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CEMENT KILN DUST WITH FINE VOLCANIC ASH AS SUBSTITUTE FILLERS FOR HOT MIX ASPHALT

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Abstract

Waste and by-product materials are often used as substitutes for raw materials in asphalt mixtures to lessen building costs, minimize environmental problems, and protect natural resources. This study investigates the feasibility of employing two kinds of ashes, fine volcanic ash (FVA) and cement kiln dust (CKD), which are abundantly available in various regions of Yemen, as substitute hot mix asphalt filler (HMA) for conventional fillers. A traditional filler, basalt filler (BF), was partially and totally replaced at different percentages. FVA replaced 15%, 30%, 45%, 60%, and 100% by weight of the filler. CKD replaced the traditional filler with 25%, 50%, 75%, and 100% by weight of fillers as a partial replacement. The total replacement of traditional fillers includes 20% CKD + 80% FVA, 40% CKD + 60% FVA, 60% CKD + 40% FVA, and 80% CKD + 20% FVA. The evaluation of the planned HMA was done using conventional mechanical and volumetric characteristics. Marshall stability, direct compression (DC) tests, and indirect tensile strength (ITS) were employed to evaluate the influence of FVA with CKD fillers on the asphalt mixture's mechanical characteristics. The outcomes of the experiment demonstrated that 60% CKD + 40% FVA was used instead of the traditional mineral filler. A novel HMA was introduced, demonstrating enhanced stability, increased bulk density, decreased voids filled with bitumen (VFB), and lower flow compared to the mixture used as a control. Results showed that FVA and CKD may respectively substitute 30% and 75% of the BF. The ITS and the DC exhibited an increase. Therefore, incorporating CKD and FVA as fillers in is a sustainable solution that enhances performance, durability, and environmental benefits in asphalt construction.

Keywords: (Cement Kiln Dust – Volcanic ash – Hot Mix Asphalt – Marshall Test - Indirect Tehsil Strength – Direct compression strength)

1. INTRODUCTION

Based on World Bank data, the quantity of waste produced worldwide is rising daily. The global projection indicates an expected annual production of waste production by 2030: 2.59 billion tons. Forecasts suggest a 70 percent increase in waste generation by 2050, increasing from 2.01 billion tons to 3.40 billion tons per year in 2016 [1]. Two waste management options exist at present: recycling and disposal [2]. Recycling waste rather than disposing of it is essential to sustainability when considering current and anticipated increases in waste volumes. Given its exceptional in-service performance, the asphalt mixture is the material most frequently used in road pavement. Three components constitute an asphalt mixture: fillers, aggregates, and asphalt binders. Given that filler and asphalt binder work together to generate asphalt mortar, a basic dispersion system in asphalt mix and a filler is important. The physicochemical reactions that occur between the asphalt-filler components within asphalt mastic has a significant effect on the performance of the Hot Mix Asphalt (HMA).

Furthermore, the addition of fillers can improve the mix's resistance to temperature-related plastic deformation by filling up the asphalt mixture gaps that affect stability. [3]. The enhanced functionality of asphalt mixtures with substitute solid waste additives, such as copper slag [4], brick dust [5], bamboo fiber with sugarcane bagasse fiber [6] bagasse ash, groundnut shell [7] and coal fly ash [8], has prompted researchers to look into other wastes as fillers [9]. Bypass dust, commonly referred to as cement kiln dust (CKD), represents a waste substance that is usually designated for landfills and is created as a secondary result of the cement production process. It is a fine, powdery substance that resembles cement Portland in appearance. This by-product is made up of small particles high in sulfates, chlorides, and alkalis; heavy metals may also be present, derived from partially and unburned raw materials [10].

CKD was introduced to enhance the qualities of soil, asphalt granular layers, and asphalt mixtures to protect the environment [11], [12],[13]. In addition to exhibiting a longer fatigue life than conventional asphalt mixes, the resistance to freeze-thaw cycles were increased in asphalt mixtures, including CKD filler [14]. According to Abed et al. [15], CKD added to asphalt mixtures improved a pavement's rutting life while also increasing cohesiveness by 14.5%, stiffness by 13.5%, Marshall flow by 37%, air voids by 38%, and Marshall stability (MS) by 17%. Al-Asi et al. [16] examined the potential of utilizing cement manufacturing's residue, CKD, to enhance HMA engineering characteristics. The study examined the effects of incorporating CKD in asphalt mixtures containing basalt and limestone fillers. The research revealed that the addition of CKD resulted in an increase in viscosity and raised the softening point of the asphalt cement (AC).

Volcanic ash (VA) mainly contains the Al, Mg, Si, and Ca minerals, as well as heavy elements, such as Cu, Mn, V, Zr, Zn, and Fe [18].VA particles are produced during volcanic eruptions under conditions of high temperature and pressure. They exhibit various shapes and microporous topologies [19]. According to Yong and Dupre's formula, a higher degree of roughness in a filler's area could enhance the bitumen's wetting effect [20]. Furthermore, bitumen is more strongly physiochemically adsorbed by volcanic ash than by packing material due to the hazardous chemical composition of volcanic ash. Liu et al. [21] investigated the utilization of volcanic rocks instead of limestone. The study was carried out using infrared, SEM scanning, and X-ray photoelectron spectroscopy. The results suggest that the asphalt mastic with VSP outperformed the limestone powder in terms of basic performance. Volcanic stone powder could be used as an inorganic filler in place of limestone powder. The characteristics of the AC-WC asphalt mixture using volcanic ash as a filler instead of cement were given by Sufanir et al. [22]. The goal of this study was to determine the maximum stability value using an experimental method. Volcanic ash deposits make up 0%, 25%, 50%, 75%, and 100% of the filler weight. The results show that, at 15% replacement level and 6% asphalt level, the highest stability value of 1151 kg is observed. The performance of the mixture's volumetric characteristics has been positively enhanced by filling the HMA with volcanic ash. The maximum stability was improved when hot asphalt mixtures were made using only volcanic ash as filler. Basalt stones and volcanic ash fillers used in asphalt concrete mixes are proven to result in superior fatigue, creep/slippage, and stripping resistance than CSD [23].

