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Effect of Filler Types on Moisture Damage of Asphalt Mixtures

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ABSTRACT

The filler in the asphalt mixture is essential since it plays a significant role in toughening and stiffening the asphalt. Changes in filler type can lead the asphalt mixtures to perform satisfactorily during their design life or degrade rapidly when traffic and environmental effects are considered. This study aims to assess the impact of filler types such as limestone dust (LS) and hydrated lime (HL) on Marshall characteristics and moisture damage in asphalt mixtures. Three different percentages of HL were employed in this study to partially replace the LS mineral filler: 1.5, 2.0, and 2.5% by aggregate weight. Furthermore, a control mixture was created with 7% LS by overall aggregate weight for the wearing course layer. The Marshall method was used to obtain the optimal asphalt content and the asphalt mixes' volumetric properties. The optimum asphalt content was used to prepare the asphalt concrete mixes, which were then tested for moisture damage resistance using the indirect tensile strength (ITS) and the index of retained strength (IRS). The findings demonstrate that resistance to moisture damage can be significantly enhanced by partially substituting HL for the LS filler. This was verified by the fact that the optimum increase in the tensile strength ratio (TSR) was 7.29% at 2.5% of HL, and at the same HL percent, the greatest rise in the IRS was 9.81% compared with the control mix.

Keywords: Moisture damage, Hydrated lime, Limestone dust, Indirect tensile strength, Index of retained strength.

1. INTRODUCTION

Over the past few decades, flexible pavement deterioration caused by moisture has received a lot of attention. The harmful effects of this distress contribute to other distresses like rutting and fatigue cracking. Consequently, the lifespan of asphalt concrete is considerably reduced by the susceptibility of flexible pavements to fatigue cracking, moisture damage, and permanent deformation **(Ezzat and Abed, 2020)**. Water intrusion is a main cause of these pavement distresses, which degrade the pavement's structural integrity. The asphalt pavement's performance may deteriorate more rapidly in the presence of water due to

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reduced binder and aggregate adhesions as well as the loss of asphalt cohesion. Moisture damage has a considerable effect, such as increased maintenance and restoration costs for damaged pavements, in addition to public safety issues **(Abuawad et al., 2015)**. Modifications have to be applied in asphalt mixtures to satisfy the requirements and address these issues, which is a common strategy used with aggregate or asphalt binder to mitigate the impact of moisture on asphalt pavement **(Al-Qadi et al., 2014)**.

Additives such as filler can be desirable for optimizing the aggregate bonding with asphalt and also decreasing the moisture in mixtures. Consequently, adopting an appropriate filler is essential to minimizing the impact of moisture on the asphalt mixtures. The properties of the asphalt concrete mixture are considerably affected by the filler material, and this influence corresponds with the filler's characteristics. Through laboratory testing, (**Alabady and Abed, 2023)** employed two various types of fillers. Cement kiln dust was used as a percent of (25, 50, 75, and 100%), and HL was used as a percent of (1, 1.5, 2, and 3%) by weight of LS. The purpose of this study was to determine Marshall's properties and sensitivity to moisture. Results show that the mixes with cement kiln dust and HL had a greater tensile strength ratio than the mixes without any addition. Another study **(Albayati et al., 2022)** indicated that a 3% HL content would be more appropriate for enhancing asphalt mixtures' fatigue resistance. Various three-HL sizes were employed, which are micro, sub-nano, and nanoscale. This study demonstrated that the size of HL particles was strongly correlated with the ability of asphalt mixtures to prevent distress.

(Satar et al., 2018) investigated four different percentages of meta-kaolin filler in asphalt pavement based on asphalt weight: 2%, 4%, 6%, and 8% as a prime instance in order to utilize it in place of joint filler. Moreover, the results demonstrated that 2% meta-Kaolin filler improved the stiffness of the asphalt mixtures. **(Diab and Enieb, 2018)** Shown the effect of filler mechanisms on mastic scale and asphalt mixtures due to their considerable effect on properties on both asphalt mixtures and mastic. Three different mineral fillers with varying percents: LS, cement bypass dust, and HL were used. This study revealed that filler types and content are essential factors in guaranteeing the asphalt mixes' performance in field settings. **(Wang et al., 2018)** observed that mixtures modified with cement filler may reduce moisture susceptibility. Similarly, the performance of asphalt mixtures was effectively modified **(Hu et al., 2017; Hu et al., 2018; Coudhary et al., 2019)** by adding waste brake pads as fillers. The results indicated great outcomes in improving the workability of asphalt mixtures relating to moisture tolerance and high-temperature susceptibility.

