Cement Kiln Dust as Substitute Fillers for Hot Mix Asphalt

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Abstract:

To reduce construction costs, eliminate environmental issues, and protect natural resources, waste and by-product materials are frequently substituted for raw components in asphalt mixtures. This study investigates the feasibility of employing cement kiln dust (CKD), which is 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 of CKD with 25%, 50%, 75%, and 100% by weight of fillers. The evaluation of the planned HMA was done using conventional mechanical and volumetric characteristics. A total of 15 bituminous concrete mix specimens with bitumen content of 4%, 4.5%, 5%, 5.5%, and 6% were created, and the optimum asphalt content was 5.24 %. The impacts of four different (CKD) samples with filler contents of 25%, 50%, 75%, and 100% by weight were compared with respect to bituminous concrete performance. The outcomes of the experiment demonstrated that CKD may substitute 75% of the BF at a bitumen content of 5.24%, 13.76 KN Marshall stability value, 4.02% air voids, 75 % VFB, 2.370 g/cm3 bulk density and 2.57 mm flow. Therefore, incorporating CKD as fillers in HMA is a sustainable solution that enhances performance, durability, and environmental benefits in road asphalt construction.

Keywords: Cement Kiln Dust; Hot Mix Asphalt; waste filler; Marshall Testes

غبار فرن الأسمنت كبديل للمواد المالئة لمزيج الأسفلت الساخن

الملخص:

لتقليل تكاليف البناء والقضاء على المشاكل البيئية وحماية الموارد الطبيعية، يتم استبدال النفايات والمواد الثانوية بشكل متكرر بالمكونات الخام في خلطات الأسفلت. تبحث هذه الدراسة في جدوى استخدام غبار فرن الأسمنت (CKD)، والذي يتوفر بكثرة في مناطق مختلفة من اليمن، كبديل للمادة المالئة في الخلطة الاسفلتية الساخنة (HMA) بديلا للمواد المالئة التقليدي. تم استبدال المادة المالئة التقليدية، البازلت (BF)، جزئيًا وكليًا بنسب مختلفة من CKD بنسبة 25٪ و 50٪ و 75٪ و 100٪ من وزن المادة المالئة. تم إجراء تقييم HMA المخطط له باستخدام الخصائص الميكانيكية والحجمية التقليدية. تم إنشاء مجموعه 15 عينة من خليط البيتومين بمحتوى اسفلتي 4٪ و 4.5٪ و 5٪ و 5.5٪ و 6٪، وكان محتوى الأسفلت الأمثل 5.24٪. تمت مقارنة تأثيرات أربع عينات مختلفة (CKD) بمحتوى مادة مالئة بنسبة 25٪ و 50٪ و 75٪ و 100٪ بالوزن فيما يتعلق بأداء الخرسانة البيتومينية. أظهرت نتائج التجارب أن CKD قد يحل محل 75٪ من BF عند محتوى بيتومين 5.24٪ وقيمة استقرار مارشال 13.76 KN و 4.02٪ فراغات هوائية و 75٪ VFB وكثافة 2.370 جم / سم 3 وتدفق 2.57 مم. لذلك، فإن دمج CKD كمواد مالئة في HMA هو حل مستدام يعزز الأداء ،الثبات والفوائد البيئية في بناء الطرق الإسفلتية.

الكلمات المفتاحية : غبار افران الاسمنت، الخلطة الاسفلتية الساخنة، نفايات المواد المالئة، اختبارات مرشال.

1. Introduction

According to comes from the World Bank, the amount of waste created globally is increasing every day. According to the global prediction, 2.59 billion tons of trash are predicted to be produced annually by 2030. By 2050, waste production is expected to have increased by 70% from 2.01 billion tons to 3.40 billion tons annually in 2016 [1]. Currently, there are two methods to control waste: recycling and disposal [2]. When taking into consideration the present and projected increases in waste volumes, recycling waste instead of disposing of it is crucial to sustainability. Furthermore, by filling the gaps in the asphalt mixture that compromise stability, fillers can strengthen the mix's resilience to temperature-related plastic deformation [3].

