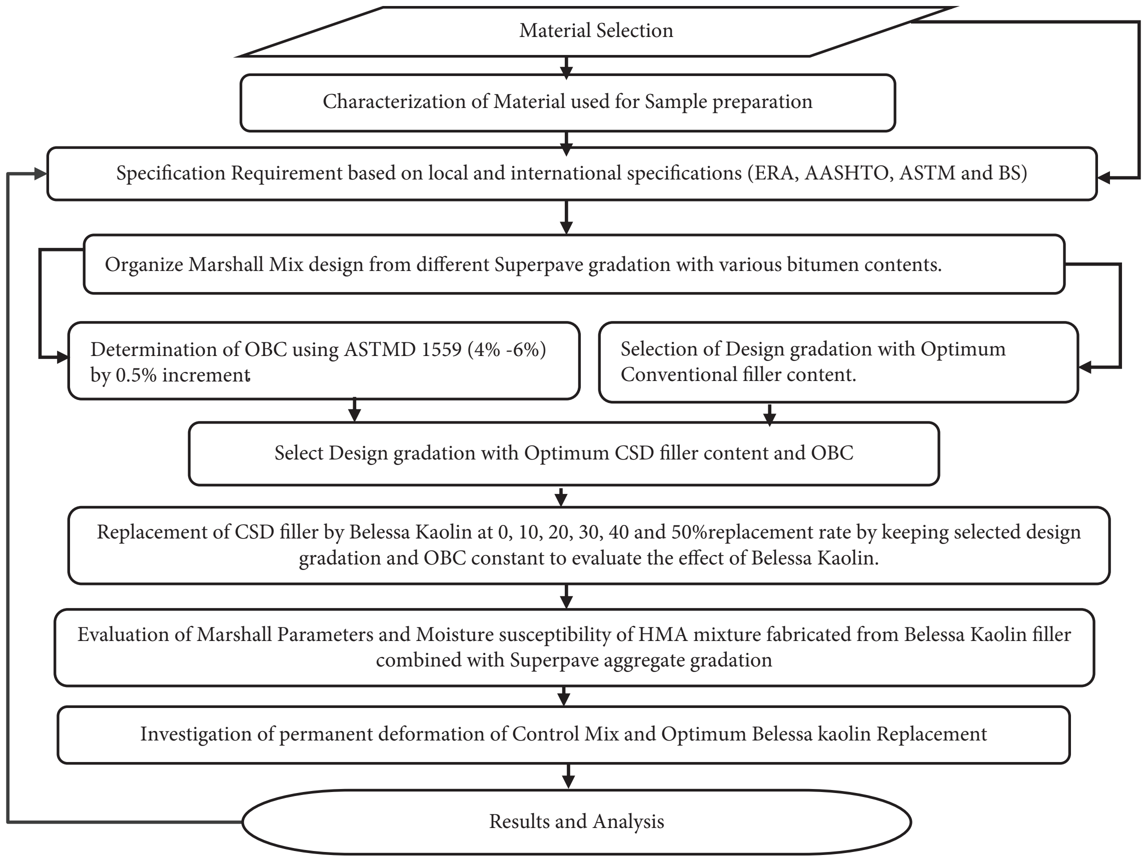

Figure 1: Flowchart of research design.

Table 1: Physical properties of crushed stone aggregate (CSD) and Belessa kaolin.

Physical property	Properties of mineral filler		Specification ASTM D242
	Crushed stone dust	Belessa kaolin	
Plastic index (PI)	Nonplastic	Nonplastic	<4
Apparent specific gravity (GSA)	2.668	2.619	N/A

N/A = not available.

Table 2: Chemical composition of Belessa kaolin.

Chemical composition	Test results	Requirement ASTM C 618 (%)	Result status
SiO_2	63	35 and above	Pass
Al_2O_3	24.1		
Fe_2O_3	2.84		
$SiO_2 + Al_2O_3 + Fe_2O_3$	89.94	70 and above	Pass
MgO	0.03	5 and below	Pass
CaO	1.05	3 and below	Pass
Na_2O	0.03		
K_2O	0.06		
TiO_2	0.47		
MnO	0.03		
Total	90.61		
LoI	9.69		

The above table illustrates the final proportion of each aggregate material in the asphalt binder, and the proposed aggregate gradation blending has met the requirement of Superpave aggregate gradation. Using these gradations, the asphalt mixture is prepared and evaluated by using the Marshall mix design method. Figures 4 to 6 show that the three types of Superpave aggregate gradations based on three varying percentages of filler (5, 6, and 7%) with 19 mm maximum aggregate size were designed from percent passing.

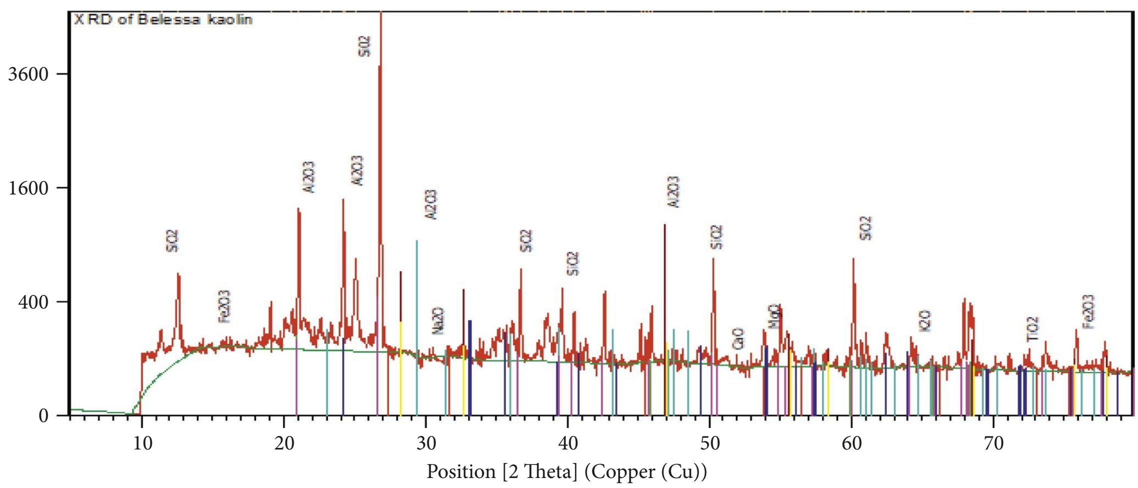

Figure 2: XRD pattern of Belessa kaolin.