(Chen et al., 2015) illustrated their study on partially replacing recycled rubber tyres with LS filler; however, this will reduce the asphalt mixes' susceptibility to moisture damage because of the loss of bond between the aggregate and asphalt. **(Kuity et al., 2014)**demonstrated that LS filler had better resistance to moisture compared with fly ash, brick dust, and recycled concrete waste aggregate dust. **(Liang et al., 2023)** performed their study to analyze the implication of different fillers on the mechanical characteristics and durability of mixtures, including cement, brake pad powder, LS, and HL. The results showed that HL filler was more effective in resisting moisture damage on pavements. Other laboratory investigations demonstrated that asphalt mixtures' resistance to water, freezing, and thawing cracks can be significantly improved with 2.5% HL as a filler **(Albayati et al., 2020)**.

Similar experiments revealed that the mechanical characteristics of the mixtures were enhanced by adding 2.5% HL to the overall weight of the aggregate while partially replacing LS **(Al-Tameemi et al., 2016; Albayati and Mohammed, 2016; Al-Tameemi et al., 2019;**

Aljbouri and Albayati, 2024). Another study clarified that incorporating 1.5% HL into mixtures increased moisture resistance in terms of ITS and IRS**(Ismael and Ahmed, 2019)**. It has been proven that better mixture strength and aggregate bonding could be attributed to the use of reactive fillers such as HL **(Lesueur et al., 2013; Preti et al., 2021)**.
Furthermore, HL may interact with the asphalt functional group to produce a specific waterproofing compound that effectively decreases the moisture of the mixtures **(Grajales et al., 2021).**
Based on previous studies, filler materials, such as HL, can be used to reduce moisture damage. In addition to being used, the filler components increase the asphalt binder mixture's stiffness and stability. The primary object of this study is to investigate the mechanical characteristics regarding mix design and moisture damage of asphalt mixtures that incorporate partially HL in place of LS to produce asphalt mixtures less susceptible to moisture damage.

2. MATERIALS

The locally available materials were chosen to achieve this study, which were used in Iraqi pavement construction: asphalt cement (40–50), aggregate, and mineral filler.

2.1 Asphalt Cement

The asphalt cement type employed in this study is AC (40–50) penetration grade. It was supplied from the Al-Daurah refinery. The test findings, as indicated in **Table 1**, are in compliance with the specifications provided by **(SCRB /R9, 2003)**.

Table 1. Asphalt characteristics.

Test	Unit	Results	ASTM Specification
Penetration, at 25°C	1/10mm	44	**(ASTM D5, 2013)**
Ductility, at 25°C	cm	138	**(ASTM D113, 2007)**
Flash Point	°C	249	**(ASTM D92, 2018)**
Softening Point (Ring & Ball)	°C	52	**(ASTM D36, 2014)**
Specific gravity, at 25°C	-	1.03	**(ASTM D70, 2021)**

2.2 Aggregates

Crushed quartz aggregate from the Al-Nibaie quarry was used. The physical characteristics of coarse and fine aggregate have been identified by laboratory experiments. The test results displayed in **Table 2** indicate that the aggregate's characteristics fall within the specification limits.

Table 2. Coarse and fine aggregate characteristics.

Test	ASTM Specification	Results	
		Coarse aggregate	Fine aggregate
Bulk Specific Gravity	**(ASTM C127, 2015; ASTM C128, 2015)**	2.61	2.651
Apparent Specific Gravity	**(ASTM C127, 2015; ASTM C128, 2015)**	2.642	2.684
Water Absorption	**(ASTM C127, 2015; ASTM C128, 2015)**	0.54	0.723
Los Angeles Abrasion %	**(ASTM C131, 2020)**	16. 6	-------

The aggregate gradation was assigned based on **(SCRB /R9, 2003)** for surface courses. The aggregate gradation that was used is displayed in **Fig. 1**.

