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Enhancement of Hot Mix Asphalt stability by utilizing Cement Kiln Dust and Styrene-Butadiene-Styrene Polymer

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Abstract

Utilization of additives can be an effective way to improve the durability and performance of HMA, making them more resistant to Moisture and deformation. Plus, they can reduce the need for maintenance and repairs, saving you time and money in the long run. In this study, CKD was used in place of limestone as a filler in the asphalt mixture in proportions of 0%, 25%, 50%, 75%, and 100%, and polymer SBS 4%by weight of asphalt. According to the findings, replacement-content CKD had the highest asphalt content. When the CKD is between 25% and 50%, Stability, Flow, and Indirect Tensile Strength are improved, while the density of the asphalt mixture decreases and the amount of air voids increases at higher ratios. While SBS leads to an increase in the hardness of the adhesives. As a consequence, the stability of the SBS-containing mixes resulted in higher values than the control and additive-containing mixtures (CKD), as well as a decrease in the number of air voids. According to the results, CKD should not constitute more than half of the filler weight in the asphalt mixture.

Keywords: Hot Mix Asphalt, Cement Kiln Dust, ITS, Styrene-Butadiene-Styrene, Stability

1. Introduction

The road network is exhibiting extreme degradation, such as raveling and stripping, due to water intrusion breaking the aggregate-asphalt-film bond [1]. This is exacerbated by heavy traffic loads resulting from an increasing number of vehicles and trucks, Furthermore, weather and humidity might have a role in causing pavement discomfort. [2]. In order to reduce environmental pollution and conserve natural resources related to pavement construction [3]. Binder modification is one method for increasing the properties of an asphalt mixture. Engineers have studied and produced several anti-stripping additives to enhance the properties of asphalt mixtures, notably their resistance to moisture damage [4]. When asphalt concrete is damaged by moisture, water is allowed to seep in, where it performs a stripping operation on the asphalt binder film and aggregate, reducing their ability to hold together. As a result, the pavement's resistance to wear and tear is diminished. Asphalt qualities, aggregate features and composition, and environmental conditions all have a role in asphalt concrete's resistance to moisture damage. These factors significantly contribute to asphalt concrete's resistance to water damage [5]. Additives are utilized to improve efficiency in (HMA) pavements and address various types of distress, including permanent deformation, moisture-induced fatigue, and low-temperature fractures. There are a variety of additives that can be incorporated directly into the asphalt cement (AC) as a binder modifier or mixed with the aggregates. [6]. In order to enhance the properties of bitumen, Through molecular interactions or chemical processes, a suitable polymer must form a secondary network or new balancing system inside the binder. (SBS) has been shown to be a useful ingredient for boosting the durability and longevity of asphalt mixes by enhancing their mechanical qualities. [7], permanent deformation [8], [9], low-temperature cracking [10], and moisture damage [11], [12]. Cement kiln dust (CKD) is a by-product of the Portland cement manufacturing process. Its composition can vary significantly between sources due to changes in raw materials and manufacturing processes. The large amount of CKD produced requires either disposal or recycling, which can be costly and time-consuming, and has negative environmental implications [13]. In this research, the use of CKD at different percentages was examined by weight of aggregate, and SBS by weight of bitumen, combined in HMA and their effects on mechanical properties, particularly moisture damage resistance. Additionally, the impacts of SBS and CKD on these mixes' characteristics were contrasted. Polymer modified binders and binder-aggregate blends were analyzed by Marshall, who looked at their physical and mechanical properties using standard tests of polymer-modified ration,

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softening point, and indirect tensile strength. Mixture stability tests.

2. Main Objective

The list included the following pledges in further detail:

1- Evaluate the Marshall properties of heated asphalt formulations of SBS and CKD were used in place of limestone as a filler in the asphalt mixture.

2- Determine the sensitivity to moisture when using (CKD) and (SBS).

3. Source Materials

Research's components, which are already being utilized to construct roads in Iraq, are easily accessible locally. The local market produces limestone dust (Ls) and cement kiln dust (CKD). All materials were acquired from commercial sources.

3.1 Asphalt Binder

Asphalt is the most commonly used material in pavement construction today because of its high engineering performance capabilities such as elasticity, adhesion and water resistance. The asphalt cement employed in this project has a penetration grade of 40-50. It was acquired from the Dora refinery, which is located south-west of Baghdad. To establish the physical properties of the asphalt binder, it was subjected to a battery of tests that are normally performed in labs. The test results were to meet the [14] are shown in Table (1).