The absence of fillers, a vital component in asphalt mixtures, underscores the need to consider alternative solutions that fulfill engineering requirements and are economically viable. Waste disposal has become a pressing environmental issue with substantial implications. Furthermore, research on the utilization of FVA incorporating CKD dust as a filler in asphalt mixtures has been limited. Thus, this study aims to investigate the impact of incorporating CKD with FVA as a filler in the asphalt mixture. This objective can be attained through the following:

* Finding the optimum ratio of CKD with FVA can provide high performance compared to conventional asphalt mixtures (basalt crash filler), CKD asphalt mixtures, and FVA asphalt mixtures.

* The effect of CKD with FVA on mix performance with various tests, including MS, ITS, and DC test, is investigated.

2. MATERIALS AND EXPERIMENTAL SETUP

The study's overall activity plan is shown in Figure 1. Materials employed in this experiment included asphalt with a 60/70 penetration grade, BF, CKD, and FVA.

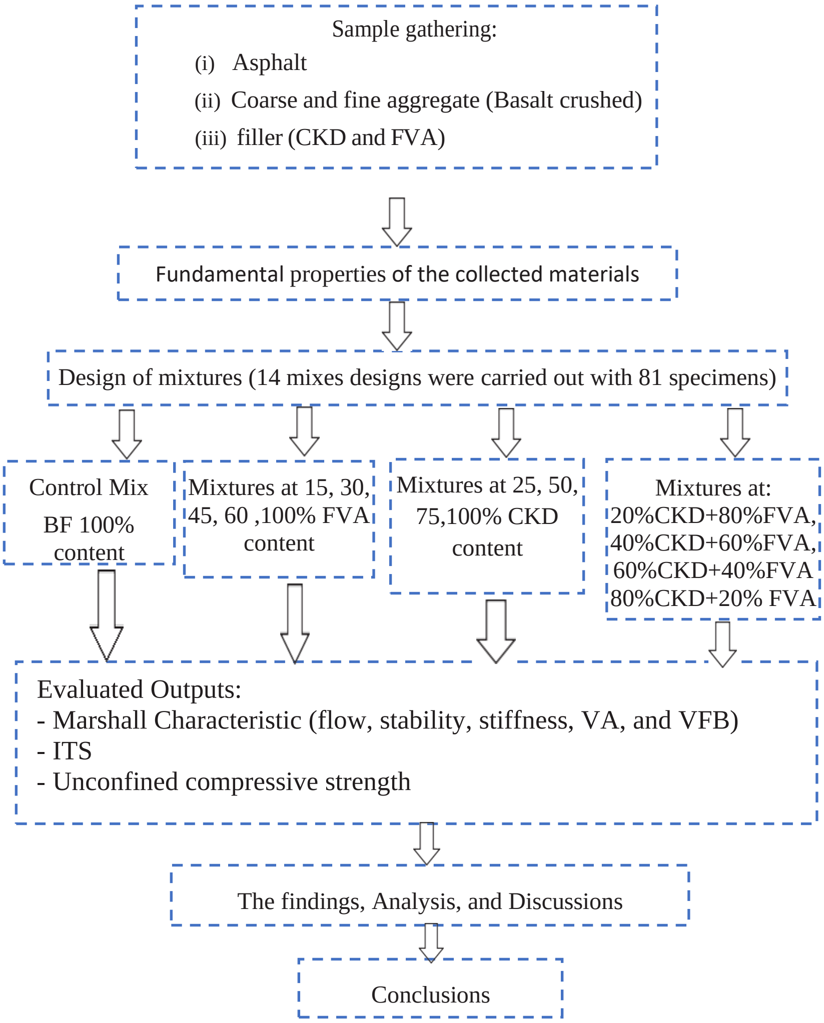

Figure 1. The activity framework

2.1. Properties of Materials

2.1.1. Asphalt.

AC 60/70 manufactured at Oman Refinery was brought to the site (by bulk) and utilized to create the investigated mixes throughout this investigation. AC is tested in a lab to determine the degree of penetration. Table 1 lists the characteristics of the asphalt binder.

2.1.2. Aggregate.

This study collects four sizes of aggregates from the source AL-Amjad crusher plant on the right side of Sana'a Mareb main road. The aggregate source is rock-formed hills. The formation is made up of columns of basalt of igneous origin. These aggregate fractions have been tested to determine their suitability for use according to the AASHTO standard [24]. A nominal maximum aggregate size of 12.5 mm was utilized in the mixture. The aggregate gradation comprises aggregate (1), with 7% passing between 19- and 12.5-mm sieve, aggregate (2), with 43% passing between 12.5- and 9.5-mm sieve, aggregate (3), with 4% passing between 9.5- and 4.75-mm sieve, and aggregate (4), with 46% passing through the 4.75 mm sieve. Additionally, a minimum of 4.6% filler by weight of aggregate was included in the composition. Figure 2 displays the gradation of the mixed aggregate and the specified limit. The aggregate gradation employed in this study is dens-grade(D-5), which was used to meet the requirements of the wearing surfaces, as indicated in Table 2. Table 3 demonstrates the basic properties of the aggregate employed in this investigation.

Table 1. The characteristics of asphalt used.

Characteristics	Designation AASHTO AASHTO No.	Results	AASHTO Specification
Penetration (25° C, 0.1 mm)	T-49	62	60-70
Specific gravity	T-228	1.028	1.01-1.06
Softening point (°C)	T-53	51	46-56
Flash point, c°	T-48	235	≤250

Table 2. Aggregate Gradation

Sieve size(mm)	Used gradation (%)	Specification limit (%)	Mean Specification
19.5	100	100	100
12.5	95.13	90–100	95
4.75	59.3	44–47	59
2.36	42.7	28–58	43
0.3	13.3	5–21	13
0.075	4.6	2–10	6