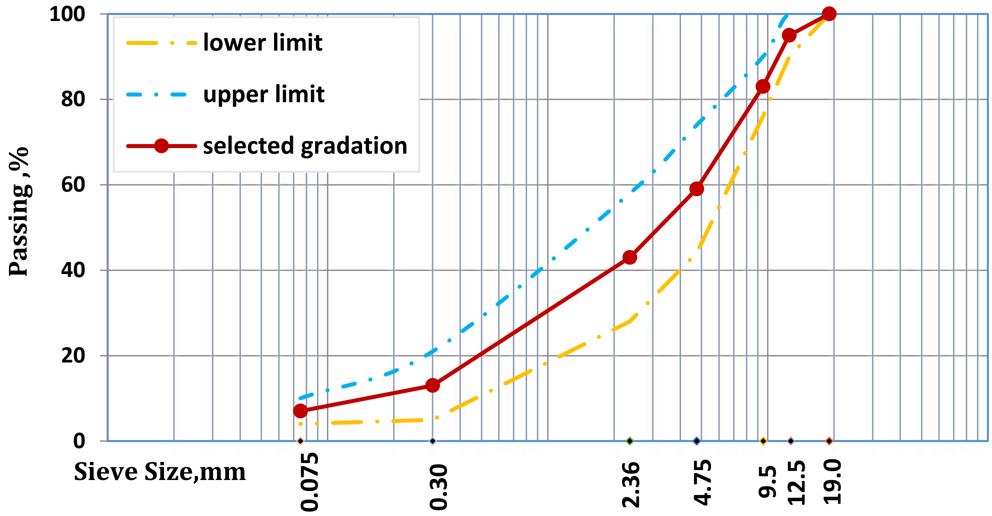


Figure 1. Design aggregate gradation.

2.3 Mineral Filler

Limestone dust (LS) and hydrated lime (HL) were employed to create an asphalt concrete mixture. **Fig. 2** shows these two types of mineral fillers. The availability and low cost of LS made it a common filler. It was utilized at a percentage of 7% of the mixes' overall weight, which is in the midrange selected by **(SCRB /R9, 2003)**, for type IIIA of wearing courses. On the other hand, HL has long been considered an appropriate choice for use in pavements. (**SRCB/R9, 2003)** has been recommended to use 1.5% HL as the anti-stripping additive to resist moisture damage. Moreover, this study used HL at three different percentages (1.5, 2, and 2.5%) as a partial substitute for LS**.** The physical properties of the HL and LS supplied from the Karbala governorate's lime factory, southeast of Baghdad, are demonstrated in **Table 3**.

Table 3. Mineral filler's properties.

Material Property	Limestone dust	Hydrated lime
Specific Gravity	2.72	2.42
Passing No.200 (%)	93	98

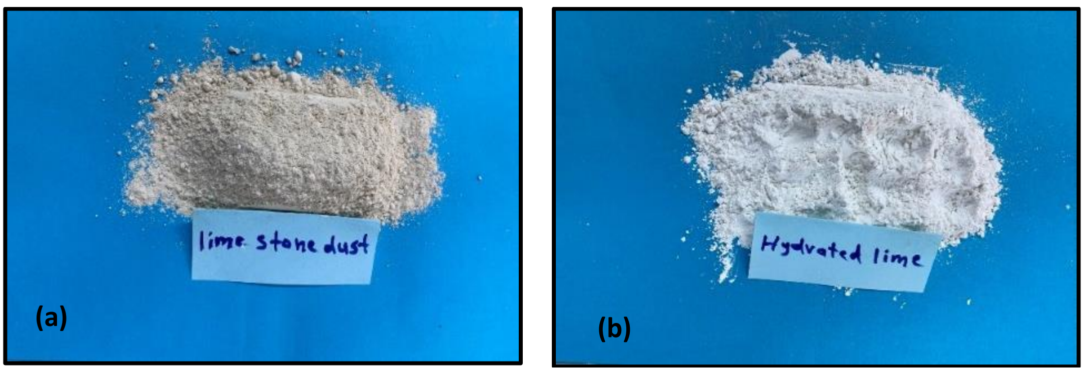


Figure 2. Types of Mineral Filler, **a)** LS, **b)** HL

3. EXPERIMENTAL WORK

The Marshall test, indirect tensile strength, and index of retained strength were used in the testing method to determine the optimal asphalt composition and moisture sensitivity.