Researchers are now investigating various wastes as fillers due to the improved functionality of asphalt mixtures with substitute solid waste additives. 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].

In order to safeguard the environment, CKD was developed to improve the properties of soil, asphalt mixtures, and asphalt granular layers [11], [12], and [13]. Asphalt mixtures with CKD filler showed improved resilience to freeze-thaw cycles in addition to having a longer fatigue life than traditional asphalt mixes [14]. Abed et al. [15] reported that the addition of CKD to asphalt mixtures increased cohesiveness by 14.7 percent, stiffness by 13.5 percent, Marshall flow by 37%, air voids by 38%, and Marshall stability (MS) by 17%, in addition to improving rutting life. Al-Asi et al. [16] investigated the possibility of improving HMA engineering properties by using CKD, a waste from cement manufacture. The effects of adding CKD to asphalt mixtures with fillers made of limestone and basalt were investigated in this study. The study found that adding CKD caused the asphalt cement's (AC) viscosity to

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rise and its softening point to rise. Fadhil et al., 2021 [17]investigated the impact of using white cement kiln dust as a mineral filler on the properties of hot asphalt concrete mixtures. To make asphaltic concrete mixes, various percentages of WCKD from the Fallujah cement plant were combined with two filler types (100 % WCKD, 50 %WCKD+50 % cement (C), 100 % C, 50 % WCKD+50 % limestone (L), and 100 % L). The performance of these various asphaltic concrete mixes was evaluated using five tests. standard Marshall Test at 60 and 70 ° C, to test immersed samples for four days in water at room temperature (24 ° C), and Indirect Tensile Strength Test (ITST) to test conditioning and un-conditioning sample. All of the stability test values 9 of mixtures containing WCKD increased when they were immersed in water in the Marshall test. This could be due to parts of WCKD and C hardening and setting. The flow values were within the ISSRB, although they were generally higher than the specification for all of the immersed samples, particularly for 100 %L, which had the largest deviation of about 27.5 % more than the upper specification limit (4mm). This finding suggests that using limestone as a filler is the riskiest option for roads that may be submerged in water. Except for immersed samples of 100 % WCKD and 50 % WCKD+50 %L, which gave greater than the allowable top value, all air void findings for all samples under three types of test settings were within the ISSRB (5 %). The percentages of retained tensile strength for ITST test results indicate that all samples were within the ISSRB, but the samples of 100 % WCKD and 50 % WCKD+50 % C gave the best results of 92.11 % and 93.89 %, respectively, indicating that all samples were within the ISSRB. Based on the preceding conclusions. Along with improving fatigue life, indirect tensile strength (ITS), and stripping resistance, CKD added to the HMA mixtures increased the optimal binder concentration. When CKD filler was used instead of limestone, the optimal binder concentration in HMA mixtures increased. Marshall Stabilities showed no discernible change in the mixes with the limestone filler [18].

Waste disposal has become a pressing environmental issue with substantial implications. Furthermore, research on the utilization of CKD dust as a filler in asphalt mixtures has been limited. Thus, this study aims to investigate the impact of incorporating CKD as a filler in the asphalt mixture. This objective can be attained through the following:

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

- The effect of CKD on mix performance with Marshall test is investigated.

2. Objective of the study

The objectives of this study are to:

- Investigate CKD as a filler element in asphalt mixture manufacture.
- Reduce environmental pollution by utilizing waste CKD in flexible pavement.

3. Research Methodology

3.1. Materials and Methods

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, and CKD. Volcanic ash was added to the mix in increments of 0-60% to demonstrate. It has an impact on the volumetric characteristics and performance of asphalt mixtures.

