Effect of Quality and Quantity of Locally Produced Filler on Moisture Damage Hot Asphaltic Mixtures

Haider F. A. Alabady[1,a*] and Alaa H. Abed[1,b]

[1]Civil Engineering Department, College of Engineering, Al-Nahrain University, Baghdad, Iraq

[a]haiderfadhil762@gmail.com and [b]alaa.h.abed@nahrainuniv.edu.iq

*Corresponding author

Abstract. The modern road network is of the most important requirements of the present life. The filler is regarded as one of its major components, and it has great importance in the mixture. When improving its properties and specifications, the hot mixing properties of the asphalt mix are improved**.** The results of the tests conducted for this research showed that the addition of 1.5% H.L to the control mixture led to a significant increase in the stability of Marshall and air voids, with a rise in (20.4 and 7%), respectively, with an increase in the optimum asphalt content. Moreover, the increase in the tensile strength ratio (TSR) was at the same rate and amounted to 13.6% when compared to the control mixture. The mixtures containing cement kiln dust also led to an increase in the stability of Marshall and air voids. The most significant increase was when replacing it by 50% (23.5 and 6%), respectively, with an increase in the asphalt content. The ratio of indirect tensile strength to tensile strength when CKD is 25% and 50% increases by (6.4% and 12.3%) respectively. These properties deteriorate when the cement kiln dust content increases or hydrated lime increases**.**

Keywords: Moisture damage; hot mix asphalt; anti-stripping; lime; CKD; tensile strength ratio; air voids.

1. INTRODUCTION

In recent years, there has been a significant increase in premature failures of newly constructed asphalt concrete pavements in Baghdad and other Iraqi cities. These failures are mainly attributed to the heavy and repetitive traffic loads and the varying weather conditions. As a result, flexible pavements are prone to moisture damage, fatigue cracking, and permanent deformation (rutting), which significantly reduce the lifespan of asphalt concrete [1]. One of the key factors contributing to these pavement distresses is the infiltration of water, which compromises the integrity of the pavement. The consequences of moisture damage on a city are substantial, both in terms of economic costs associated with maintenance and restoration of damaged pavements and public safety concerns. These expenses have had a widespread impact on the community [2-7]. To address these issues, modifications need to be made to the asphalt mixes in order to meet the required criteria. One common approach is to use additives or modifiers in combination with the asphalt binder or aggregate to mitigate the effects of moisture degradation. A wide range of additives and modifiers are utilized to enhance the performance of asphalt mixes. However, it's important to consider that some of these additives and modifiers may affect the sensitivity of the asphaltic mixtures to moisture [8].

For this particular investigation, hydrated lime and cement kiln dust were employed. Previous studies suggest that adding hydrated lime to hot mix asphalt, ranging from 1% to 3% of the aggregate's dry weight, improves its resistance to moisture [9,10]. This study aims to assess the impact of partially replacing limestone dust with hydrated lime and cement kiln dust on the moisture susceptibility of asphalt concrete. Furthermore, a comparison of the performance of the paving system between the control combination and the modified asphalt concrete mixture will be conducted. Asphalt pavement moisture sensitivity is caused by many factors, including binder and aggregate physical and chemical qualities, design, and construction quality. Anti-stripping additives must preserve excellent HMA qualities while improving moisture resistance, according to [11]. As reported by ASTM D6927 [12] focused on the characteristics of cement kiln dust (CKD) and their influence on the properties of HMA using Marshall Stiffness, indirect tensile strength, and moisture susceptibility tests. CKD was more efficient than limestone mineral filler in increasing the softening point and viscosity of asphalt cement and decreasing its penetration. The addition of CKD to the HMA mixes increased the indirect tensile strength (ITS) and tensile strength ratios (TSR) of the studied limestone and basalt HMA mixes [13].

The inclusion of CKD improved the tensile strength ratios (TSR) and Marshall Stability of the examined limestone HMA mixtures Containing 5% CKD for the limestone HMA mixes were larger by 11% and higher optimal binder concentration in HMA mixtures [14]. ASTM D-3203-05 [15] Studied the Effect of Hydrated Lime addition by (1, 1.5, and 2) % from weight of aggregate on moisture susceptibility of asphalt mixtures, depending on test IRS and TSR test, H.L significantly increased the values of tensile strength ratio, from a scientific point of view, this improvement in resistance to damage from water could be explained by the effect of chemical action caused by the presence of Ca^{++} in the lime material. The main objectives of this research are:

- Evaluate the Marshall properties of heated asphalt formulations of hydrated lime and Cement kiln dust used in place of limestone as filler in the asphalt mixture.
- Determine the sensitivity to moisture when using Cement kiln dust and hydrated lime.