3.1 Field Emission Scanning Electron Microscopy (FESEM)

(FESEM) is an advanced technique employed for capturing images of the crystalline structure, exterior morphology, and material particle size at different magnification levels. The microstructure image was acquired in this study using a Quattro S crossbeam in order to characterize the mineral filler.

3.2 Marshall Test

(ASTM D6926, 2020) was utilized to compute the optimal asphalt content (OAC) and Marshall properties. At first, different aggregate portions and filler were incorporated into a (1150) gm batch. After that, the mix of aggregates was heated to approximately 150°C in a container for two hours. Meanwhile, asphalt cement has five percentages ranging from 4-6, with an increase of 0.5. It was separately heated for two hours at 155 °C in order to reach a viscosity of 170 c.St., as shown in **Fig. 3**. After that, they were completely combined at 155 °C for two minutes. Consequently, the blend was put into cylindrical molds (2.5 ×4 inches) and heated for ten minutes at 145 °C for compaction at 280 c.St., then compacted by the Marshall Compactor by applying 75 blows per face. The bulk-specific gravity was established for each specimen using (**ASTM D2726, 2021)**.

Table 4. Marshall test results

OAC (%)	Stability (kN)	Flow (mm)	Bulk density (gm/cm^3)	VTM (%)	VMA (%)	VFA (%)
4.9	10.55	3.43	2.328	3.75	16.15	76.78
(SCRB /R9, 2003) specification for type IIIA						
4-6	8 min	2-4	-	3-5	14 min	-

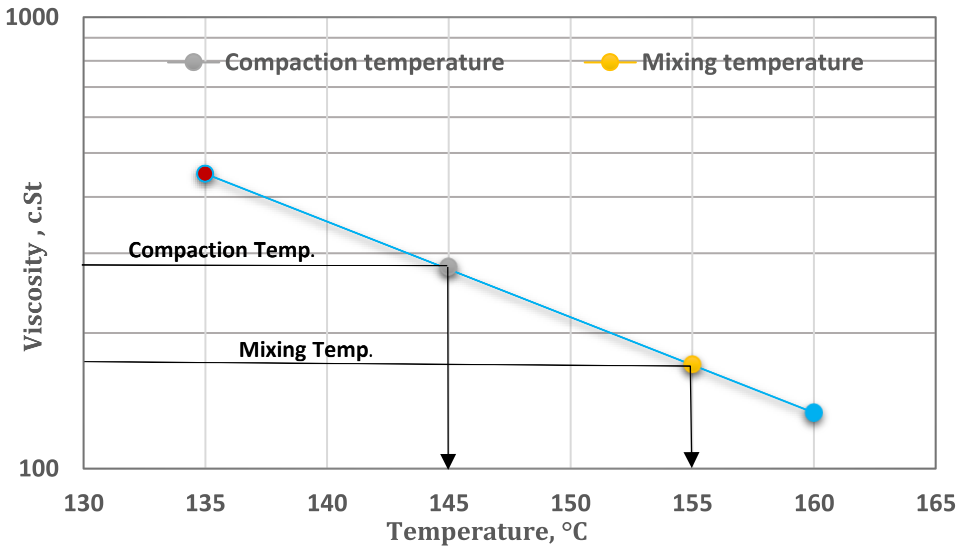


Figure 3. Temperature-viscosity relationship.

Figure 4. Marshall test, **a)** Specimens, **b)** Device.