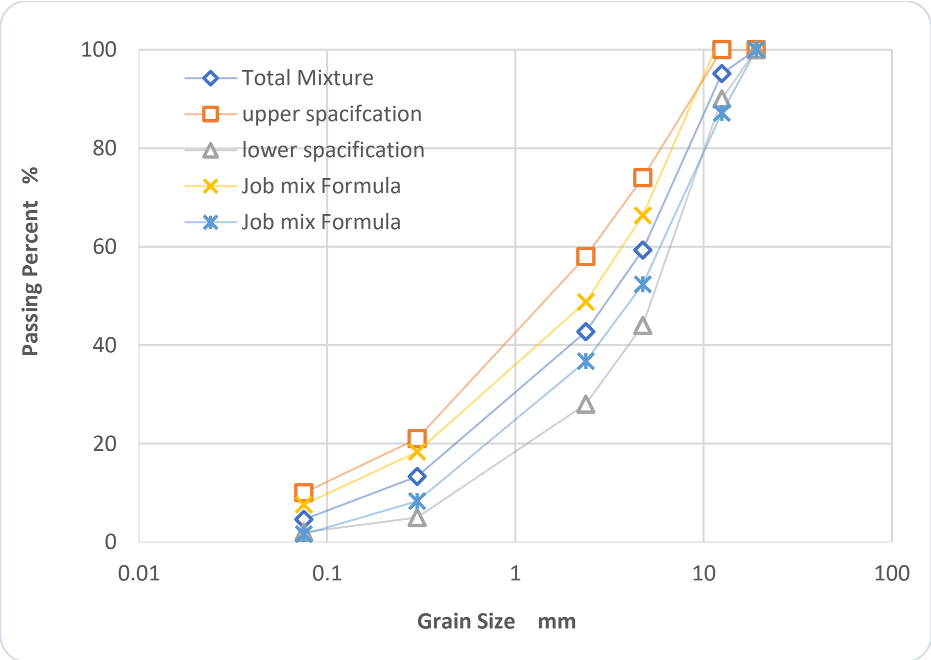

Figure 2. The aggregate's grain size distribution

Table 3. Fundamental Characteristics of the Aggregate

Items	Actual Value %		Specification Limit
1-Specific Gravity and Water Absorption T 84, 85, and C 128:	Specific γ	W abs	
Fraction 19.5–12.5b mm	2.854	0.959	
Fraction 12.5–09.5 mm	2.726	2.018	4 Max. for W absorption
Fraction 09.5–4.75 mm	2.886	2.098	
Fraction 4.75–min. mm	2.623	2.872	
2- Lose Angeles Abrasion T96	12.7		25 Max.
3- Plasticity Index (PI) T 89	Non-plastic		non-plastic
4- Sand Equivalent T 176	90.5		75 Min.

2.1.3. Fillers

2.1.3.1. Cement Kiln Dust.

CKD was supplied from the Amran cement plant, which is located northwest of the capital, Sana'a, as shown in Figure. 3. CKD was then sieved on No. 200 sieve, as shown in Figure. 4. This waste has a high Cao content based on the chemical components of the CKD, as shown in Table 4. If not used, the naturally occurring CKD of less than 0.075 mm in particle size has a negative impact on the environment.

2.1.3.2. Volcanic rock.

Quaternary Volcanic outcrops dominate surface geology in various sections of Yemen. Figure 5 depicts a map of the principal granular volcanic ash locations, with an estimated surface area of 17,000 km2 [25]. Much volcanic ash can be found in cities and suburbs. Thus, this material has not been used in engineering. Given its availability in many regions in great quantities and at no cost, this kind of material is one of the substitutes that can be applied to the building of roads. Figure 6 illustrates that the rocks' particle size is controlled to be less than 15 cm. Once the stones were evenly mixed, non-volcanic rocks were taken out of the mixture. The volcanic stone ash was generated by following these steps. The shelf-type abrasion tester from Los Angeles was filled with crushed volcanic rocks and operated for 0.5 hours. The ash and pulverized stone residue were filtered through a sieve with a 0.075 mm particle size after the Los Angeles abrasion test. The volcanic rocks ash needed for the test, as indicated in Figure 7, was the ash that was left over after flotation. Table 5 provides an overview of the volcanic ash chemical content.

Figure 3. CKD at Amran cement plant

Figure 4. CKD Ash

Table 4. Chemical composition of CKD (Amran cement plant).

Component	SiO_2	Al_2O_3	Cao	MgO	FeO_3	Na_2O	K_2O
Percentage (%)	17.01	3.65	57.45	1.42	3.68	0.14	1.03

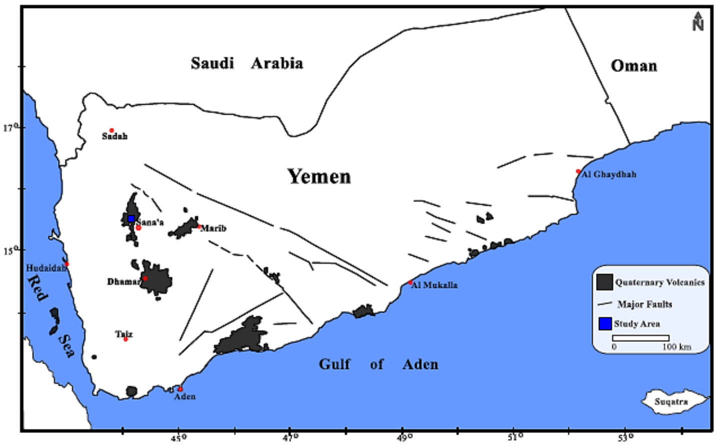

Figure 5 The principal sources of Quaternary volcanic ash in Yemen [27]

Figure 6. Volcanic stone

Figure 7. Volcanic ash

Table 5. Chemical composition of volcanic ash [26]

Component	SiO_2	TiO_2	Al_2O_3	FeO_3	So_3	MgO	Cao	K_2O
Percentage (%)	46.64	2.1	16.7	12.5	0.05	7.8	9.3	2.7

2.2. Experimental Setup

2.2.1. Mixture Design.

This study uses the Marshall Test Method, also known as ASTM [28] because of a shortage of suitable Yemeni testing facilities (specifically, Gyratory Compactor Superpave). It was used to create asphalt concrete mixes and analyze their qualities. ITS and DC were used to examine the impact of FVA with CKD fillers on the mechanical characteristics of asphalt mixes.

2.2.1.1. Marshall test.

This study used the Marshall procedure [28] and followed the standard specifications, as shown in Table 6. The 14 mix designs were utilized. Control mix (traditional filler) was replaced with FVA by weight of filler at 15%, 30%, 45%, 60%, and 100%. CKD replaced the control mix at 25%, 50%, 75%, and 100% and 20% CKD + 80% FVA, 40% CKD + 60% FVA, 60% CKD + 40% FVA, and 80% CKD + 20 % FVA, by weight of filler.