2. 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), cement kiln dust (CKD), and Hydrated Lime (H.L). All materials were acquired from commercial sources.

2.1 Asphalt Binder

Asphalt is today's most commonly used material in pavement construction 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, located southwest of Baghdad. To establish the physical properties of the asphalt binder, it was subjected to a battery of tests normally performed in labs. The test results to meet the SCRB R/9 [11] are shown in Table 1.

Table 1: Physical properties of AC (40-50).

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

2.2 Aggregate

The Al-Nibaee quarry provided the coarse and fine aggregate (crushed). According to the SCRB R/9 [11] Requirements, the sizes of coarse aggregate (19 mm) 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.

Material	Property	ASTM Designation	Value
Physical Properties of Coarse Aggregate	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
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

2.3 Mineral Filler

Mineral filler is typically used to improve the mixture's characteristics and fill the voids. In this study, three different types of fillers were employed. They came from two different local sources in Iraq: Hydrated lime (H.L) used as a percent of (1, 1.5, 2, and 3%) and 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 physical properties are shown in Table 3.

Table 3: The chemical and physical properties of H.L, CKD.

Property		Limestone	Cement Kiln Dust
Chemical Analyses	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
Physical Properties	Specific gravity	2.72	2.92
	% Passing N0.200	94	89.5
	Color	white to gray	Light gray

2.4 Scanning Electron Microscopy (SEM)

Figure 1 shows the surface shape of the types of used fillers, H.L has a coarse granular shape with a sharp edge, as it was produced from crushing stone. It differs from cement kiln dust, which forms an irregular, spherical shape, while limestone dust is irregular and spaced lumps.

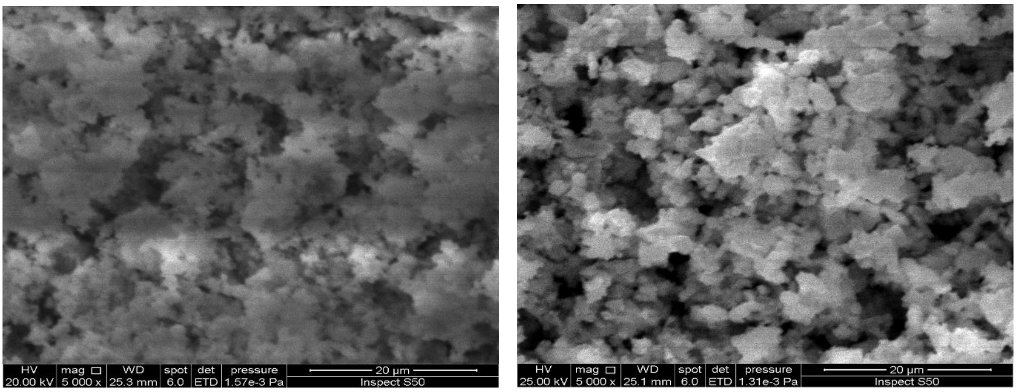

Figure 1: SEM image at zoom 5.000X for a) CKD and b) H.L.

3. EXPERIMENTAL PROCEDURE

As prescribed by SCRB [11], the job mix formula was used to determine the percent combination for (Type II) binder course. The aggregate gradation is shown in Table 4 and Figure 2.

Table 4: Gradation of combined aggregate for wearing course.