Table 3: Physical properties of aggregate.

Test	Test method	Test result (25–14 mm	(6–14 mm)	(3–6 mm)	Specification
Bulk dry specific gravity (GSB)		2.638	2.649	2.528	—
Saturated surface dry (SSD)	AASHTO T 85–91	2.647	2.66	2.571	—
Apparent specific gravity (GSA)		2.66	2.68	2.64	—
Water absorption (%)	BS 812, part 2	0.331	0.427	1.666	<2
Aggregate impact value (AIV) (%)	AASHTO T176-86		8.06		—
Flakiness index (FI)	BS 812 part 105		29.90		<45
Aggregate crushing value (ACV) (%)	BS:812 part 110		17.55		<25
Los Angeles abrasion (LAA) (%)	AASHTO T 96′		11.0		<30

Table 4: Physical properties of CSD and Belessa kaolin filler.

Test	Properties of mineral filler: Crushed stone dust	Belessa kaolin	Specification ASTM D242
Apparent specific gravity (GSA)	2.668	2.619	—
Plastic index (PI)	NP	3.24	<4

NP: nonplastic.

3.7. Marshal Tests Results. The Marshal mix design method was used to determine the optimum asphalt content and evaluate the stability of the mixtures in the laboratory. The marshal test of a specimen prepared with varying amounts of conventional filler at 5, 6, and 7% of crushed stone dust as filler by weight of aggregate with different bitumen contents (4, 4.5, 5, 5.5, and 6%). Table 8 indicates the properties of the mixture at various asphalt content for mixes with different conventional filler content (CSD). It concludes that at 5% filler, the stability is greater than both 6% and 7% filler. Also, the flow in 5% filler is found almost within the required specification. This enables that gradation with 5% is favorable than the other gradation.

3.8. Effect of Partial Replacement of Belessa Kaolin on HMA. The effect of the Belessa kaolin on the HMA mix is evaluated by using the Marshall mix design and performance measuring parameters. Depending on the selected optimum bitumen content, and design gradation with 5% optimum filler content, stone dust filler was partially replaced by Belessa kaolin filler with five different proportions at a replacement rate of 10, 20, 30, 40, and 50% by the mass of total conventional filler contents as shown in Table 9.

3.8.1. Effect of Partial Replacement of Belessa Kaolin on Marshal Stability. Marshall stability of a test specimen is the maximum load required to produce failure when the specimen is preheated to a prescribed temperature placed in a special test head and the load is applied at a constant strain. Therefore, the effect of Belessa kaolin on the stability is shown in Figure 7 with different proportions of both conventional and nonconventional filler contents that have satisfied the requirement specification. However, its Marshall stability becomes decreases at 10% of replacement and starts to increase at 20% and 30% of Belessa kaolin replacement. Also, at 40% and 50%, it starts decreasing. Based on the resulting replacement of CSD by

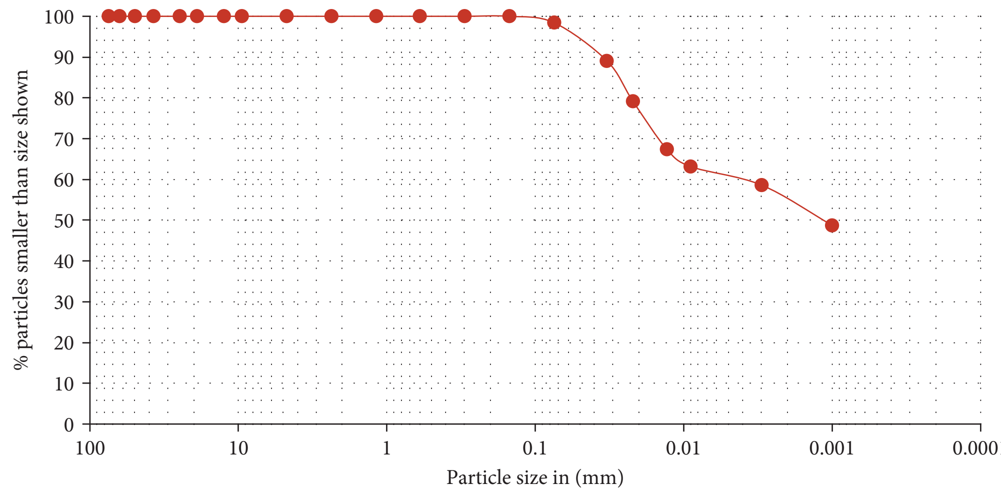

Figure 3: Particle size distribution of Belessa kaolin.

Table 5: Asphalt binder quality test.

Test	Test method ASTM	Test result	Specification as per ERA, 2013
Penetration	ASTM D5	63.06	60–70
Ductility	ASTM D113	96.33	Min. 50
Softening point	ASTM D36	51.4	46–56
Flash point	ASTM D92	293.67	Min. 232
Fire point	ASTM D92	353.5	Min. 280
Specific gravity	ASTM D70	1.040	—

Table 6: Aggregate blending proportion.

Filler content (%)	Bin 1 (coarse aggregate) (%)	Bin 2 (intermediate aggregate) (%)	Bin 3 (fine aggregate) (%)	Total (%)
5	24	30	46	100
6	26	26	48	100
7	22	32	46	100

Belessa kaolin, it has shown an increment at 20% and 30%. Although other percentages of replacement are less than the control mix, all meet the requirement as per ERA 2013 flexible pavement specifications [28]. Therefore, the replacement of Belessa kaolin at 30% has a significant effect on the mixture.