Table 1: Physical Properties of AC (40-50)

Property	Test condition	ASTM Designation	Units	Results	Limits
Penetration	40-50	41.4	1/10 mm	D5	5sec., 100 gm, 25°C, 0.1mm
Rotational Viscometer	< 3.0	0.65	Pa.sec	D4402	135 °C
Ductility	>100	>100	cm	D113	25°C, 5 cm/min
Flash Point (°C)	>232	270	°C	D92	---
Softening Point	---	58	°C	D36	---
Specific Gravity	---	1.04	gm/cm 3	D70	25°C

3.2 Aggregate

The Al-Nibaee quarry provided the coarse and fine aggregate (crushed). According to the (SCRB R/9, 2003). Requirements, the sizes of coarse aggregate between sieve size (19mm) and sieve No.4 (4.75 mm). The coarse and fine aggregates' physical characteristics are displayed in Table (2).

Table 2: Physical Properties of Coarse and Fine Aggregate

Physical Properties of Coarse Aggregate			
Property	ASTM Designation	Result	SCRB R9, 2003 Specifications
Bulk Specific Gravity	C-127	2.579	----
Apparent Specific Gravity	C-127	2.601	----
Percentage of Water Absorption	C- 127	0.53	----
% Wear (Abrasion in Los Angeles)	C- 131	15.78	30 Max
Physical Properties of Fine Aggregate			
Bulk Specific Gravity	C-128	2.61	---
Apparent Specific Gravity	C-128	2.632	---
Percent Water Absorption	C-128	0.952	---

3.3 Mineral Filler

Mineral filler is typically used to improve the mixture's characteristics and fill in the voids. In this study, three different types of fillers were employed. They came from two different local sources in Iraq: limestone dust (LS), cement kiln dust (CKD) from the Karbala lime factory, used as a percent of 0%, 25%, 50%, 75%, and 100% by weight of limestone. The chemical composition and the physical property is shown in Table (3).

Table 3: The Chemical and Physical of LS, CKD

The Chemical Analyses of LS, CKD		
Chemical composition	Limestone	Cement Kiln Dust
CaO	51.1	68.63
SiO_2	2.7	8.95
Al_2O_3	1	6.752
Fe_2O_3	0.16	6.213
SO_3	1.16	0.371
MgO	1.2	----
L.O.I	42.6	1.464
The Physical Properties of LS, CKD		
Property	Limestone	Cement Kiln Dust
Specific gravity	2.72	2.92
% Passing N0.200	94	89.5
Color	white to gray	Light gray

3.4 Styrene-Butadiene-Styrene polymer (SBS)

Polymers work as anti-strip agents. Most of the time, polymers are mixed in with the asphalt binder. In this study, one type of polymer was chosen to be added to the bitumen, which made up 4% of the total weight of asphalt. The additive is called SBS polymer (Styrene Butadiene Styrene). It is the most well-known accepted bitumen modification, frequently used by the whole bitumen industry. The presence of SBS polymer at varying concentrations enhances the tensile strength of a material and also increases the ratio of tensile strength, thereby positively impacting its resistance to moisture damage and the adhesion force between the aggregate and bitumen. The physical properties of Modified A-C shown in Table (4).

Table (4): Physical Properties of Modified Asphalt Cement (4% SBS)

Test	Test condition	ASTM Designation	Units	results	Limitation
Penetration	5sec., 100 gm, 25°C, 0.1mm	D5	1/10 mm	39	----
Rotational Viscometer	135 °C	D4402	Pa.sec	1.20	< 3.0
Ductility	25°C, 5 cm/min	D113	cm	>100	>100
Flash Point (°C)	----	D92	°C	270	>232
Softening Point	-----	D36	°C	72	>65
Specific Gravity	25°C	D70	gm/cm3	1.04	---

4. Selection of Aggregate and Gradations

Job mix formula as prescribed by **(SCRB, 2003)** was used to determine the percent combination for (Type II) binder course. The aggregate gradation, is show in Table (4) and Figure (1).