Table 6 Marshall Parameter specifications.[24]

Items	Specification ASTM D6927-15L
Compaction blows	75
Stability (KN)	9 Min.
Flow (mm)	2–4
VFB%	65–75
Air Voids %	3–5
Rigidity Ratio (stuffiness)	3 Min

For the control mixture, the Optimum Asphalt Content (OAC) was found to be 5.245%. This OAC was used to prepare all HMA samples to ensure uniformity throughout the investigation.

In each mix design (control mix), five asphalt content percentages were used, namely, 4%, 4.5%, 5%, 5.5%, and 6%, by sample weight. The temperatures for mixing and compaction were 160 °C and 143 °C, respectively. A total of 15 asphalt mixture samples are 4 inches in diameter, and each bitumen percentage has three samples. The samples were heated and then quickly compacted in a mold. In the compactor, after correctly mixing the aggregate and bitumen. Each side of the compactor had 75 blows. The examples of asphalt concrete prepared for the Marshall test are depicted in Figure 8.

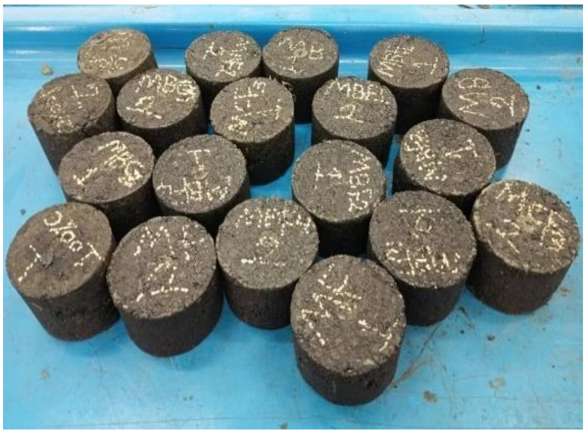

Figure 8. Asphalt concrete samples for MS testing.

Several tests were run on the samples that were collected after the Marshall Mix samples. The Marshall flow parameters and stability, as well as the mix's theoretical maximum specific gravity and bulk specific gravity, were all tested to determine the bituminous mix's characteristics and choose the mix that meets the necessary requirements. The volumetric characteristics of Marshall Mixture samples were calculated using Gmm and Gmb to evaluate the mix's quality.

The Marshall Standard Test is performed by immersing compacted asphalt concrete samples in hot water for 30 mins. to 40 mins at the standard test temperature of 60 C°, followed by diametrical loaded at a rate of 50.8 m/min. The effective bitumen concentration of freshly made conventional samples was measured using MS and flow parameters according to ASTM standards. Experiments on conventionally prepared samples determined the proportion of effective bitumen.

2.2.1.2. Direct Compression (DC).

According to ASTM [29], the DC test evaluates how materials behave and deform under static crushing stresses. The specimen is subjected to varying weights and compression forces. One of the most important characteristics of paving mixtures was thought to be the compressive strength of the dense mixture. Several researchers [30] and [31] have used the compression test in designing and evaluating paving mixtures. For this test, Marshall test samples that are approximately 100 mm (4.0 inches) in diameter with a height between 62 and 67 mm are also employed, and the compaction of specimens was explained in detail in the Marshall test. Fifteen specimens were prepared, where 12 were treated and 3 were controls.

The universal compression machine is the apparatus utilized in this test. The specimens were stored in an air bath at 25 C° for not less than 4 h before testing. The Marshall specimen was put through a continuous 5.08 mm per min strain test in a compression machine until failure. The maximum load that was applied to the specimen defines the point of failure. The amount of load, expressed in kg, is required to notify the specimen's failure at 25 C°. The observed load value at failure (P) in kg and the specimen diameter (D) in mm are used to compute the (DC) test values (Sc) using the following equation:

$$SC= P / (\frac{\pi D2}{4}) \qquad [kg/ cm2] \qquad (1)$$

2.2.1.3 Indirect Tensile Strength Test ASTM D-4123.

Carneiro and Barcells [32] independently invented the indirect tensile test in Barazile and Japan [33] to determine cracks in samples. In the ITS test, compressive loads operating parallel to the vertical diametrical plane are applied to a cylindrical specimen.

This loading design results along the vertical diametrical plane in a comparatively uniform tensile stress perpendicular to the direction of the applied load. A cylindrical specimen (4 in diameter and 3±0.2 in thickness) is subjected to a single compressive load acting vertically and parallel to the diametric plane to conduct an indirect tensile test. The following steps can be used to summarize the test procedure:

1- Once the test specimen's height has been established, gently center it on the lower loading strip.

2- Before testing, specimens are submerged for 60 mins. in a water bath set at 25 °C. To enable the upper test plate to slide freely, the testing head's plate is cleaned, and a small layer of oil is applied to the guide rods.

3- In a compression machine, Marshall specimens were subjected to a continuous strain rate of 5.08 mm/min until failure.

4- Tensile stress at failure formulas have been developed and made simpler. These calculations presuppose that the HMA is elastic, homogeneous, and isotropic. [25]. The load value upon failure (P), measured in kg., The following formula is used to calculate the ITS values (St) based on the specimen diameter (D) in cm and specimen thickness (H) in cm:

$$St = (2*P) / (\pi * H * D) \text{ (kg/ cm2)} \quad (2)$$

2.2.2. Test Plan.

Table 7 presents the test code of HMA for each mixing ratio. For each single-aimed property, three samples were prepared for testing according to the mentioned methods. Simultaneously, density and air void were determined from prepared samples, and the average was adopted.

Table 7. Test Code of Prepared HMA

NO.	Mix	Filler material percentages		
1	**MB**	100	0	0
2	**MBC1**	75	25	0
3	**MBC2**	50	50	0
4	**MBC3**	25	75	0
5	**MC**	0	100	0
6	**MBF1**	85	0	15
7	**MBF2**	70	0	30
8	**MBF3**	55	0	45
9	**MBF4**	40	0	60
10	**MF**	0	0	100
11	**MCF1**	0	20	80
12	**MCF2**	0	40	60
13	**MCF3**	0	60	40
14	**MCF4**	0	80	20

MB (mix with BF and control mix), MCF (mix with CKD and FVA), MBF (mix with BF and FVA), MF (mix with FVA), MBC (mix with BF and CKD), and MC (mix with CKD).

3. RESULTS AND DISCUSSION:

3.1 Marshall Test Results:

The test has been applied for all mix (42) specimens. The results are shown in Table 8.