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

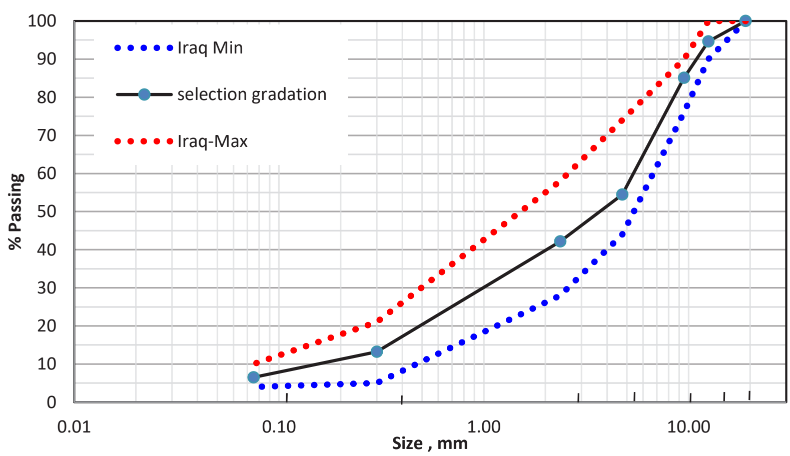

Figure 2: The binder course requirements and grading scheme.

The aggregate was first screened, washed, and dried at a temperature of 110°C until it attained a weight that remained consistent throughout the operation. After that, the aggregate was broken up into the required sizes. 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°C 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 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 the aggregate particles could be thoroughly covered with asphalt cement. Weigh the dry sample, which consists of 1200 grams (aggregate plus filler) [12].

3.1 Marshall Testing

To carry out the Marshall Test, cylindrical specimens with 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°C for 34 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. The bulk specific gravity and density [13], theoretical (maximum) specific gravity [14], and percent air voids [15] were determined for each specimen. The percent of air voids was then calculated from Equation (1):

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

3.2 Moisture Susceptibility Test

The tensile strength of asphalt concrete is an important factor in its performance, particularly concerning prevailing conditions and moisture sensitivity [16]. A test is used to evaluate the impact of moisture on asphalt mixtures with and without anti-stripping additives, as covered in [17]. Four Marshall Specimens were initially prepared with varying 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, as shown in Figure 3, 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 [18]:

$$\text{ITS} = \frac{2000\text{p}}{\pi\text{tD}(\text{kPa})} \qquad (2)$$

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).

$$\text{TSR} = \left(\frac{\text{Scon}}{\text{Suncon}}\right) * 100\% \qquad (3)$$

TSR of (80%) or higher is considered the bare minimum by [12].

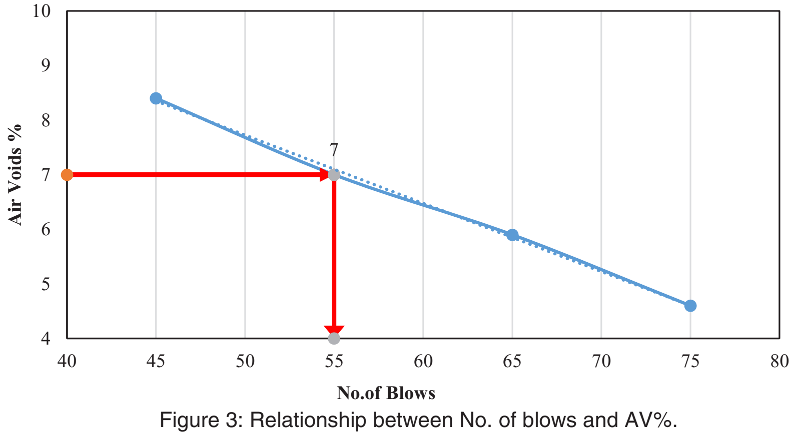

Figure 3: Relationship between No. of blows and AV%.

4. 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 [11]), the asphalt content acquired for the mix design of paving mixes satisfies the design parameters defined for the binder layer.

4.1 Marshall Properties

Figure 4 comprehensively compares the results obtained for all mixtures for the effect of additives Types on Optimum Asphalt Mixture. A high stability value indicates a stiffer asphalt mixture. Figure 5 shows the stability values of the hot asphalt mixes compared to the control mixture that contains (limestone dust). The mixtures containing (CKD) and (H.L) have higher stability values than the control mixture. The samples containing H.L increased the stability; the maximum stability corresponds to 1.5%. Replacing limestone with hydrated lime increases the hardness of the mixture.

On the other hand, the addition of hydrated lime increases the viscosity of asphalt cement [19,20]. For cement kiln dust, the stability increased. 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, primarily due to the higher surface area of CKD, which tend to absorb more asphalt. Based on the Marshall Flow values shown in Figure 6, the mixture with limestone dust has the highest value compared to CKD and H.L.