Table 6: Gradation of Combined Aggregate for wearing Course

Sieve Size (mm)	Iraqi SCRB, R9,2003 Max	Iraqi SCRB, R9,2003 Min	Selection Gradation
19	100	100	100
12.5	100	90	95
9.5	90	76	85
4.75	74	44	54
2.36	58	28	42
0.3	21	5	13
0.075	10	4	7

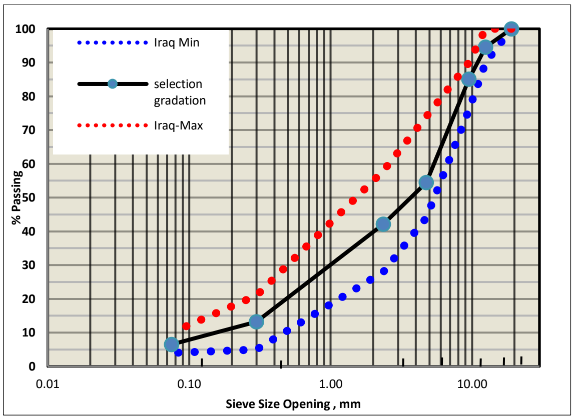

Figure 1: The wearing Course Requirements and Grading Scheme

5. Scanning Electron Microscopy (SEM) and EDX

During the EDX measurement, different regions were focused on and the corresponding peaks are shown in Figure (2). Both Ca and C can be seen in the synthesized composite nanostructures in the EDX spectrum. Various materials are evaluated for surface cracks, defects, contaminants, or corrosion by means of SEM examination. The surface shape of the types of used fillers. Cement and kiln dust, which forms an irregular, spherical shape, while limestone dust is irregular and spaced lumps**.**

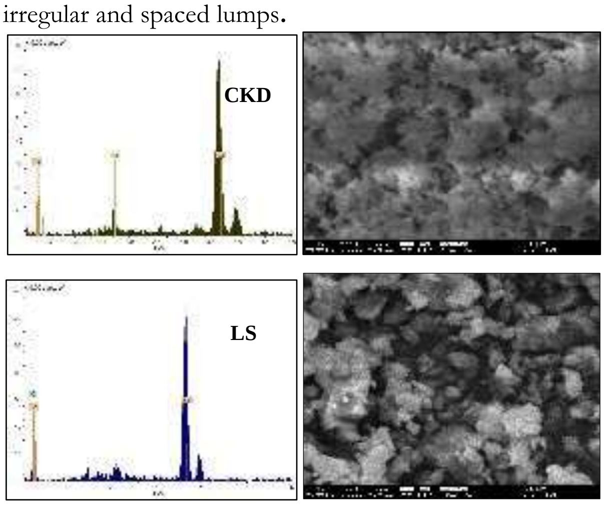

Figure 2: EDX pattern and SEM image at zoom 5.000X for all fillers

6. Experimental Procedure

The aggregate was first screened, washed, and dried at a temperature of 110 degrees Celsius until it attained a weight that remained consistent throughout the operation. After that, the aggregate was broken up into the various sizes that were required. In order to fulfill the gradation criteria outlined in section 4, a mixture of coarse and fine aggregates, together with mineral filler, was formulated. After the aggregates were blended and processed, they were heated to a temperature of 160 degrees Celsius before being combined with asphalt cement. After being heated to a temperature of 150 degrees Celsius, the asphalt cement achieved a kinematic viscosity that fell somewhere in the range of 170 to 20 centistokes. After that, asphalt cement was added to the heated aggregate in increments until the required quantity was reached. After that, the mixture was stirred by hand with a spatula for two minutes so that all of the aggregate particles could be thoroughly covered with asphalt cement. Weigh the dry sample, which consists of 1200 grams (aggregate plus filler) [15].

6.1 Marshall Testing

For the purpose of carrying out the Marshall Test, cylindrical specimens with dimensions of 4 inches in diameter and 2.5 inches in height will need to be created. On a hot plate, the Marshal Mold spatula and the compaction agitator are brought up to a temperature in the region of 120-150 degrees Celsius. After the asphalt cement has been heated to the same temperature range as the aggregate, which is between 150 and 180 degrees Celsius, it is blended with the aggregate, and then the asphalt mixture is put in a mold that has already been heated. Before removing the specimen from the mold, it is given time to acclimate to ambient temperature and cool for twenty-four hours.. Marshall Every specimen is put through a series of stability and flow tests. The cylindrical sample is heated in a water bath at 60 degrees Celsius for thirty to forty minutes before being crushed on the lateral surface at a continuous rate of two inches per minute (fifty-eight millimeters per minute) until the maximum load (failure) is attained, as shown in Figure (3).