3.8.2. Effect of Partial Replacement of Belessa Kaolin on Flow. The Marshall flow is the vertical deformation of the specimen at the failure point. It is clearly shown in Figure 8, and Marshall flow values obtained from the laboratory-prepared mixes using all of Belessa kaolin percentages meet the Marshal criteria (2.0 mm–3.5 mm) except for 50% replacement. For mixes prepared using 0, 10, 20, and 30% of Belessa kaolin replacement rate, the flow values obtained are relatively the same. Higher values of flow were also obtained for mixtures prepared using 40% Belessa kaolin replacement rate. At 50% replacement rate, the flow does not meet the requirement as per Ethiopian road authority specifications.

3.8.3. Effect of Partial Replacement of Belessa Kaolin on Air Void of the Mix. The voids in the total mix refer to the total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture. Based on Figure 9, each mix does not follow a general pattern. According to the test results, all HMA mixtures prepared with partial replacement by Belessa kaolin filler provided the air void content within the range of 3 %–5% as per specified by ERA, 2013 flexible pavement manual [28], as well as Asphalt Institute Specification [31]. Figure 9 shows that at 30% Belessa kaolin filler content, the air void percentage was 4.16%, which is the least air void and nearest to the air void value 4.10% of the control mix. Therefore, the replacement at 30% provides a better result when compared with the other mix percentages.

3.8.4. Effect of Partial Replacement of Belessa Kaolin on Void Filled with Asphalt (VFA). A void filled with asphalt is measured as the proportion of VMAs that are occupied with asphalt binder. The effect of different replacement percentages of Belessa kaolin on the voids filled with asphalt properties of the mixture is indicated in Figure 10. All the mixes, except 50% replacement, follow a general trend that with an increasing replacement rate of Belessa kaolin, the VFA in the total mix increases. According to the

Table 7: Adopted Superpave aggregate gradation of asphalt mix for 19 mm nominal size.

Sieve size in (mm)	Sieve size raised to 0.45 power	Percentage passing for three Superpave gradations			Specifications of Superpave gradation			
					Control points		Restricted zone	
		5%	6%	7%	Lower	Upper	Lower	Upper
25	4.257	100	100	100	100			
19	3.762	92.5	92	93	90	100		
12.5	3.116	80	81.5	81		90		
9.5	2.754	69	72	70				
4.75	2.016	51	52.5	51.5				
2.36	1.472	33	32	31	23	49	34.6	34.6
1.18	1.077	20	21	20			22.3	28.3
0.6	0.795	14	15	14			16.7	20.7
0.3	0.582	11	12	11.5			13.7	13.7
0.15	0.426	8	9	9.5				
0.075	0.312	5	6	7			2	8

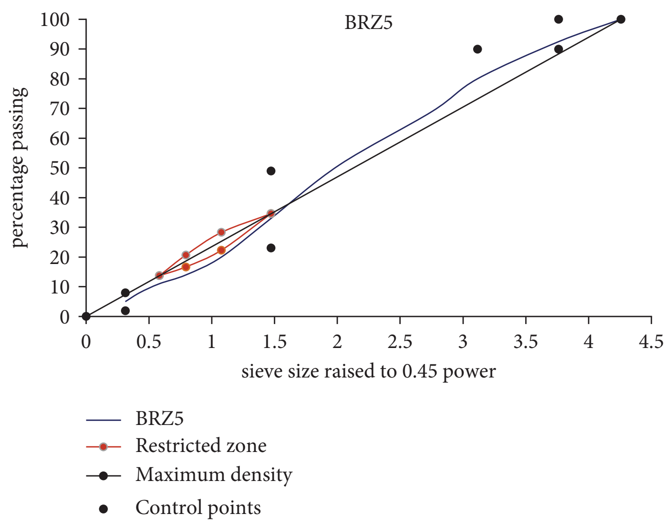

Figure 4: Superpave gradation using 0.45 power chart for 5% CSD filler.

experimental results, VFA values increase with an increased replacement rate of Belessa kaolin filler until it reaches 40% replacement rate. Then, it starts decreasing when it reaches 50% replacement rate. According to ERA pavement design, manual VFA values in hot mix asphalt mixtures are within a range of 65%–75%. Thus, as illustrated in Figure 10, all mixtures with Belessa kaolin combined with Superpave gradation are satisfied the requirement.

3.8.5. Effect of Partial Replacement of Belessa Kaolin on Void in Mineral Aggregate (VMA). The void in mineral aggregate is the volume of intergranular void space between the aggregate particles of a compacted paving mixture. The effects of different percentages of Belessa kaolin filler on the VMA of the bituminous paving mixture are demonstrated in Figure 11. The general pattern of the figure is as the replacement rate of Belessa kaolin increases, the VMA of the paving mixture also increases. Based on the laboratory results, VMA values increase with an increased replacement rate of Belessa kaolin filler. It is indicated that the VMA of all hot mix asphalt mixtures is within the allowable limits specified in the ERA 2013 flexible pavement manual [28]. According to the ERA pavement design, manual VMA values in hot mix asphalt mixtures have to be greater than 13%. Thus, as illustrated in Figure 11, all mixtures with Belessa kaolin combined with Superpave gradation are satisfied the requirement.