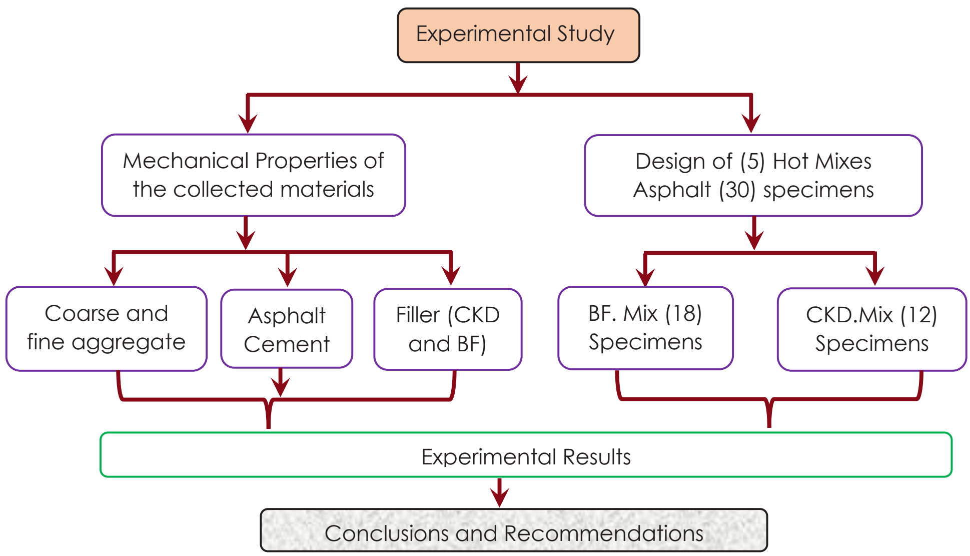

Figure (1): The activity framework

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3.2. Material used

3.2.1. Asphalt

The Oman Refinery produces asphalt cement (AC) 60/70, which is transported to the site in bulk and used to make the mixes under examination. The degree of penetration of asphalt cement is measured in a laboratory setting in accordance with AASHTO guidelines. The qualities of the asphalt binder are listed in Table 1.

Table (1): Asphalt Characteristics

characteristics	Designation No. AASHTO.	Result	AASHTO Specification
Penetration at 25 co, 0.1mm	T 49	62	60-70
Flash point, co	T 48	235	≤ 250
Specific gravity	T 228	1.028	1.01-1.06
Softening point, co	T 53	51	46-56

3.2.2. Aggregates

Source AL-Amjad crusher plant, located on the right side of Sana'a Mareb major road, is where four sizes of aggregates are gathered. Hills made of rock are the source of the aggregate. Columnar basalt of igneous origins makes up the formation. The AASHTO and ASTM standards have been followed in testing to evaluate the suitability of these aggregate fractions for use. The mixture was created using NMAS, or nominal maximum aggregate size of 12.5 mm.

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. The mixed aggregate's gradation and the designated limit are shown in Figure 2. As shown in Table 2, the aggregate gradation utilized in this study is dens-grade, which was used to satisfy the wearing surfaces' standards (BS EN 13108-1). The fundamental properties of the aggregate utilized in this study are displayed in Table 3.