Figure 3: Samples in a water bath at 60°C for 30 min, stability, flow, bulk density test and after failed

The bulk specific gravity and density [17], theoretical (maximum) specific gravity [18], and percent air voids [19] were determined for each specimen. The percent of air voids was then calculated from the equation (1) shown below:

$$\%AV=\left[1-\frac{\text{bulk specific gravity}}{\text{Max.Theo.specific gravity}}\right]\times 100 \quad \text{.......... Eq (1)}$$

6.2 Moisture Susceptibility Test

The tensile strength of asphalt concrete is an important factor in its performance, particularly in relation to prevailing conditions and moisture sensitivity[20]. A test is used to evaluate the impact of moisture on asphalt mixtures with and without anti-stripping additives, as covered in. [21] Initially, four Marshall specimens were prepared with varying numbers of blows to determine the number of blows needed to achieve 7±1% air voids. In this case, 55 blows were used. After determining the number of blows, each set of specimens was divided into two groups: one group was unconditioned and the other group was conditioned by being placed in a vacuum container filled with distilled water and frozen at -18°C for 16 hours before being thawed at 60°C for 24 hours and then left in a water bath at 25°C for 1 hour. The (ITS) was then calculated for each specimen, and the average ITS was calculated for each group using equations (2) and (3) as described by [22], from the equation (2) and equation (3) shown below:

$$ITS = 2000p / \pi tD \ \ (Kpa) ------- Eq(2)$$

Where, ITS =stands for indirect tensile strength, (kpa),
P =for the maximum applied force needed to cause the specimen to fail, (N),
t =for the specimen's thickness, (mm), and
D =for its diameter (mm).

$$TSR = (Scon / Suncon) * 100\% ----- Eq(3)$$

TSR of (80%) or higher is considered the bare minimum by [15].

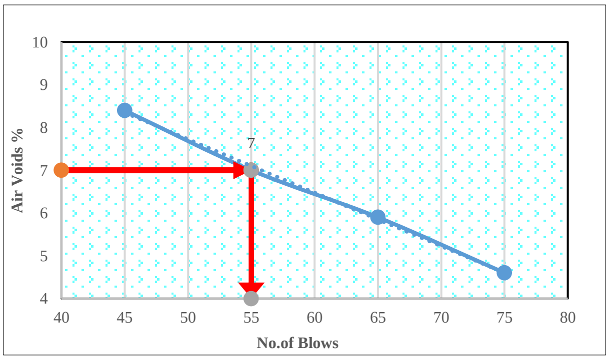

Figure 4: Relationship between No. of Blows and AV%

7. Test Results and Discussion

The optimal asphalt concentration for the HMA of asphalt cement was determined by creating three specimens at five different asphalt percentages (4%, 4.3%, 4.6%, 4.9%, and 5.2% by weight of total mix). The ideal asphalt percentage for the control mixture is calculated to be (4.65 % of the weight of the mixture). According to the Iraqi Specification (SCRB, 2003), the asphalt content acquired for mix design of paving mixes satisfies the design parameters defined for the binder layer.

7.1 Marshall Properties

In this study, Marshall Tests were conducted to see whether the asphalt mixes with various additives still met acceptance standards when the optimal asphalt binder level was used. Figure (5) shows the stability values of the hot asphalt mixes compared to the control mixture that contains (limestone dust). For cement kiln dust, the stability increased by about (8.2, 23.5, 16.3, and 4.1) % for lime content (25, 50, 75, and 100) %, respectively. The maximum increase in stability occurred at 50% CKD by weight of the aggregate, as Marshall Stability and hardness increase until the percentage of CKD content (50%), after which Marshall stability and hardness begin to decrease. This is partly because CKDs have a larger surface area, and larger surfaces have a greater propensity to absorb more asphalt. For the aforementioned reason CKD can be used in part as mineral filler instead of common mineral filler in asphalt concrete mixture production. While CKD cannot be fully used because the amount of asphalt must exceed the upper limits of (Iraqi Roads IS) specifications. SBS leads to an increase in the hardness of the adhesives. Therefore, the stability of the mixes that include SBS ends up resulting in higher values than those of the mixtures that served as controls as well as the mixture that contained the (CKD). It was determined that the Marshall Stability value (14.5 KN) increased 45% by adding 4% SBS. This advance is due to the large amount of chemical similarities between the polymer and bitumen. The flow value was smaller than the control mixture for asphalt mixture. Based on the Marshall Flow values shown in Figure (6), the mixture with limestone dust has the highest value compared to cement kiln dust, but increases flow when SBS additive. The flow value increases when CKD is added and then starts to decrease when the amount of CKD is increased. This can be attributed to the higher air voids value of the mixtures with slaked lime and cement kiln dust compared to the mixture of Portland cement and limestone.