The flow value increases when CKD is added and then decreases 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 limestone. The bulk density value results for all additives were as shown in Figure 7. 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/cm^3) at (100%) respectively, and the highest value was at (50%). The results of the air voids are shown in Figure (8), showing the effect of H.L, CKD on the content of the air voids. The air voids increased when the hydrated lime content increased from 0 to 3.0 percent, and the maximum increase of air voids was recorded at 3%. When CKD increased from 0 to 100%, the value of air voids increased. Effect of HL, CKD, and content on (VMA), as shown in Figure 9. VMA increases with the increase of slaked lime or cement kiln dust in the mixture. The highest difference between slaked lime and limestone dust fillings was observed at partial replacement of 3% limestone, which was 16.5 and 14.2. All special values of VFA for the mixtures containing additives were higher than the control mixture in certain proportions. As shown in Figure 10, it is noted that CKD needs more asphalt to wrap on its surface due to its relatively higher specific surface area, which leads to lower. When using hydrated lime, in general, the percentage of VFA increased when the percentage of hydrated lime was increased.

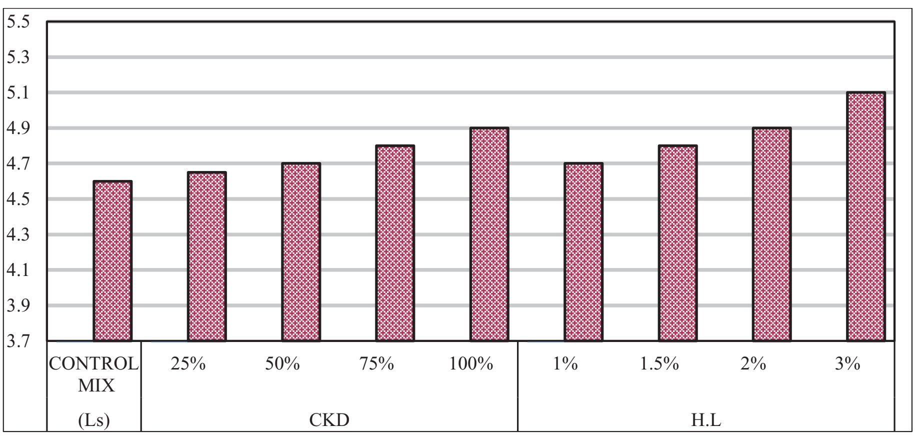

Figure 4: Effect of different additives on optimum asphalt mixture.

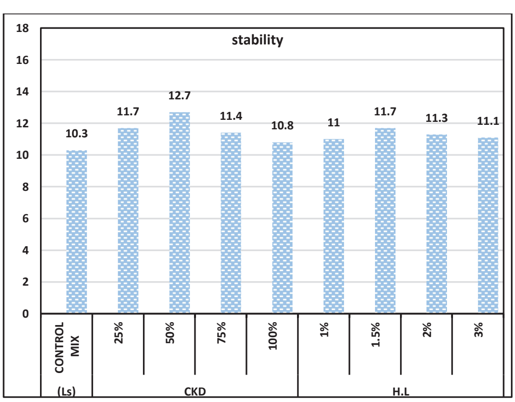

Figure 5: Influence of stability.

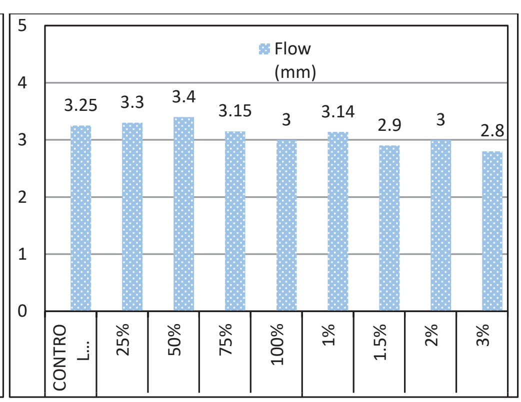

Figure 6: Influence of flow.