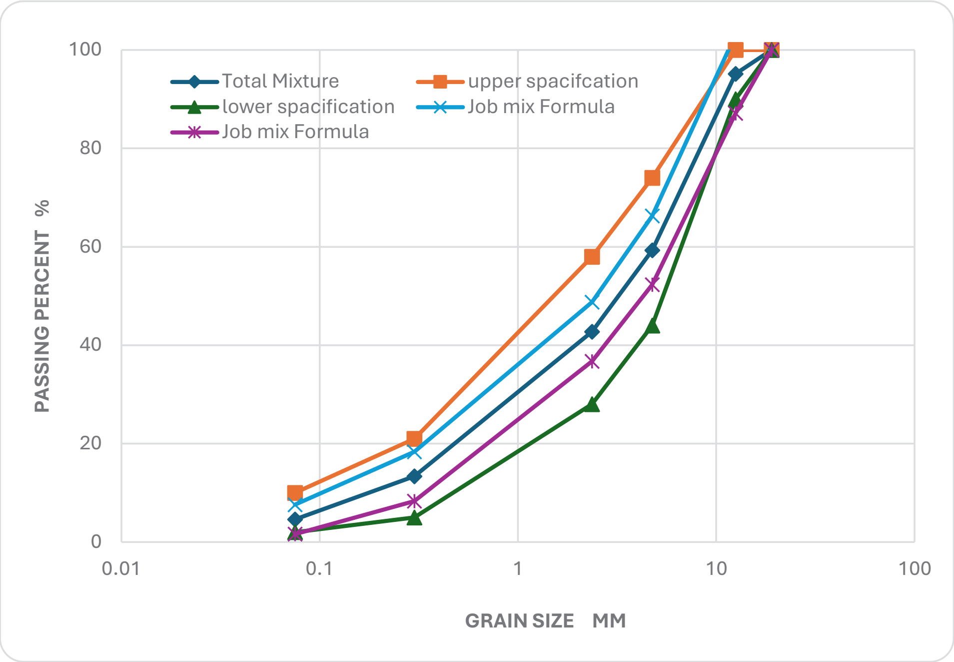

Figure (2): The aggregate’s grain size distribution

Table (2): Aggregate Gradation

Sieve size (mm) (% pass)	Used gradation (% pass)	Specifications limits (% pass)	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

Table (3): Fundamental Characteristics of the Aggregate

Items	Actual Value %		Specification Limit
	Specific γ	W abs	AASHTO T84, T85
1-Specific Gravity and Water Absorption T 84, 85 and C 128: Fraction 19.5-12.5b mm Fraction 12.5-09.5 mm Fraction 09.5-4.75 mm Fraction 4.75-minums mm	2.854 2.726 2.886 2.623	0.959 2.018 2.098 2.872	4 Max. for W absorption
2- Lose Angeles Abrasion T96	12.7		25 Max.
3- Plasticity Index (PI) T 89 and D 4318	Non – Plastic		Non – Plastic
4- Sand Equivalent T 176	90.5		75 Min.

3.2.3. Cement Kiln Dust

CKD was supplied from the Amran cement plant, which is located northwest of the capital, Sana'a, as shown in Fig. 3. CKD was then sieved on No. 200 sieve, as shown in Fig. 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. Tables 4 provide an overview of the CKD chemical content.

Figure (3): CKD at Amran Cement Factory

Figure (4): volcanic stone ash

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

Component	SiO2	Al2O3	Cao	MgO	FeO3	Na2O	K2O
Percentage (%)	17.01	3.65	57.45	1.42	3.68	0.143	1.03

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4. Experimental Setup

4.1. Mixture Design

Due to a lack of appropriate Yemeni testing facilities, we used the Marshall Test Method, commonly known as ASTM D1559, in this investigation (particularly, Gyratory Compactor Superpave). It was employed to mix and evaluate asphalt concrete mixtures.

4.1.1. Marshall test

this study used the Marshall procedure (ASTM D1559) and we followed the standard specifications as shown in table 5. Five mix design, with different VA percentage of 0, 15, 30, 45 and 60 % of total filler weight. As a control mix, the 0% ash content mix design was employed with BF filler.

Table (5): Marshall Parameter specifications

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

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 5.

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.

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Figure (6): Samples of asphalt concrete for tests of Marshall stability

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° as shown in figure 7 , 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

Figure 7: Water Path for Marshall Specimens

5. Results and Discussion

5.1. Effect of Adding CKD on Marshall HMA Characteristics

5.1.1. Determination of Optimum Asphalt Content of Control Specimen

Five different percentages of asphalt cement are tried (4, 4.5, 5, 5.5, and 6%) by weight of aggregate (1200 grams), with the gradation utilized in this study being dense graded (D-5) for surface course. Three Marshall specimens are made and tested for each percentage. The optimal asphalt content (OAC) is determined as an average asphalt content value corresponding to maximum unit weight, maximum stability, 70% voids filled with bitumen VFB and 4% air voids (AV). While the flow is being verified in accordance with the ASTM specification. Table (6) shows the obtained Marshall properties at the OAC and the specification limits and figure 8 shown the Marshall test plotted curves