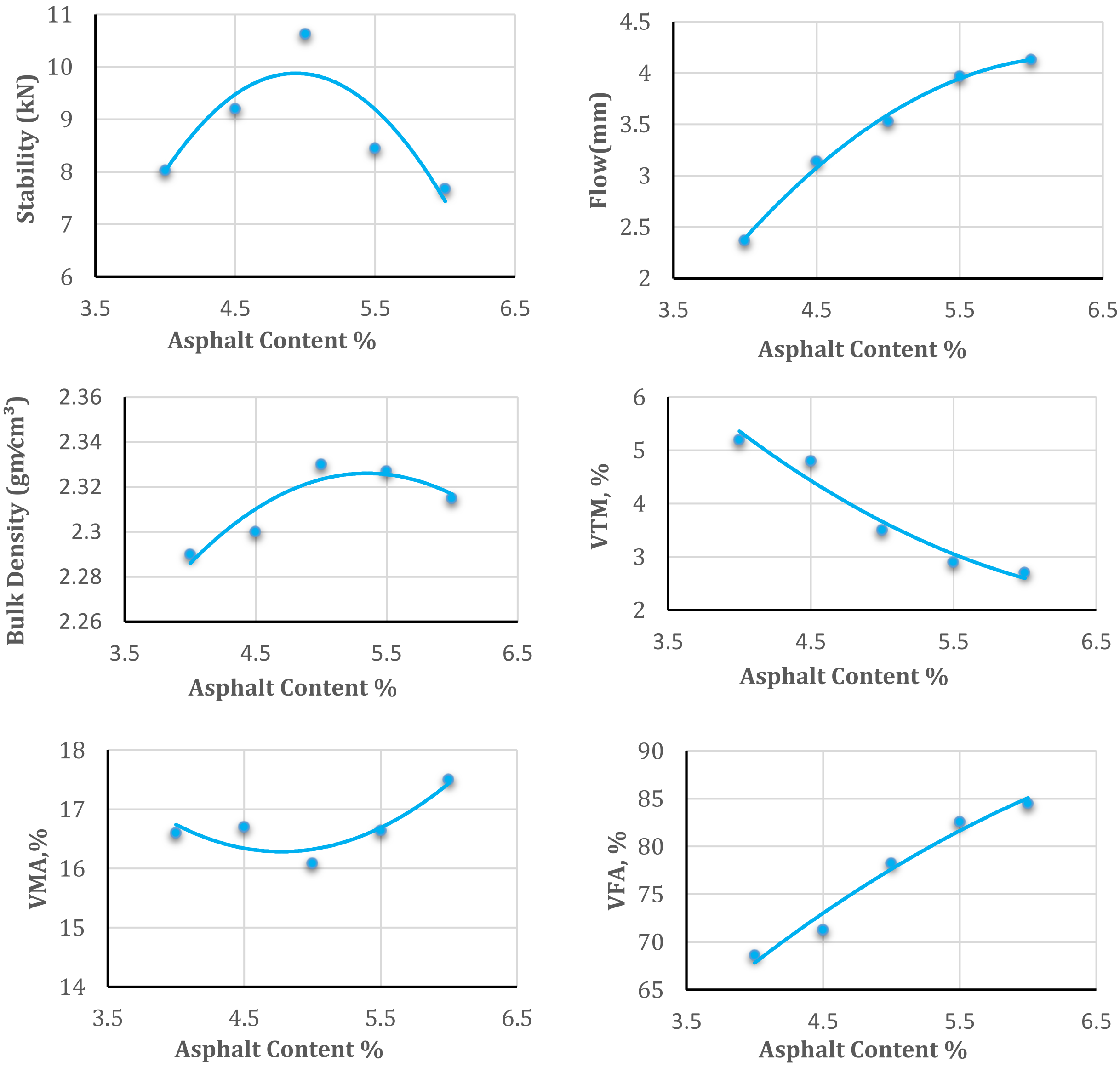


Figure 5. Mix design results of asphalt concrete with the Marshall method.

3.3 Indirect Tensile Strength

(ASTM D4867, 2014) was used to estimate the moisture damage of asphalt concrete mixtures. Five Marshall specimens were first created using a trial method with 35, 45, 55, 65, and 75 blows, respectively. In order to evaluate the number of the blows that gives 7±1% air voids, to achieve this percentage, 53 blows were performed, as shown in **Fig. 6**.