3.8.6. Effect of Partial Replacement of Belessa Kaolin on Bulk Density. The unit weight of the mix is not affected by the amount of Belessa kaolin significantly. The unit weight of each mixes with a different replacement rate of Belessa kaolin is within the range of requirement. Figure 12 shows that the bulk density increases with an increase of Belessa kaolin until it reaches 30% of Belessa kaolin filler content. Then, the bulk density starts decreasing as the replacement rate increases. Based on the investigation results, the replacement rate of 30% of Belessa kaolin provides greater bulk density when compared with other replacement rates. It is expected that the bulk density increases as the amount proportion (percentage) of Belessa kaolin increases in the mixture up to 30%, and then, it decreases. This is because an increase in the amount of Belessa kaolin will

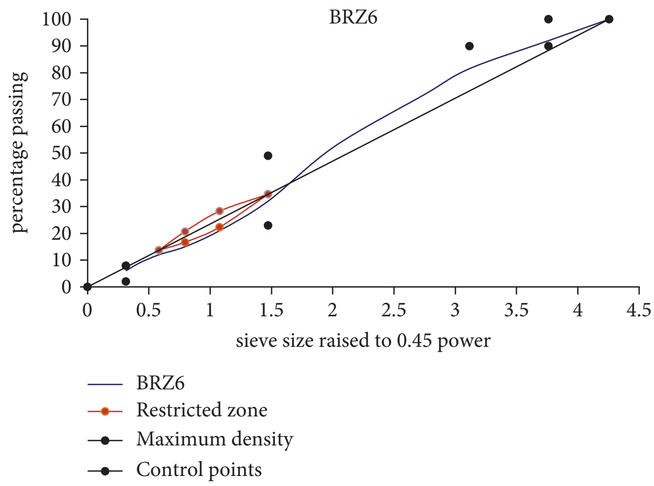

Figure 5: Superpave gradation using 0.45 power chart for 6% CSD filler.

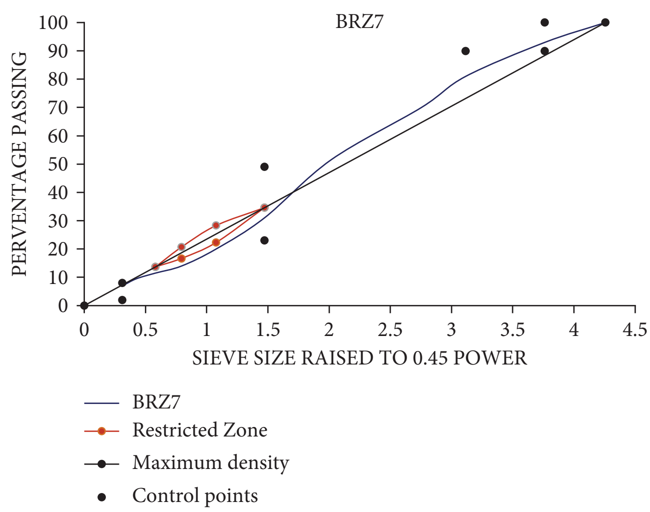

Figure 6: Superpave gradation using 0.45 power chart for 7% CSD filler.

increase the amount of fines in the mix, and a large amount of fine particles tends to push the larger particles apart and act as lubricating ball bearings between these larger particles which subsequently lower the bulk density.

3.9. Effect of Partial Replacement of Belessa Kaolin on Moisture Susceptibility

3.9.1. Tensile Strength Ratio (TSR) Test Results. The indirect tensile strength (ITS) of unconditioned and conditioned samples was determined for this study. The TSR value is expressed as the percentage of the ratio of conditioned to unconditioned values. The effects of different percentages of Belessa kaolin filler on the moisture susceptibility of the bituminous paving mixture are demonstrated in Figure 13. Based on the laboratory results, the tensile strength ratio increases with an increase of Belessa kaolin until it reaches 30% of Belessa kaolin filler content. Then, the TSR starts decreasing as the replacement rate increases. According to the American Association of State Highway and Transportation Officials (AASHTO) pavement design manual [32], the TSR value in hot mix asphalt mixtures is a minimum of 80%. Thus, as illustrated in Table 10, all mixtures with Belessa kaolin combined with Superpave gradation satisfied the requirement except for 50% replacement rate. Based on the investigation results, the replacement rate of 30% of Belessa kaolin provides greater moisture susceptibility when compared with other replacement rates. This investigation shows that the indirect tensile strength (ITS) value decreases with increasing Belessa kaolin content; because as the amount of Belessa kaolin filler increases, lower interlock and internal friction between aggregate particles which lead the mix had poor internal resistance against external loads.

3.10. Selection of Optimum Belessa Kaolin Filler Content. The control mix with 0% of Belessa kaolin was referenced as the control for the determination of optimum filler

Table 8: Marshal test results for different percentages of CSD filler at 4% VIM.

Mix properties	Percent of CSD filler content			Specifications of asphalt institute	
	5%	6%	7%	ERA	Asphalt institute
OBC (%)	5.1	5.3	5.5	4–10	4–10
VFA (%)	71.5	72	72.5	65–75	65–75
VMA (%)	14	14.8	14.5	Min. 13	Min. 13
Stability (kN)	11.2	10.5	9.85	Min. 8	Min. 7
Flow (mm)	3.0	3.40	3.25	2–3.5	2–3.5
Bulk density (g/m^3)	2.32	2.31	2.31	—	—
VIM (%)	4	4	4	3–5	3–5

Table 9: Marshal properties at the different proportion of Belessa kaolin and CSD.