Figure (7) shown that the value of bulk density of SBS is the highest value as it reached (2.351) and increased by (0.3) %. As for the asphalt kiln dust, where the bulk density values were increasing, but when the cement kiln dust content increased, the density values began to decrease, reaching (2.321 gm/cm3) at (100%) respectively, and the highest value was in (50%). Reducing the density of the mixture due to its low specific gravity with respect to Li where the value of the specific weight of cement was (2.92), which is inversely reflected on the results of air voids (% AV). When CKD increased from 0 to 100%, the value of air voids increased, as the increase was by (3.5, 6, 7.7 and 8.5%) at CKD content (25, 50, 75, and 100%) respectively, but, the value of the air voids at 4% SBS decreased by a small percentage, due to the increase in the adhesion of the bonding materials between them, as show in Figure (8).

VMA increases with the increase of cement kiln dust in the mixture. The maximum value was 15.65% where contains (100% CKD). While the value of VMA decreases to 13.7% when using SBS as shown in Figure (9). All special values of VFA for the mixtures containing additives were all higher than the control mixture in certain proportions and as shown in Figure (10), and it was the lowest value when using SBS 4% and it decreased by (1.5%). The CKD-containing mixtures were increasing as the percentage of increase reached about (1.5, 1.6%) at (25, 50% CKD), it reached a maximum value at (50%) where it corresponds to (72.5), but it began to decrease to reach a minimum value at (75%), at It is also noted that CKD needs more asphalt to wrap on its surface due to its relatively higher specific surface area, which leads to lower. The optimum asphalt content shown in Figure (11), increases when the addition of cement kiln dust increases, where reached 4.96 about 100% CKD. This is due to the increased surface area of CKD, which tends to absorb more bitumen.

The PMB mixture contributes to the stability of the mixture, which allows it to work effectively even with increased movements of the load across the road surface.