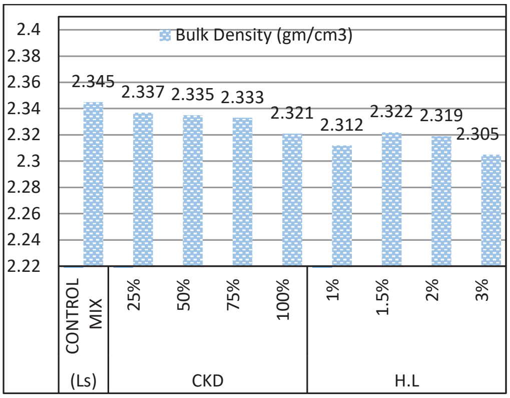

Figure 7: Influence of bulk density.

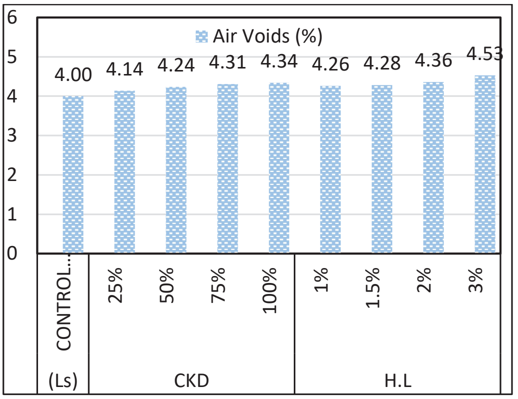

Figure 8: Influence of AV%.

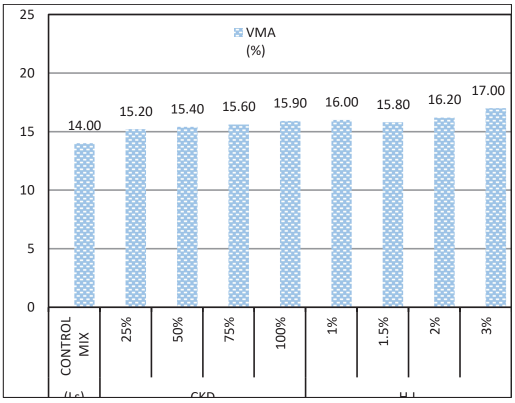

Figure 9: Influence of VMA.

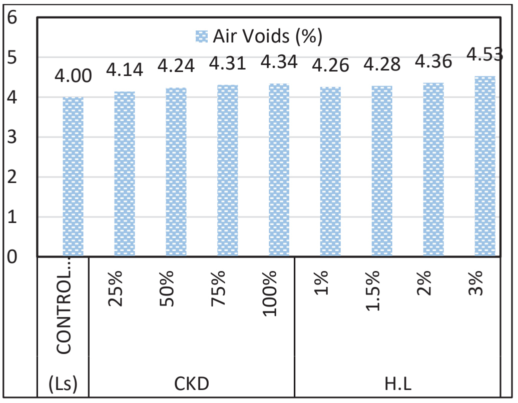

Figure 10: Influence of VFA.

6.2 Indirect Tensile Strength (ITS)

To show the effect of filler types in hot asphalt mixtures on moisture sensitivity, cement kiln dust was also used with four different percentages of limestone dust filler weight. The results showed that using the CKD led to a significant increase in the values of ITS non-conditioned and conditioned, as shown in Figure 11. 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 increase is attributed to the CKD has finer particles compared to LS filler. Also, the reason for this is due to the surface area of (CKD) which tends to absorb more asphalt of the mixture when increasing the content of the CKD. Therefore, the amount of asphalt must exceed the upper limits of the Iraqi standard hence increases the production costs.