Percentage of Belessa kaolin replacement	GSB (Mg/m^3)	VIM (%)	VMA (%)	VFA (%)	Stability (kN)	Flow (mm)
0	2.320	4.10	13.91	70.54	10.99	3.04
10	2.315	4.29	14.53	70.49	10.69	3.15
20	2.317	4.24	14.90	71.56	11.02	3.10
30	2.319	4.16	15.28	72.73	11.62	3.08
40	2.313	4.35	15.97	72.73	10.32	3.48
50	2.311	4.54	16.03	71.67	9.64	3.73

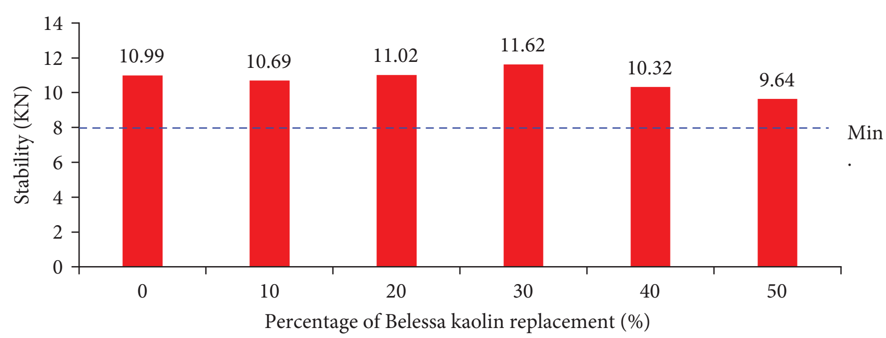

Figure 7: Relationship between stability and replacement rate of Belessa kaolin at OBC.

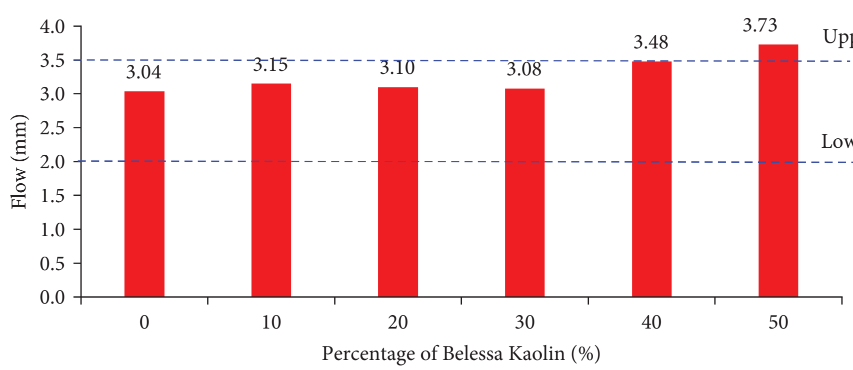

Figure 8: Relationship between flow and replacement proportion of Belessa kaolin at OBC.

proportion. Marshall properties and moisture susceptibility are used to find the optimum filler content that produces an HMA mixture with the best performance. Asphalt mixture with an optimum filler content satisfies the following conditions: maximum stability, maximum bulk density, air void, and tensile strength ratio are within the allowed range of specifications. Table 11 shows the stability values of all HMA mixtures for different percentages of Belessa kaolin filler content that met both local and international specifications. However, the maximum stability value was found from the mixture corresponding to 30% of Belessa kaolin filler relative to other proportions. Also, the corresponding result of the air void and bulk density values are 4.16% and 2.319 gm/cm^3, respectively, which are almost the same as the control mix. The moisture susceptibility of 30% Belessa kaolin, which is 82.38%, is the largest result obtained from each mix. This shows that Belessa kaolin with this percentage improves the moisture susceptibility of the mix with 100% CSD.

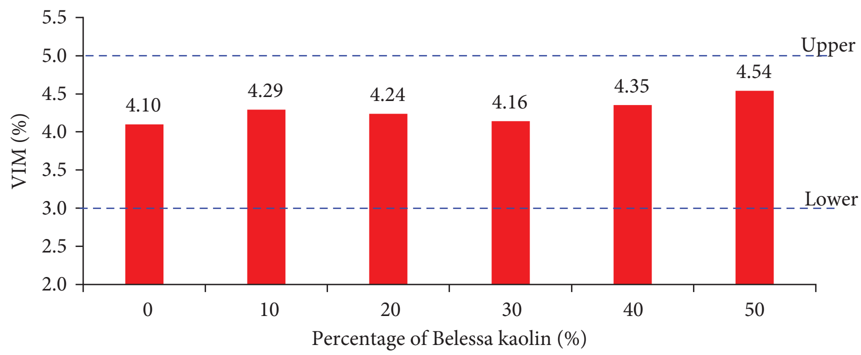

Figure 9: Relationship between air void (VIM) and replacement proportion of Belessa kaolin at OBC.

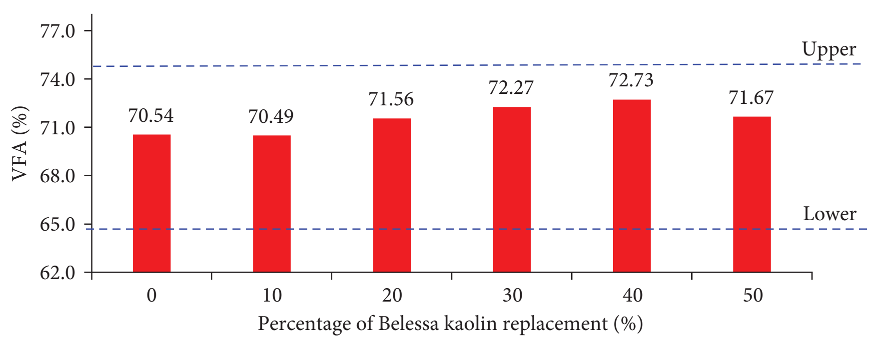

Figure 10: Relationship between VFA and replacement proportion of Belessa kaolin at OBC.

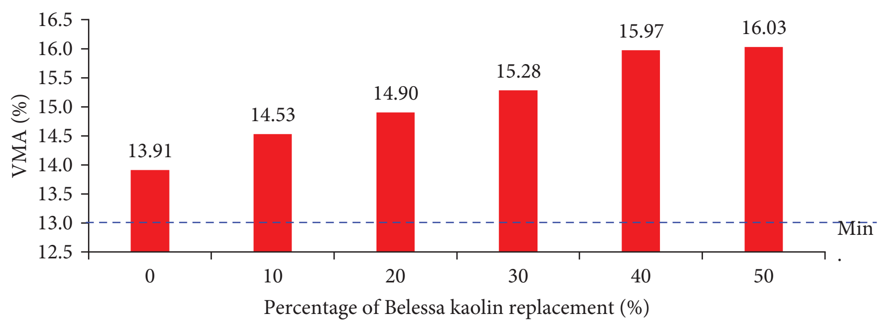

Figure 11: Relationship between VMA and replacement proportion of Belessa kaolin at OBC.