Table (6): Marshall Characteristics for Control Mix

Marshall Characteristics	(OAC) %	Stability KN	Flow (mm)	Rigidity Ratio KN/ mm	Unit Weight gm/ cm3	AV%	VFB%
Value	5.245	12.771	3.86	3.293	2.361	4.87	71.22
Specification Limits	(4.00 – 11.00)	9 Min	(2 - 4)	3 min	---------	(3-5)	(65-75)

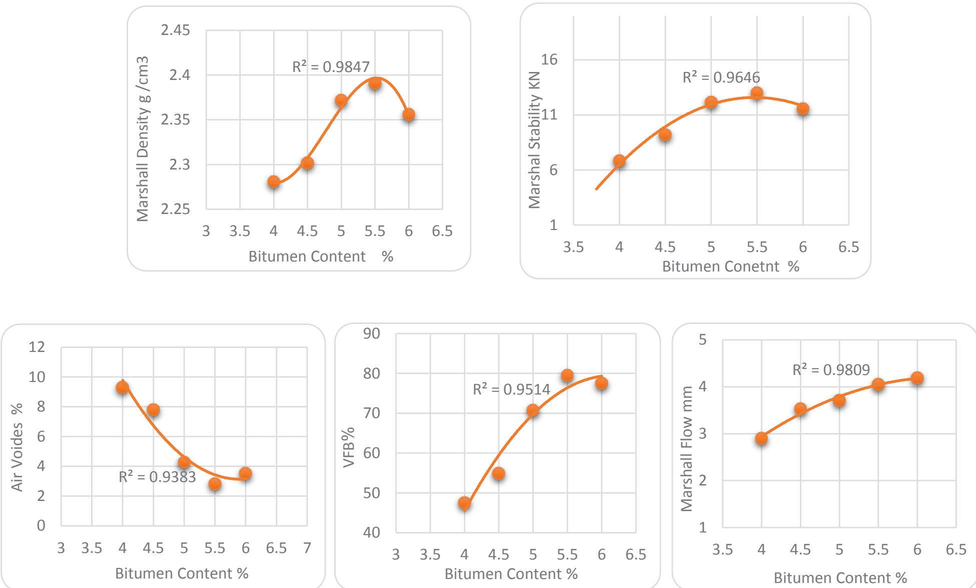

Figure (8): Marshall Test Results for control mix

5.1.2. Effect of Adding CKD on Marshall Mix Characteristics

Three Marshall specimens are made and investigated at each percentage, yielding a total of 12 specimens for the CKD additive and 15 specimens for the control mix. For both control and treated specimens with CKD, Marshall characteristics (Stability, Flow, unit weight, AV%, and VFB%) are computed. Marshall property results are shown as relationships between (Stability, Flow, unit weight, AV%, and VFB%) and asphalt content (AC). Another graph shows the mixture stiffness (stability/flow) ratio as a function of AC and VA percentage. The CKD employed is utilized in varying quantities of 25, 50, 75, and 100% relative to the total weight of the filler. The correlation between the achieved stability and the different percentages of CKD at the optimal asphalt content (OAC) is illustrated in Figure 9.

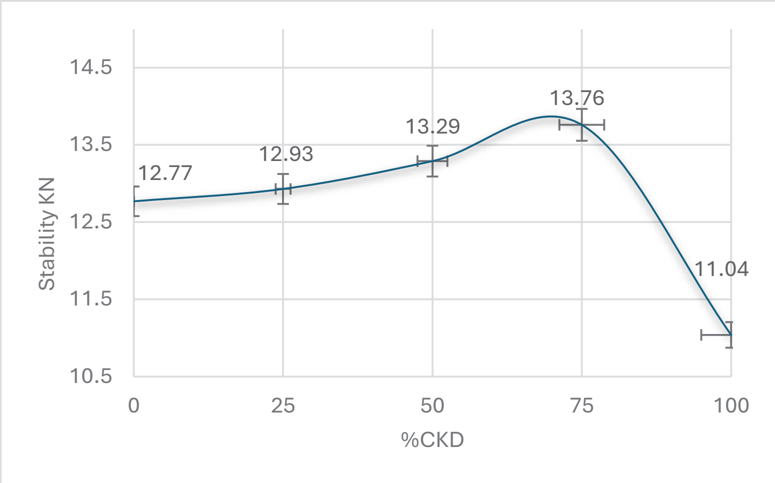

Figure (9): The Effect of CKD on Marshall Stability at (OAC)