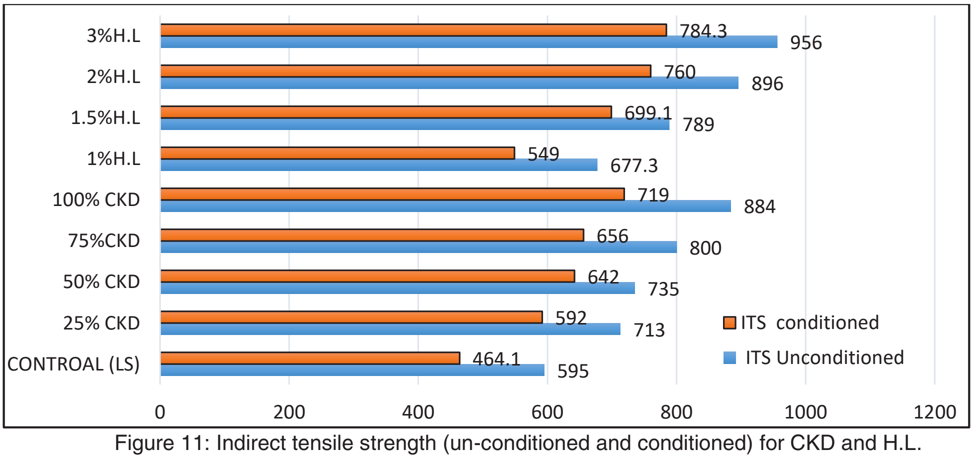

Figure 11: Indirect tensile strength (un-conditioned and conditioned) for CKD and H.L.

For hydrated lime, the values of ITS (un-conditioned and conditioned) tensile strength and TSR ratio were higher for 1.5% hydrated lime than for (1, 2, and 3) % lime content when the lime content was increased. The mixture became agglomerated due to the absorption of a large amount of asphalt, due to its softness more than the used filler. This means that increasing the amount of hydrated lime beyond the threshold value of 1.5 percent of 0.5 percent did not enhance the moisture damage resistance any further and exhibited a trend of a slight decrease in tensile strength with an increase in the added, as shown in Figure 12.

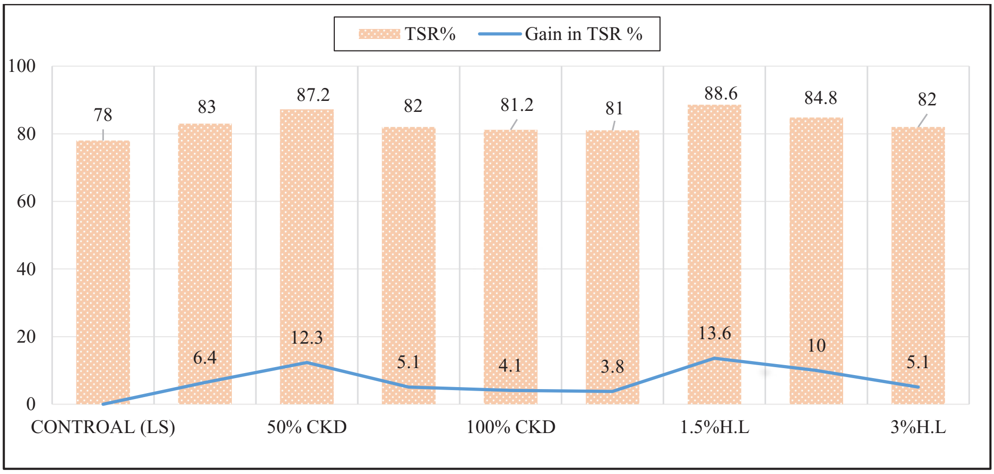

Figure 12: Effect of H.L and CKD content on the TSR and variable ratio.

7. CONCLUSIONS

- The filler material has a significant effect on the properties of the HMA mixture, and this effect is related to the properties of the filler itself. All asphalt mixtures met the minimum tensile strength ratio (TSR) requirements of % 80 specified by ASHTTO T-283 for testing mixes for susceptibility to moisture perishability.
- 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.
- The mixtures containing CKD showed an increase in Marshall's stability values compared to the control mixture and a decrease in flow values with increasing CKD content. Air voids and voids increase in mineral aggregates while bulk-specific gravity decreases.
- The tensile strength ratios of the slaked lime mixtures were higher than those without the additive. This indicates that the use of hydrated lime reduced moisture susceptibility. The addition of 1.5% of hydrated lime content to the total weight of the aggregate recorded the highest increase in the TSR value. This percentage reaches 13.6% from the control mixture for the asphalt mixture.
- Air voids and voids increase in mineral aggregates. At the same time, bulk-specific gravity decreases after adding hydrated lime in the dry process, and Marshall's stability values increased compared to the control mixture, then decreased with increasing lime content. It showed a decrease in flow values with increasing lime content. Mixtures containing a high percentage of hydrated lime possess a higher asphalt cement content, and the highest value of optimal asphalt content (5.1%) was obtained with 3%.

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