Therefore, the replacement of crushed stone dust at the rate of 30% of Belessa kaolin provides a better result than the other mix rate.

Table 11 shows that the HMA mixture prepared with partial replacement of Belessa kaolin filler at 30% replacement rate blended with a below-restricted zone of Superpave gradation satisfies the requirement of both local and international specification limits for all tested hot mix asphalt parameters. Stability and moisture susceptibility of the control mix are improved at 30% Belessa kaolin replacement by the weight of crushed stone dust. However, the other replacement rate satisfied the required specification; 30% of Belessa kaolin content is selected to be the best filler material replacement proportion based on this study.

3.11. Effect of Optimum Belessa Kaolin on Permanent Deformation (Rutting). In this study, the rutting resistance of the control mix (0% Belessa kaolin) and the mix with optimum Belessa kaolin (30% Belessa kaolin) are compared. All of the results obtained in the wheel-tracking test meet the limit value in UNE-EN requirements [33] for this test. Based on Table 12 and Figure 13, the sample with 100% crushed stone dust has a 3.17 mm mean rut depth whereas the sample with 30% of Belessa kaolin filler reached a 3.09 mm mean rut depth (RD). Also, the wheel tracking slope (WTS) for each test specimen per 1000 cycles is investigated. The wheel truck test of the control mix and 30% Belessa kaolin is 0.112 and 0.11, respectively. The proportional rut depth (PRD) for each specimen under test at different cycles in percentage was also examined. The mean proportional rut depth of the control mix and 30% Belessa kaolin is 5.89 and 5.86, respectively. This is confirmed with a similar study [8] bamboo fiber (BF) and sugarcane bagasse fiber (SCBF) as additives decrease the rutting depth significantly, i.e., the BF has

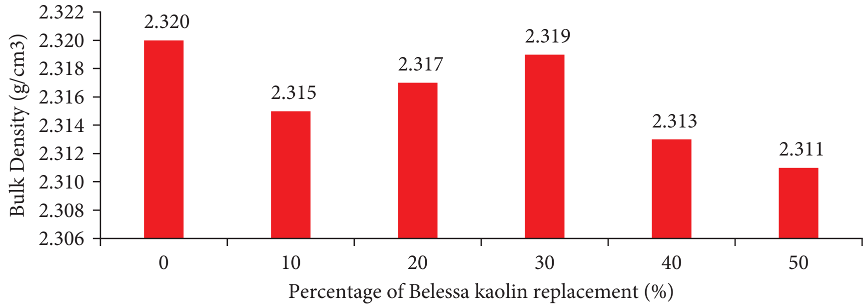

Figure 12: Relationship between bulk density and replacement rate of Belessa kaolin at OBC.

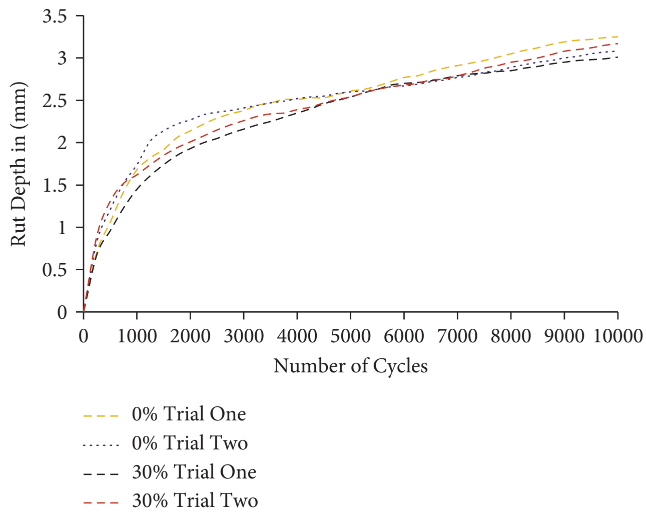

Figure 13: Rutting test result of control mix and 30% Belessa kaolin.

Table 10: TSR results in the different proportions of Belessa kaolin and CSD.

Percentage of Belessa kaolin replacement	Tensile strength of conditioned (kPa)	Tensile strength of unconditioned (kPa)	Tensile strength ratio (%)
0	717.19	877.34	81.75
10	697.43	857.55	81.33
20	717.83	880.49	81.53
30	727.13	882.77	82.37
40	705.3	877.5	80.38
50	657.05	894.61	73.45

Table 11: Comparison of optimum replacement proportion of Belessa kaolin with specifications.

HMA parameters	Control mix (0% Belessa kaolin)	Belessa kaolin at 30% replacement	ERA pavement design manual, 2013		International specification (Asphalt Institute, 1996)		Remarks
			Min.	Max.	Min.	Max.	
Stability (kN)	10.99	11.62	8	—	8	—	Pass
Bulk density (g/cm^3)	2.32	2.319	—	—	—	—	Pass
VIM (%)	4.1	4.16	3	5	3	5	Pass
VFA (%)	70.54	72.73	65	75	65	75	Pass
VMA (%)	13.91	15.28	13		13		Pass
Flow (mm)	3.04	3.08	2	3.5	2	3.5	Pass
TSR (%)	81.75	82.35	80	—	80	—	Pass

Table 12: Summary of wheel truck test result at optimum Belessa kaolin and control mix.