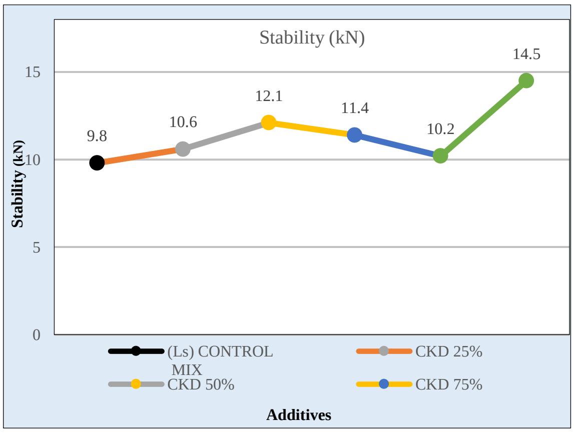

Figure 5: influence on the stability of CKD and 4%SBS

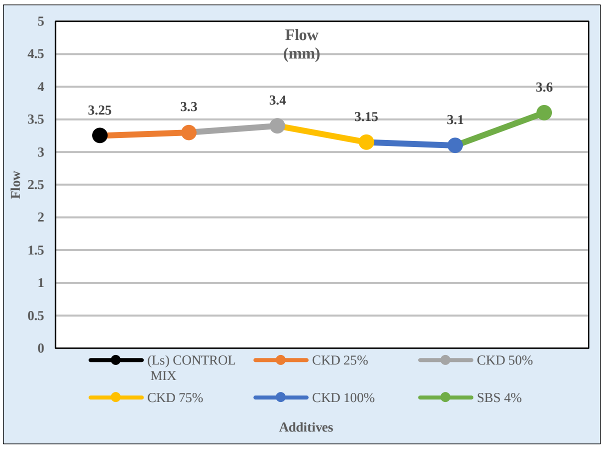

Figure 6: influence on Flow of CKD and 4%SBS

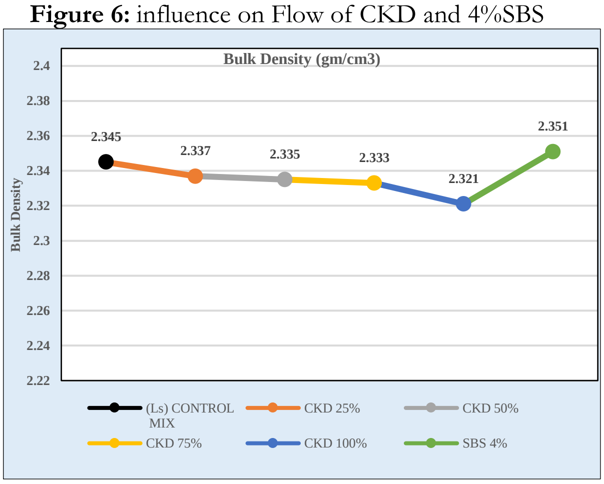

Figure 7: influence on Bulk Density of CKD and 4%SBS

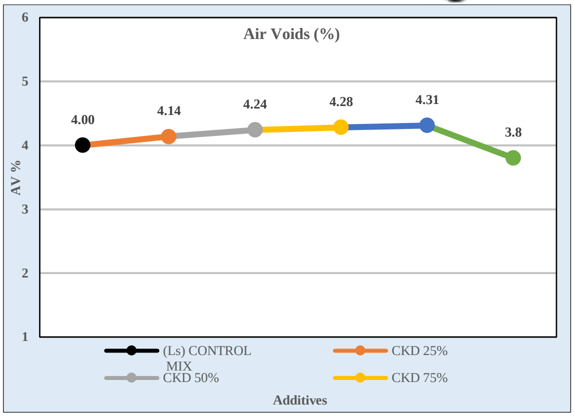

Figure 8: influence on Air Voids of CKD and 4%SBS

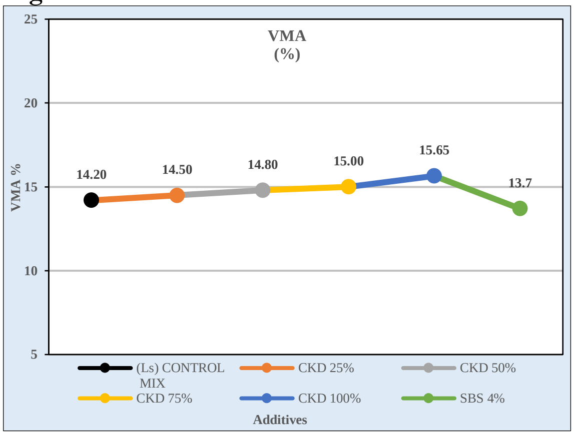

Figure 9: influence on VMA % of CKD and 4%SBS

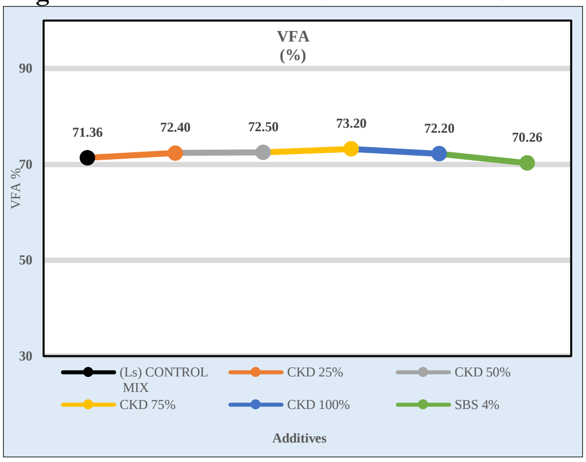

Figure 10: influence on VFA % of CKD and 4%SBS

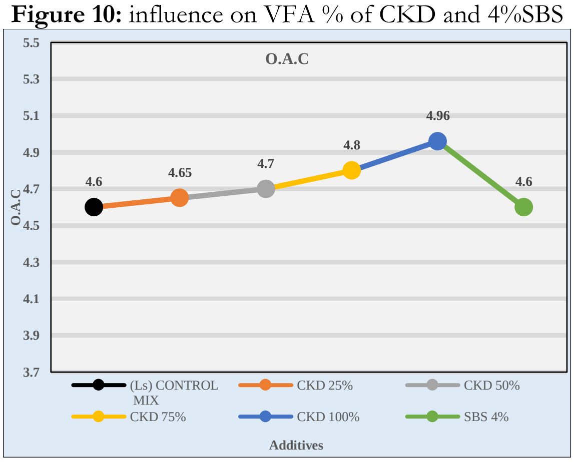

Figure 11: Effect of CKD and 4% SBS on Optimum Asphalt Mixture

4.2 Indirect Tensile Strength (ITS)

That the mixtures containing (SBS) have higher values of tensile strength at failure under static load, indicating greater cohesive strength of modified mixture, increase coherence and adhesiveness of the binder, and prevent bitumen from being stripped from aggregate particles. Consequently, when a result, the value of TSR rises when it reaches (90 %) and increased by (15.3%) than the control mixture. as in Figure (12).When the CKD content (25 and 50%) of limestone dust the ITS (conditional and unconditional) values and the TSR values are increasing by (5.7, 14.9%) respectively, of the control mixture. But when the CKD content is (75-100%) of the limestone, the ITS and TSR values start to decrease to be (4.8 and 0.6 %). The reason for this is that when the concentration of the CKD grows, the surface area of the CKD may absorb a greater quantity of asphalt from the mixture, and therefore the quantity of asphalt must exceed the maximum limits of the Iraqi standard, raising manufacturing costs, as shown in Figure (13).

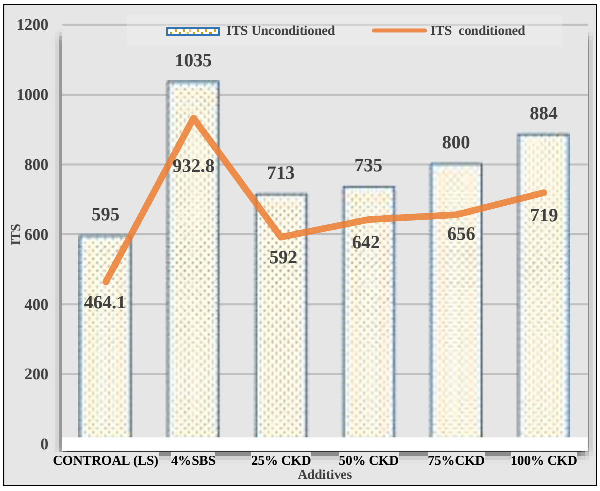

Figure 12: Indirect Tensile Strength (un-conditioned and conditioned) for CKD and SBS 4%

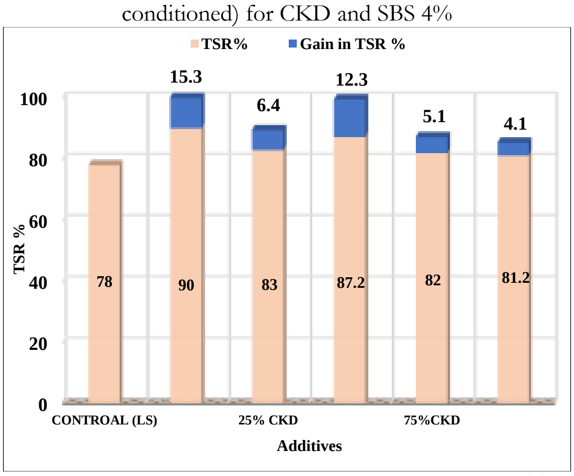

Figure 13: Effect of 4% SBS and CKD Content on the TSR and Variable ratio