3.1.1. Determination of Optimum Asphalt Content of Control Specimen.

Five distinct amounts of AC are tried (4%, 4.5%, 5%, 5.5%, and 6%) by weight of aggregate (1200 grams), with the gradation utilized in this study being densely graded for surface course. Three Marshall specimens are made and tested for each percentage. The average value of asphalt content that equates to the optimum unit weight, maximum stability, 70% of VFB, and 4% of air voids (AV) is the optimal asphalt content OAC. The flow is verified in accordance with the ASTM specification [24]. As shown in Figure 9, we found OAC=5.245% and the other characteristics indicated in Table 8.

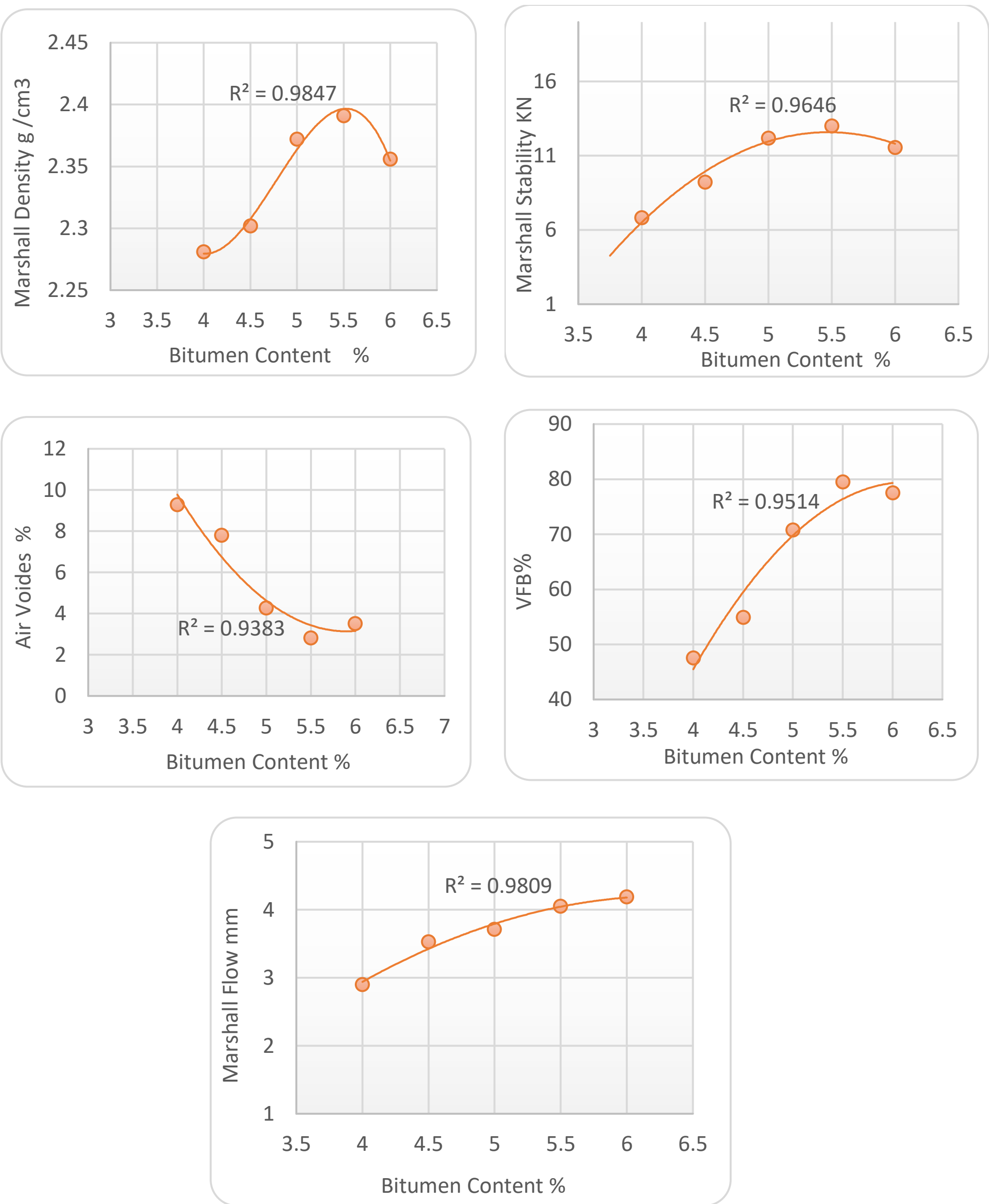

Figure 9. Marshall Test Results for control mix

Table 8. Marshall Characteristics for All Mixes

Marshall Characteristics	Stability (KN)	Flow (mm)	Rigidity Ratio (KN/mm)	Unit Weight (gm/cm3)	AV (%)	FVB (%)
MB (control mix)	12.77	3.86	3.29	2.361	4.87	71.22
MBC1	12.93	2.82	4.65	2.355	4.62	72.17
MBC2	13.29	2.71	4.91	2.362	4.32	73.56
MBC3	13.76	2.57	5.35	2.37	4.02	75
MC	11.04	3.50	3.15	2.315	6.22	65.47
MBF1	11.28	3.94	2.86	2.358	4.51	70.68
MBF2	13.84	3.54	3.96	2.380	4.1	74.77
MBF3	12.81	3.96	3.23	2.366	4.65	72.19
MBF4	11.86	3.97	3.00	2.363	4.77	71.64
MF	9.04	4.01	2.10	2.360	4.85	71.30
MCF1	10.35	3.51	3.20	2.337	5.83	64.95
MCF2	11.52	3.54	3.30	2.339	5.18	67.53
MCF3	12.73	3.66	3.50	2.368	4.75	72.58
MCF4	9.4	3.77	2.70	2.337	5.81	67.24
Specification Limits	9 Min.	(2–4)	3 Min.	------	(3-5)%	(65–75)%

3.1.2 Volumetric Properties.

Volumetric property results for the planned HMA are presented in Figs. 10 and 11 for densities and air void, respectively, for various HMAs with different filler compositions. Densities were calculated using ASTM D 2726, whereas air void was calculated using ASTM D 3203. However, the continuous replacement of BF by CKD leads to a continuous increase in densities and decrease in air void until 75% replacement. For example, a specimen with 75% CKD showed a 0.38% increase in density and a 17.45% decrease in air void, which could be a result of different reasons. First, the lowest density of CKD provides higher quantities of the smallest particles than BF that helps in a more compact mixture skeleton. Second, the angular shape particle of the BF, in contrast to CKD, increases the asphalt mastic's viscosity and dissipates the compaction effort [34].