Specimen type	Mean rut depth (mm)	Mean WTS (μmm/ cycles)	Mean PDR (%)	Specification as per EN 13108		
				Rate (μmm/ cycle)	PRD (%)	RD (mm)
Control mix (0% Belessa kaolin)	3.17	0.112	5.89	<0.15	<8	<6
30% Belessa kaolin	3.09	0.11	5.86	<0.15	<8	<6

decreased the rutting depth from 2.165 mm to 1.82 mm while SCBF decreases the rutting depth from 2.165 mm to 2.025 mm as compared to control.

4. Conclusions

(i) The physical and chemical properties of Belessa kaolin were investigated and were found suitable for replacement as a filler. The specific gravity, plastic index, and the particle size distribution of Belessa kaolin met the requirement specified in the specification. Moreover, Belessa kaolin satisfies the minimum requirement of natural pozzolan materials for use as a mineral admixture specified by ASTM having the combined percentage chemical composition of main oxides ($SiO_2 + Al_2O_3 + Fe_2O_3$) of 89.94% which is satisfactory to encounter as filler material in hot mix asphalt.

(ii) All the Marshal mix properties for all mixtures from varying filler proportion at 5%, 6%, and 7% with three different below-restricted zones of Superpave aggregate gradation satisfy both local and international specifications.

(iii) When the CSD filler content increases, the OBC increases. This is due to the fact that when the filler content is getting higher, the overall surface area of aggregate and the absorption rate of filler is increased. This implies that higher bitumen content is needed to fulfill the Marshall property requirements.

(iv) The Marshal stability increases up to 30% Belessa kaolin replacement then starts decreasing. The increase in stability may be attributed from fines of Belessa kaolin which also have higher porosity and specific surface area. Hence, the incorporation of these fillers provided higher stiffening in mastic, which in turn produced mixes with higher Marshall.

(v) The indirect tensile strength value was increased up to 30% replacement rate. This result is due to Belessa kaolin of finer filler material having a higher porosity and surface area of cellular structure tends to distribute evenly in the mix design which increases the asphalt-aggregate adhesion.

(vi) At 50%, Belessa kaolin mix has a lower moisture resistance compared to the specification. This may be due to the amount of silica and iron increasing extremely, it lowers moisture sensitivity in asphalt mix and degrades the asphalt-aggregate bonding in the presence of water.

(vii) The rut depth of the optimum Belessa kaolin is greater than that of CSD. This may be due to the fineness of Belessa kaolin is greater than fillers. Finer fillers have a tendency for uniform distribution in asphalt mixes which increased the overall stiffness of asphalt.

(viii) Based on marshal parameters and moisture susceptibility results, the optimum replacement proportion was at 30% of Belessa kaolin and 70% of CSD of filler content, which is satisfying the control specification having maximum bulk density, maximum stability, and VIM within the allowed range of specification.

(ix) The overall rutting behavior of the mix prepared with 30% Belessa kaolin was almost similar to the mix prepared with the control mix. Both mixtures fulfill the requirement as per specifications. This proves that the use of Belessa kaolin as replacement filler at optimum content in asphalt mixture provides better performance as a mixture with 100% CSD filler. From this study, the test results obtained from mixes with Belessa kaolin have a relatively similar trend to that of using crushed stone fillers, and this shows us that Belessa kaolin fillers can be used as an alternative filler type in bituminous mixtures to the widely used crushed stone.

Data Availability

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

Conflicts of Interest

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

Acknowledgments

The authors would like to express their gratitude to Jimma University, Institute of Technology Digital Repository Library, for sharing the full thesis paper as supplementary materials for research accessible at https://repository.ju.edu.et/handle/123456789/6421.

References

[1] M. S. Pourtahmasb and M. R. Karim, "Utilization of recycled concrete aggregates in stone molecular simulation of hydrogen storage in ion-exchanged X zeolites," *Advances in Materials Science and Engineering*, vol. 2014, Article ID 189745, 10 pages, 2014.

[2] S. Lee, S. Mun, and Y. Richard Kim, "Fatigue and rutting performance of lime-modified hot-mix asphalt mixturesasphalt mixtures," *Construction and Building Materials*, vol. 25, no. 11, pp. 4202–4209, 2011.

[3] A. H. Guha and G. J. Assaf, "Effect of Portland cement as a filler in hot-mix asphalt in hot regions," *Journal of Building Engineering*, vol. 28, Article ID 101036, 2020.

[4] E. R. Brown and R. B. Mallick, "Stone matrix asphalt -properties related to mixture design," NCAT Report 94-2, pp. 1–15, National Center for Asphalt, Auburn, Alabma, USA, 2012.

[5] K. Kim, S. Haeng Jo, N. Kim, and H. Kim, "Characteristics of hot mix asphalt containing steel slag aggregate according to temperature and void percentage aggregate according to temperature and void percentage," *Construction and Building Materials*, vol. 188, pp. 1128–1136, 2018.

[6] S. Belay, E. T. Quezon, and A. Geremew, "Effect of selected conventional and non-conventional mineral fillers with "enset" fibers on compaction characteristics of stone mastic asphalt pavement (SMAP)," *Jordan Journal of Civil Engineering*, vol. 15, no. 1, pp. 30–40, 2021.

[7] Y. Kibru, A. Geremew, and B. Yigezu, "Potential use of "enset" fiber ash as partialreplacement of conventional filler material in hot mix asphalt," *JCEST*, vol. 12, no. 2, pp. 91–111, 2021.

[8] K. U. Ahmed, A. Geremew, and A. Jemal, "The comparative study on the performance of bamboo fiber and sugarcane bagasse fiber as modifiers in asphalt concrete production," *Heliyon*, vol. 8, no. 7, pp. 1–17, 2022.

[9] F. Wagaw, E. T. Quezon, and A. Geremew, "Evaluation of the performance of brick dust as a filler material for hot asphalt mix design: a case study in jimma zone," *International Journal of Engineering Science*, vol. 7, no. 3, pp. 64–72, 2018.

[10] N. Asmael, "Effect of mineral filler type and content on properties of asphalt concrete mixes," *Journal of Engineering*, vol. 16, no. 3, pp. 5352–5362, 2010.