Figure 9 illustrates that at a CKD level of 75%, the peak stability value is observed, with stability rising from 12.77 KN to 13.76 KN, indicating a 7.75% enhancement which is consistent with the literature (A. Modarreset al., 2015, Al-Asi, A., & Asi, I. 2021) following which Marshall stability starts to decline. This phenomenon can be attributed, in part, to the broader surface area of CKD, which possesses a heightened capacity for asphalt absorption.

The flow value of the asphalt mixture was found to be less than the mixture used as a control. According to the Marshall Flow data illustrated in Figure 10, the control mixture exhibits the greatest value in contrast to the addition of cement kiln dust. A decrease in the value of flow is noted upon the implementation of CKD, followed by a subsequent rise when the CKD content surpasses 75%. This phenomenon is likely linked to the increased air voids present in the mixtures.

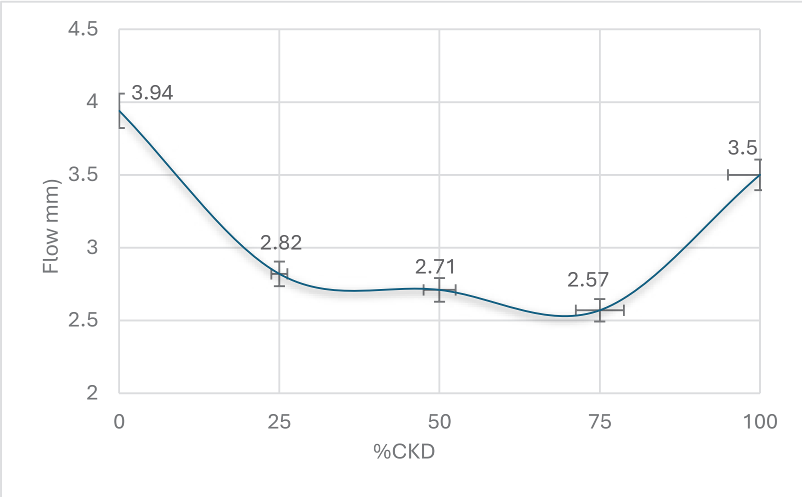

Figure (10): The Effect of CKD on Marshall Flow at (OAC)

According to Figure 11, the bulk density values exhibited an increasing trend, reaching 2.37gm/cm3. However, with a higher percentage of cement kiln dust (CKD) at 75%, there was a noticeable decrease in density values, dropping to 2.31 gm/cm3 at 100%, with the peak value observed at 75%. The outcomes is attributable to the enhancement of void packing in the mixture by CKD particles.

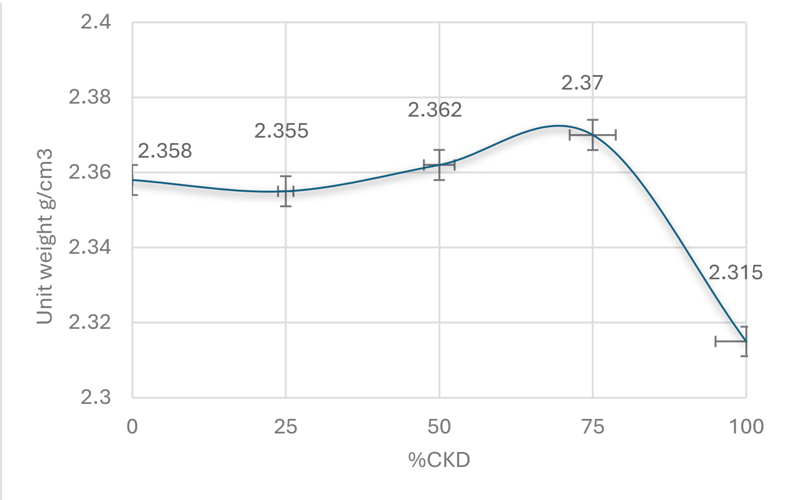

Figure (11): The Effect of CKD on Marshall Unit Weight at (OAC)