Simultaneously, the continuous partial replacement of FVA with BF, up to the selected replacement percentage (i.e., 30% replacement of FVA with BF), showed a 0.8% increase in density and a 15.81% decrease in air void. The changes might be a result of incorporating fine materials that occupied the tiny voids in the mixture skeleton. The same trend is recognized when the continuous replacement of CKD by FVA is achieved but with a lower rate of increment in densities and an increase in air void. The replacement of 60%CKD+30FVA showed a 0.3% increase in density and a 2.51% decrease in air void.

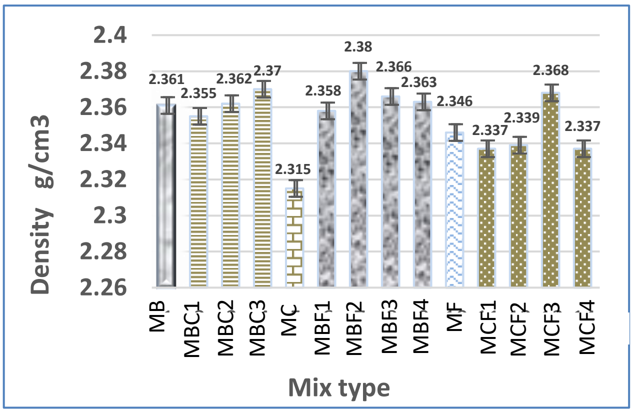

Figure 12. Comparison of Density for for HMA Comprising Different Filler Compositions

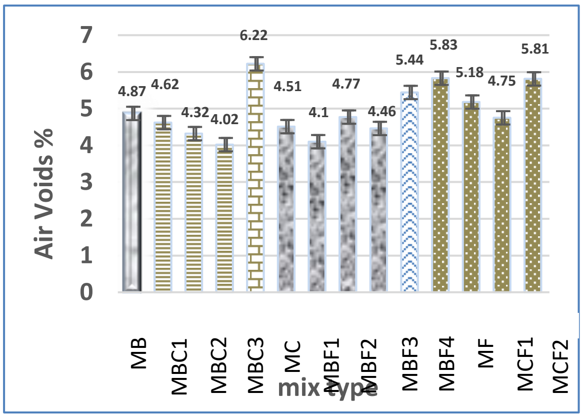

Figure 13. Comparison of Air Voids HMA Comprising Different Filler Compositions

3.1.3 Marshall Stability and Flow.

Different filler compositions are demonstrated in Figsures 12 and 13. All results satisfied the related requirements of MS and flow stated in ASTM specifications. Figure 12 shows that all stability values met the specifications with the replacement of filler content. The figure shows that content increases with the mixes' Marshal stability value, reaching its maximum stability of 13.76 KN at 75% CKD content and then declining. The reason is because CKD has larger surfaces, which tend to absorb more asphalt [32].

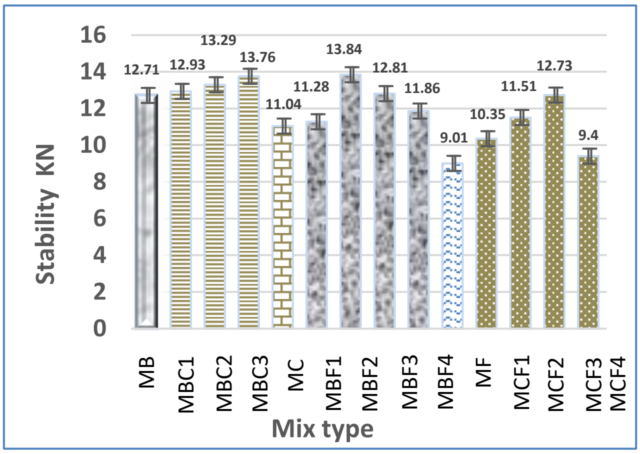

Figure 12. Comparison of Stability for HMA Comprising Different Filler Compositions

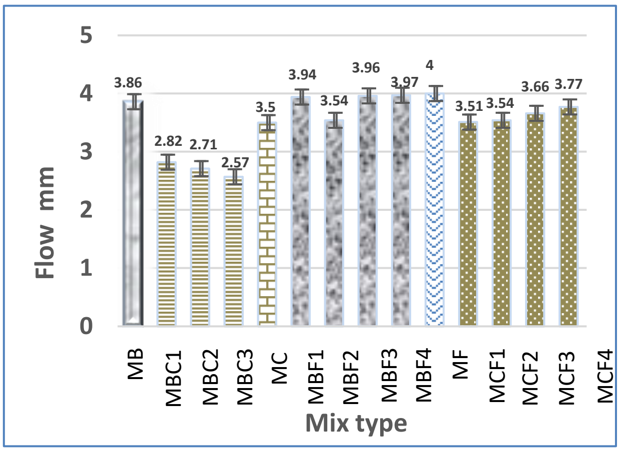

Figure 13. Comparison of Flow for HMA Comprising Different Filler Compositions

Simultaneously, Figure 12 demonstrates that at 30% of the maximum stability value occurs, and the stability increases from 11.28 KN to 13.84 KN, representing a 22.70% improvement. This change could be related to the penetration of small particles of VA into mixture voids, resulting in a dense volume. Such volume could be a result of VA's pore characteristics [21], suggesting less strength. For CKD with FVA, the stability was 12.73 KN at 60%CKD+40%FVA, which could be the same as the value of the control mix.

For heavy traffic, the maximum flow value needs to be set at (2–4) mm. [35]. At approximately 3.86 mm, the value of the control mix, is where the flow of replacement mixes oscillates. Therefore, all replacement rates are the limit specifications. When looking at Fig. 13, samples were created and tested with 75% CKD, 25% BF had the lowest flow value at 2.57 mm, and samples prepared with 100% FVA had the highest flow value at 4 mm. Height flow values within the acceptable range imply vital flexibility, enhancing the ability of HMA pavement to deform without cracking.

3.1.4 Comparative Study between Conventional and New Additives on Asphalt Mixture Properties.

A comparative analysis will be carried out to examine the most effective proportions achieved to satisfy the Marshall criteria, including 30% fine volcanic ash (FVA) + 70% BF, 75% CKD + 25% BF, and 60% CKD + 40% FVA in comparison to the control mixture.