5. Conclusion

1. Overall, the use of Polymer 4%SBS in hot asphalt mix is a highly effective way to enhance pavement performance and durability. While there is an initial cost associated with using this type of polymer modifier. But when using CKD in HMA can offer many benefits, including improved pavement performance and environmental sustainability.

2. Experimental laboratory work showed that the optimal proportion of modified SBS polymer was 4% wt. asphalt. This percentage caused the maximum expected increase in Marshall Stability and water damage resistance by (48, 15.3) %, respectively, compared to the control mixture.

3. The tensile strength ratios of CKD-containing mixtures were higher than those without additional mixtures. This indicates that the use of CKD reduced moisture susceptibility. Adding 50% of the CKD content by weight of the total mixture, recording the highest increase in the TSR value, this percentage reaches 18.21% of the control mixture for the asphalt mixture.

4. The mixtures increase in Marshall's stability values and then they decrease with increasing CKD. Mixtures also showed a decrease in flow values with increasing CKD content, Air voids and voids increase in mineral aggregates, while bulk specific gravity decreases after increasing CKD content in asphalt mixture.

5. Cement kiln dust cannot be fully used, because of its surface area the surface tends to absorb more asphalt from the mixture when the CKD content is increased.

6. References

[1] A. H. Abed and Z. I. Qassim, “Impact of Gradation and Modifier on Moisture Susceptibility of Iraqi Hot-Mix Asphalt,” 2015, no. October.

[2] K. H. I. Al Helo, Z. I. Qasim, and M. A. Abdulhussein, “Effect of laboratory aging on moisture susceptibility of polymer-modified bituminous mixtures,” *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 737, no. 1, 2020, doi: 10.1088/1757-899X/737/1/012131.