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As depicted in Figure 12, the proportion of CKD increased from 25 to 75%, a corresponding decline in air voids occurred, with reductions of (4.2, 10.86 %) noted at CKD levels of 50% and 75% respectively which is similar to the results of previous studies (Adel-Wahed et al.,2016). The decrease in air voids content can be linked to the rise in density of modified asphalt mixes and the compaction of voids within the interface zone of altered asphalt mixes. Nevertheless, the air voids value displayed a rise at 100% CKD.

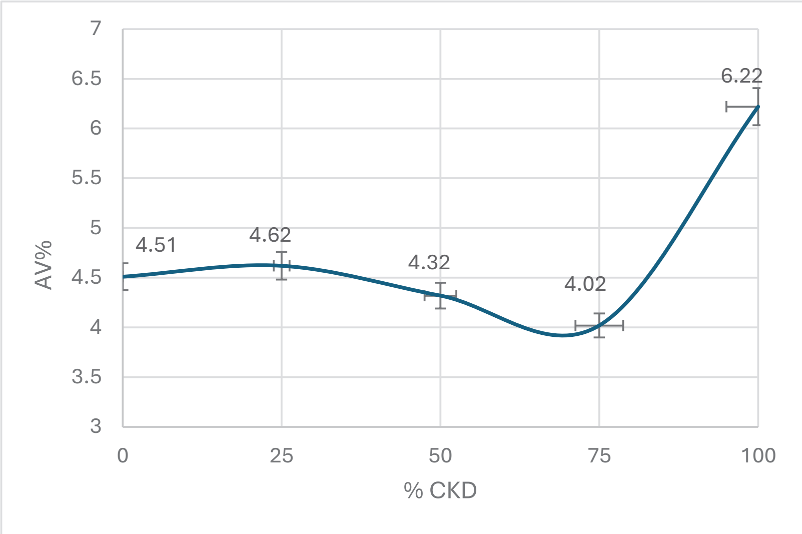

Figure (12): The Effect of CKD on AV at (OAC)

As illustrated in Figure 13, all the special VFB values in the mixtures with CKD were higher than the control mixture, with the exception of the 100% content as illustrated in Figure 13. The VFB value peaked at 75%, corresponding to a value of 75, before gradually declining to a minimum at 100%. It is important to highlight that CKD necessitates a greater amount of asphalt for coating its surface due to its comparatively larger specific surface area, resulting in reduced values.

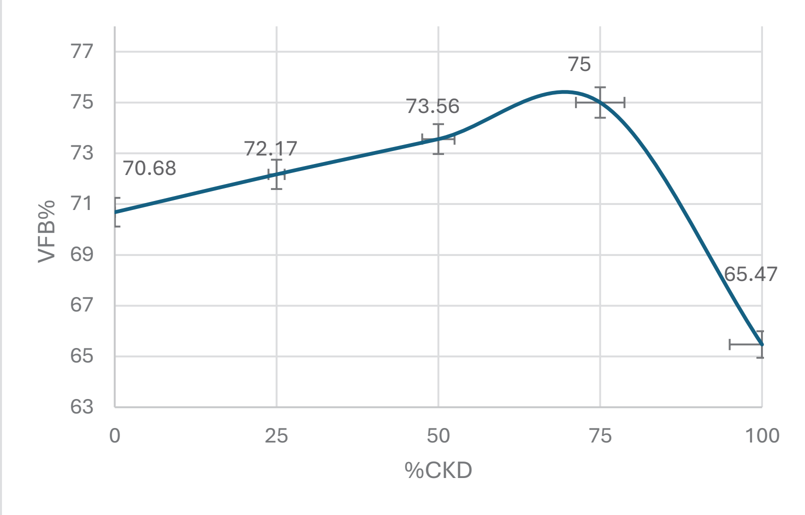

Figure (13): The Effect of CKD on VFB% at (OAC)