3.1.4.1 Asphalt Mixtures Properties Evaluation

3.1.4.1.1 Stability and Flow Evaluation.

The impact of various additives, both conventional and modified, on the stability of asphalt mixtures is illustrated in Figure 14. The analysis of the results reveals that the inclusion of FVA and CKD in the modified mixtures leads to an increase in maximum stability by 8.4% and 7.75%, respectively, which is consistent with the literature [13,14,20]. Furthermore, when CKD and FVA are used together, the stability of the mixture matches that of the control mix with a value equal to 12.73 KN. Figure 15 demonstrates the effect of utilizing various fillers on the flow characteristics of asphalt mixes compacted at OAC. The findings suggest that all additives lead to a reduction in flow values when compared to the flow value of the control mix. Specifically, FVA and CKD result in an 8.29% and 33.42% decrease in flow value, which is similar to the results of previous studies [20], while CKD with FVA leads to a 5.18% decrease in flow value. Consequently, CKD has been identified as the most effective additive for enhancing the flow properties of asphalt mixtures.

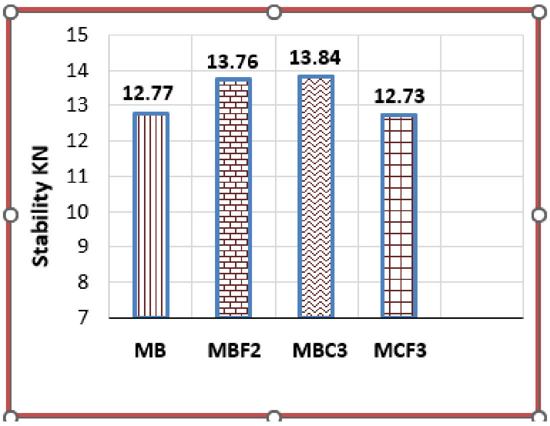

Figure 14. Effect of Adding Different Additives on Marshall Stability

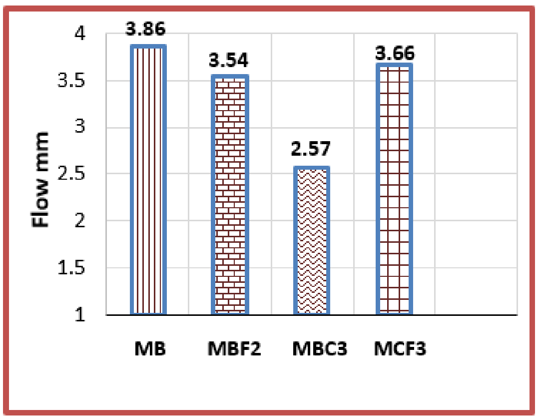

Figure 15. Effect of Adding Different Additives on Marshall Flow

3.1.4.1.2 Evaluation of Unit Weight, AV%, VFB%, and Marshall Stiffness.

Figure 16 shows the impact of various novel fillers on the unit weight properties of asphalt mixes at OAC. The findings suggest that the unit weight achieved with all additives surpasses that of the control mix. Specifically, the addition of FVA results in the highest unit weight value. Figure 17 illustrates the impact of utilizing various additives on the air voids percentage of asphalt mixtures at OAC. The depicted figure indicates that, at OAC, the proportion of air voids decreases for all types of additives in comparison to the control mix. Nonetheless, the % air voids acquired for all additive types remain within the specified acceptable limits. Both FVA and CKD lead to a reduction in air voids percentage by 15.81% and 17.45%, respectively. Moreover, the incorporation of CKD along with FVA in asphalt mixtures results in a decrease in air voids percentage by 2.46%. However, the findings demonstrate that the VFB% value shows an increase across all categories of additives falling within the specified acceptable limits, as shown in Figure 18.

Finally, Figure 19 illustrates the notable alteration in stiffness values of asphalt mixtures due to the incorporation of additives in HMA. The findings suggest that stiffness values exhibit an enhancement with the utilization of various additives. Among them, CKD emerges as the most effective additive, leading to a substantial improvement of approximately 62.61% in the stiffness of asphalt mixtures.