[11] A. I. Nassar, M. K. Mohammed, N. Thom, and T. Parry, "Mechanical, durability and microstructure properties of Cold Asphalt Emulsion Mixtures with different types of filler properties of Cold Asphalt Emulsion Mixtures with different types of filler," *Construction and Building Materials Materials*, vol. 114, pp. 352–363, 2016.

[12] A. Eltaher, "An over view of the use of mineral fillers in asphalt pavements," *Journalof Basic and Applied SCiences*, vol. 10, no. 9, pp. 279–292, 2016.

[13] A.-S. Nathem, "The effect of filler type and content on hot asphalt concrete mixturesproperties,"vol. 6, no. 21, p. 2013.

[14] Y.-R. Kim, J. S. Lutif, A. Bhasin, D. N. Little, A. Bhasin, and D. N. Little, "Evaluation of moisture damage mechanisms and effects of hydrated lime in asphalt mixtures through measurements of mixture component properties and performance testing effects of hydrated lime in asphalt mixtures through measurements of mixture component propertiesand performance testing," *Journal of Materials in Civil Engineering*, vol. 20, no. 10, pp. 659–667, 2008.

[15] H. G. Dill, "Kaolin: soil, rock and ore from the mineral to the magmatic, sedimentary and metamorphicenvironments," *Earth-Science Reviews*, vol. 161, pp. 16–129, 2016.

[16] A. Ghadimian and M. Khodami, "Mineralogy, geochemistry, and genesis of the Garak Baghi kaolin deposit in the northwest of Saveh, Irandeposit in the northwest of saveh, Iran," *Arabian Journal of Geosciences*, vol. 8, no. 5, pp. 3019–3030, 2015.

[17] C. P. Velosa Al, "Hydraulic-lime based concrete: strength development using a pozzolanic additionand different curing conditions," *Construction and Building Materials*, 2014.

[18] G.-I. E. Ekosse, "Kaolin deposits and occurrences in Africa: geology, mineralogy and utilization," *Applied Clay Science*, vol. 50, no. 2, pp. 212–236, 2010.

[19] A. Mesele, T. Gidey, T. Weldemaryam et al., "Mineralogical and geochemical characterisation of kaolin deposit from Debre Tabor area northwestern, Ethiopiadeposit from Debre Tabor area northwestern, Ethiopia," *Applied Earth Science*, vol. 130, no. 1, pp. 42–56, 2021.

[20] G. Bedassa, W. Getaneh, and B. Hailu, "Geochemical and mineralogical evidence for the supergene origin of kaolin deposits – corigin of kaolin deposits – central Main Ethiopian rift," *Journal of African Earth Sciences*, vol. 149, pp. 143–153, 2019.

[21] A. H. M. Afaf, "Effect of aggregate gradation and type on Hot Asphalt concrete mix properties," *JES. Journal of Engineering Sciences*, vol. 42, no. 3, pp. 567–574, 2014.

[22] P. Singh Rajput and R. K. Yadav, "Use of plastic waste in bituminous road construction," *IJSTE - International Journal of Science Technology & Engineering*, vol. 2, no. 10, 2016.

[23] W. Mampearachchi, P. K. Fernando, and P. R. D. Fernando, "Evaluation of the effect of Superpave aggregate gradations on Marshall mix design parameters of wearing coursegradations on Marshall mix design parameters of wearing course," *J.Natn.Sci.Foundation Sri Lanka*, vol. 40, no. 3, pp. 183–194, 2012.

[24] M. K. I. Mohd Satar, R. P. Jaya, M. H. Rafsanjani et al., "Performance of kaolin clay on hot-mix asphalt properties," in *Proceedings of the International Post Graduate Conference on Applied Science & Physics*, Qingdao, China, July 2017.

[25] M. A. Khasawneh and M. A. Alsheyab, "Effect of nominal maximum aggregate size and aggregate gradation on the surface frictional properties of hot mix asphalt mixturessize and aggregate gradation on the surface frictional properties of hot mix asphalt mixtures," *Construction and Building Materials*, vol. 244, Article ID 118355, 2020.

[26] A. Zulkati, W. Y. Diew, and D. S. Delai, "Effects of fillers on properties of asphalt -concrete mixture," *Journal of Transportation Engineering*, vol. 138, no. 7, pp. 902–910, 2012.

[27] A. Tamiru, A. Geremew, and A. Jemal, "Performance evaluation of hot-mixAsphalt mixture using belessa kaolin as a filler with superpaveAggregate gradation", aggregate gradation," University in Partial Fulfillment of the Requirements for the Degree of Master of Science in CivilEngineering (Highway Engineering), A Thesis Submitted to the School of Graduate Studies of Jimma University, 2021.

[28] Era, "Pavement design manual," *Ethiopians Road Authority Pavement Design ManualFor Flexible Pavements*, 2013.

[29] Fhwa, *Specific Pavement Studies-Eexperiments Design and Research Plan for experiment" SPS-9A*, SUPERPAVE asphalt binder study, McLean, VA, USA, 1994.

[30] Overseas Road Note 19 (Orn19), *A Guide to the Design of Hot Mix Asphalt in Tropical and Sub- Tropical Countries*, Transport Research Laboratory (TRL), Wokingham, Berkshire, 2002.

[31] Asphalt Institute, Asphalt Institute, *Manual Series No. 2. "Asphalt Mix Design Methods*, vol. MS-2, Lexington, KY, USA, 2015.
[32] Aashto, *American Association of State Highway and Transportation Officials Guide for Designof, 1993 of Pavement Structures*, American Association of State Highway and Transportation Officials, Washington, DC, USA, 1993.
[33] European Committee for Standardization, *Bituminous Mixtures: Test Methods for Hot Mix AsphaltPart 22 Wheel Tracking, EN 12697-22*, European Committee for Standardization (CEN), Brussels, Belgium, 2003.