The relationship between stiffness and concentration of CKD at OAC is visible in Figure 14. The data depicts a rise in composite stiffness as the CKD content increases to 75%, followed by a decline. Initially, an enhancement in stiffness was observed due to enhanced stability at lower flow rates. However, as the CKD concentration increased, the flow rate steadily decreased, resulting in an overall decrease in stiffness. It is of significance to highlight that the stiffness value at 75% CKD surpasses that of the reference mix.

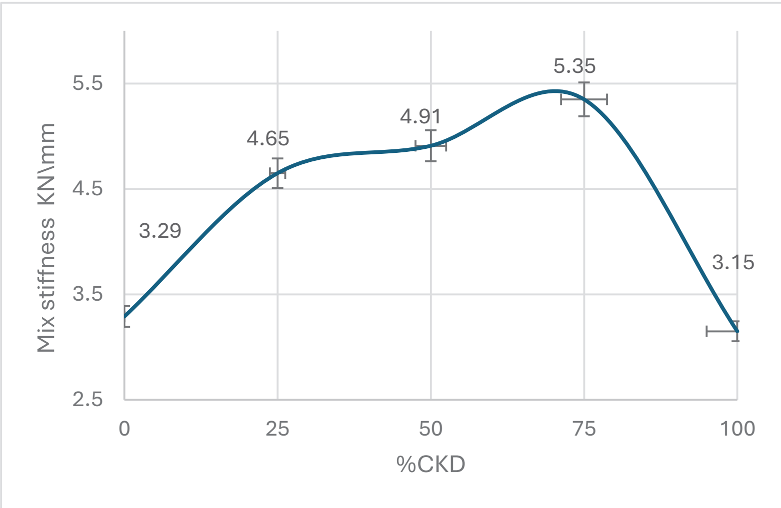

Figure (14): The Effect of CKD on Marshall Stiffness at (OAC)

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The addition of cement kiln dust (CKD) to Hot Mix Asphalt (HMA) results in a significant enhancement of the HMA properties. An increase of approximately 62.61% in Marshall stiffness is observed, along with around 7.75% and 34.77% enhancements in Marshall stability and flow, respectively, due to the presence of CKD. Concurrently, the addition of CKD raises the unit weight of the modified mixture while ensuring that the Air Voids percentage (AV%) remains within permissible limits excepted 100% CKD. It is recommended that the CKD content should be at 75% of the filler's weight in order to give the mixture the appropriate characteristics. The impact of different CKD percentages on the properties of the asphalt mixture seen in Table 7.

Table (7): Effect of Adding CKD on Marshall HMA Properties

CKD Percentage	O.A.C %	Stability (KN)	Flow (mm)	Unit Weight (gm/cm3)	AV%	VFB%
25%	5.245	12.93	2.82	2.355	4.62	72.17
50%		13.29	2.71	2.362	4.32	73.56
75%		13.76	2.57	2.370	4.02	75
100%		11.04	3.50	2.315	6.22	65.47

6. Conclusions

Considering the test results, the following conclusions can be drawn:

- The maximum Marshall stability at 5.24 percent bitumen percentage was discovered to be suggested by BD's 4.6% filler content.
- The bulk density, VFB, and Marshall stability test results for each laboratory experiment indicated a higher value as the CKD increased by up to 75%.
- 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%.
- CKD reduced air void percentages by 17.45%.
- Stiffness values exhibit an enhancement leading to a substantial improvement of approximately 62.61% in the stiffness of asphalt mixtures.
- Using CKD as fillers in HMA mixes has no impact on the mixing process or the time required.
- The other concentration of CKD gives us results in the limit specification. For heavy traffic, the CKD percent content of 75 % by weight of basalt filler can therefore offer the best performance.

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