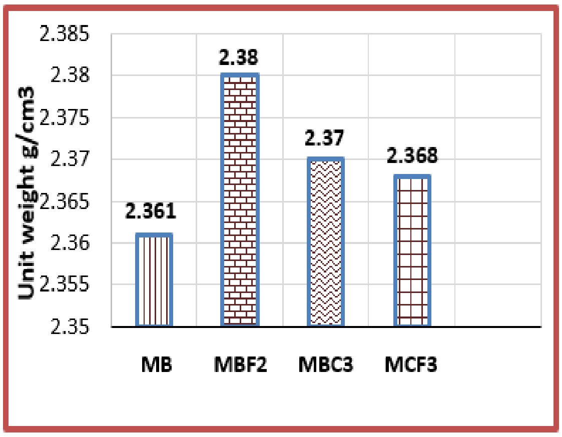

Figure 16. Effect of Adding Different Additives on Unit Weight

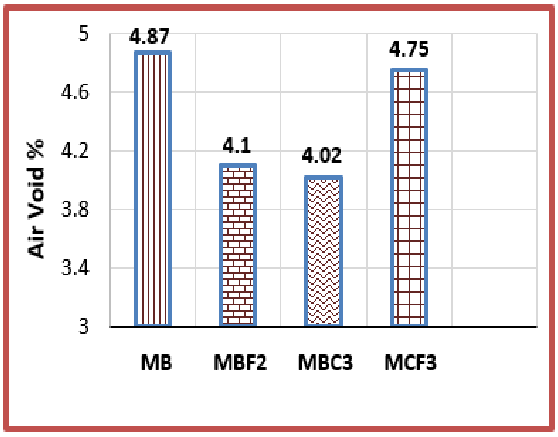

Figure 17. Effect of Adding Different Additives on Air Void

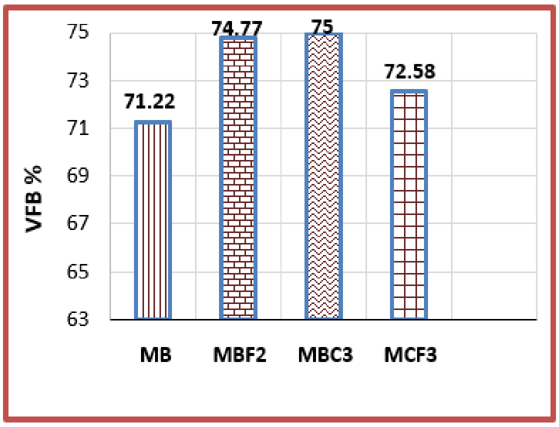

Figure 18. Effect of Adding Different Additives on VFB%

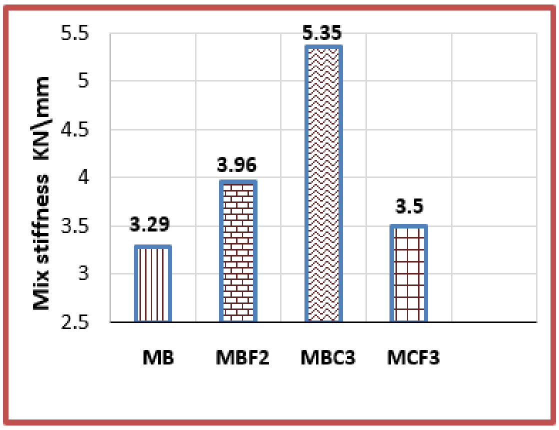

Figure 19. Effect of Adding Different Additives on Stiffness

3.2. Direct Compression (DC) Test Results.

The DC test is performed on the modified and control samples. Twelve specimens are analyzed, and the results are shown in Figure 20. The DC value increases for all types of additives that improved compressive stress compared to the control mixture. Both FVA and CKD lead to an increase by 25.5% and 18.6%, respectively, which is consistent with the literature [28]. Furthermore, the integration of CKD alongside FVA in asphalt mixtures results in a rise in the percentage of DC value by 14.1%.

3.3 Indirect Tensile Strength (ITS) Test Results.

The ITS examination is conducted with respect to the modified and control samples. A total of twelve samples are analyzed, and specimens are prepared using the methodology outlined in the Marshall method. Subsequently, they are subjected to ITS testing in accordance with ASTM D-4123. Testing of triple specimens is carried out at 25 °C in temperature. The results displayed in Figure 21 show that the incorporation of modified mixtures has led to a notable enhancement in the adhesion among the HMA particles, as evidenced by a 20 % increase in ITS values at 25 °C for 30% FVA and 17.1% for 75% CKD, which a similar result of Abbas et al. [36] . The integration of CKD alongside FVA in asphalt mixtures results in a rise in the percentage of ITS value by 8.9%.

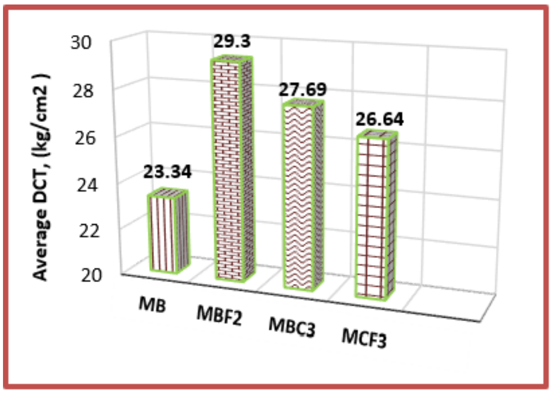

Figure 20. Effect of Adding Different DC value

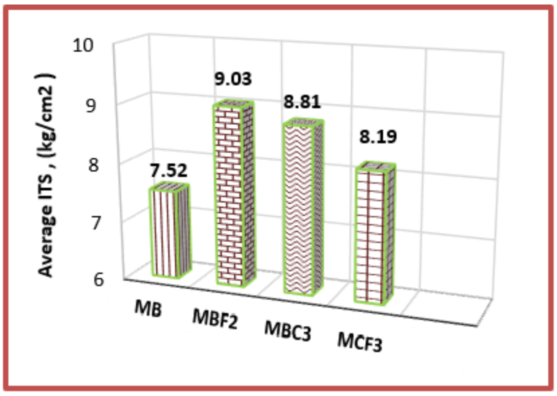

Figure 21. Effect of Adding Different on ITS value

4- CONCLUSIONS AND RECOMMENDATIONS

Principal aim of this investigation was to evaluate the viability of employing CKD in conjunction with FVA to enhance the engineering characteristics of the asphalt mixture. The investigation scrutinized the impact of partially or entirely substituting the filler in asphalt basalt HMA blends with CKD and FVA. The results of this investigation allow for the following deductions to be made:

(1) Using CKD and FVA as fillers in HMA mixes has no impact on the mixing process or the time required.

(2) The 30% FVA filler was used in place of the BF, which increased the Marshall stabilities of the mixes by 8.4% and decreased flow value by 8.29%. The 75% CKD filler was substituted for the BF, the mixes' Marshall stabilities increased by 7.75%, and their flow value decreased by 33.42%.

(3) Totally Replacing the BF with 60% CKD+40FVA filler allowed the stability of the mixture to match that of the basalt mix and reduced the flow value by 5.18%.

(4) Both FVA and CKD reduced air void percentages by 15.81% and 17.45%, respectively. Furthermore, including CKD with FVA in asphalt mixtures reduces air void percentage by 2.46%.

(5) Stiffness values exhibit an enhancement with the utilization of various additives. Among them, CKD emerges as the most effective additive, leading to a substantial improvement of approximately 62.61% in the stiffness of asphalt mixtures.

(6) The DC value increases for all types of additives in comparison to the basalt mix. Both FVA and CKD lead to an increase of 25.5% and 18.6%, respectively. Furthermore, CKD with FVA in asphalt mixtures results in a rise in DC value by 14.1%.
(7) Adding FVA, CKD, and CKD with FVA improves mix cohesiveness, as evidenced by increases in ITS by 20%, 17.1%, and 8.9%, respectively. The increase reduces the mix's breaking tendency and increases pavement fatigue life, reducing cracking propensity and increasing pavement fatigue life.
(8) The study's findings demonstrated the possibility of combining CKD and FVA to improve the HMA’s engineering qualities. The effects of other aspects not included in this study, such as moisture susceptibility, fatigue resistance, resilient modulus test, dynamic creep test, and the use of CKD with FVA in varying asphalt content, need to be further investigated.
(9) The author recommends the imperative of performing tests on the mechanical properties assessed by dynamic tests to confirm compliance for the production of asphalt mixtures

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