[3] S. Sobhi, A. Yousefi, and A. Behnood, “The effects of Gilsonite and Sasobit on the mechanical properties and durability of asphalt mixtures,” *Constr. Build. Mater.*, vol. 238, p. 117676, 2020, doi: 10.1016/j.conbuildmat.2019.117676.

[4] I. Amin, S. M. El-Badawy, T. Breakah, and M. H. Z. Ibrahim, “Laboratory evaluation of asphalt binder modified with carbon nanotubes for Egyptian climate,” *Constr. Build. Mater.*, vol. 121, pp. 361–372, 2016, doi: 10.1016/j.conbuildmat.2016.05.168.

[5] K. D. Stuart, “Moisture damage in asphalt mixtures-a state-of-the-art report,” 1990.

[6] R. Roque, B. Birgisson, C. Drakos, and G. Sholar, “Guidelines for use of modified binders,” 2005.

[7] M. S. Cortizo, D. O. Larsen, H. Bianchetto, and J. L. Alessandrini, “Effect of the thermal degradation of SBS copolymers during the ageing of modified asphalts,” *Polym. Degrad. Stab.*, vol. 86, no. 2, pp. 275–282, 2004.

[8] S. Tayfur, H. Ozen, and A. Aksoy, “Investigation of rutting performance of asphalt mixtures containing polymer modifiers,” *Constr. Build.*

Mater., vol. 21, no. 2, pp. 328–337, 2007.
[9] Z. Vlachovicova, C. Wekumbura, J. Stastna, and L. Zanzotto, "Creep characteristics of asphalt modified by radial styrene–butadiene–styrene copolymer," *Constr. Build. Mater.*, vol. 21, no. 3, pp. 567–577, 2007.
[10] U. Isacsson and H. Zeng, "Relationships between bitumen chemistry and low temperature behaviour of asphalt," *Constr. Build. Mater.*, vol. 11, no. 2, pp. 83–91, 1997.
[11] M. C. Won and M. K. Ho, "Effect of antistrip additives on the properties of polymer-modified asphalt binders and mixtures," *Transp. Res. Rec.*, no. 1436, 1994.
[12] S. Shuler and D. I. Hanson, "Improving durability of open-graded friction courses," *Transp. Res. Rec.*, vol. 1259, pp. 35–41, 1990.
[13] A. A. Elbaz, A. M. Aboulfotoh, A. M. Dohdoh, and A. M. Wahba, "Review of beneficial uses of cement kiln dust (CKD), fly ash (FA) and their mixture," *J. Mater. Environ. Sci*, vol. 10, no. 11, pp. 1062–1073, 2019.
[14] 2003) (SCRB R/9, *General Specifications for Roads and Bridges*. 2003.
[15] ASTM D6927, "Standard Test Method for Marshall Stability and Flow of Asphalt Mixtures, ASTM International, West Conshohocken, PA.," *Astm D6927*, vol. i, pp. 1–7, 2015, doi: 10.1520/D6927-15.2.
[16] ASTM D1559, "Resistence to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus," *Annual Book of ASTM Standards*. pp. 1–5, 1989.
[17] ASTM-D2726, "Standard Test Method for Bulk Specific Gravity and Density of Non-Absorptive," *Am. Soc. Test. Mater. ASTM Stand.*, vol. 04, pp. 4–7, 2000.
[18] ASTM D-2041-03, "Standard Test Method for Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures," *ASTM Int.*, pp. 1–7, 2003, [Online]. Available: www.astm.org,.
[19] ASTM D-3203-05, "Percent Air Voids in Compacted Dense and Open Asphalt Mixtures," *Aashto*, pp. 6–7, 2015.
[20] M. A. Abed and A. H. Abed, "Effect of Hybrid Modification and Type of Compaction on the Cracking Properties of Asphalt Concrete," *Al-Nahrain J. Eng. Sci.*, vol. 23, no. 2 SE-Articles, pp. 106–116, Sep. 2020, doi: 10.29194/NJES.23020106.
[21] ASTM D4867, "Standard Test Method for Effect of Moisture on Asphalt Concrete Paving Mixtures," *ASTM Int.*, pp. 1–5, 2014.
[22] A. D-6931-12, "Standard Test Method for Indirect Tensile (IDT) Strength of Bituminous Mixtures 1," pp. 4–8, 2012, doi: 10.1520/D6931-12.2.