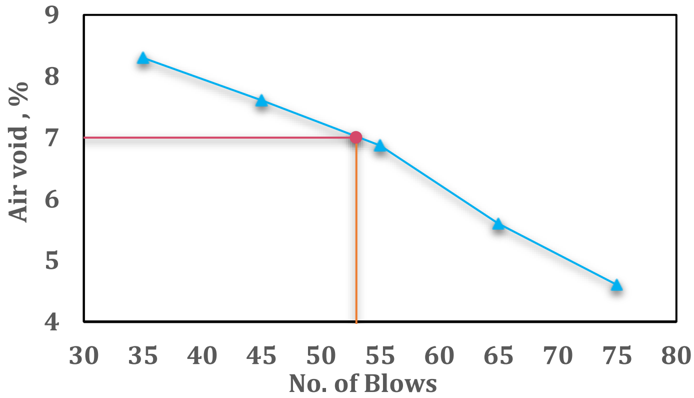


Figure 6. No. of blows-Air voids relationship.

The Marshall approach was then used to prepare six specimens for each mix. After that, two groups were created. The unconditioned group was measured at 25 °C. The other group, known as the conditional group, received a cycle of freezing and thawing exposures for 16 hours at -18 ± 2 °C and then another 24 hours at 60 ± 1 °C, and after that, a tensile test was carried out at 25 °C. A compressive force was applied to the specimens along their diametral axis at 50.8 mm/min. Eqs. (1) and (2) were applied to calculate the ITS and TSR.

$$ITS = \frac{2000\, pmax}{\pi\, t\, D} \quad (1)$$

$$TSR = \frac{ITS\, u}{ITSuc} \quad (2)$$

Where:
ITS is indirect tensile strength, kPa; P is the maximum load, N; D is the specimens' diameter, mm; t is the specimens' thickness, mm; TSR is Tensile strength ratio, %; ITSu is condition indirect tensile strength, kPa; and ITSuc is uncondition indirect tensile strength, kPa. The (ITS) test is displayed in **Fig. 7.**

Figure 7. The ITS test steps.

3.4 Index of Retained Strength Test

(ASTM D1075, 2011) was utilized to measure the compressive strength loss caused by water acting on compacted asphalt mixture specimens. The dimensions of the specimen (4×4 inches) were created according to (**ASTM D1074, 2017).** For each combination, a set of six specimens was prepared. After that, they were split into two groups. The first group, known as the dry group, conducted testing following four hours of storage at 25 °C in an air bath. The second group, known as the wet group, was submerged in a water bath for 24 hours at 60°C and afterwards ejected and put in another water bath at 25°C for two hours. Subsequently, an axial force was applied at a 5.08 mm/min rate. Eq. (3) was employed to calculate the IRS.

$$IRS = \frac{Sw}{Sd} \times 100 \quad (3)$$

where Sw is the compressive strength of wet specimens, kPa and Sd is the compressive strength of dry specimens, kPa. **Fig. 8** shows the compressive strength test.

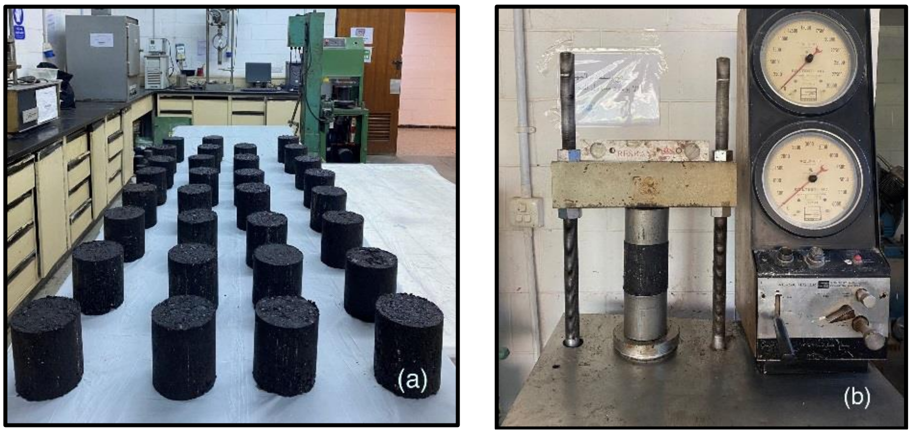
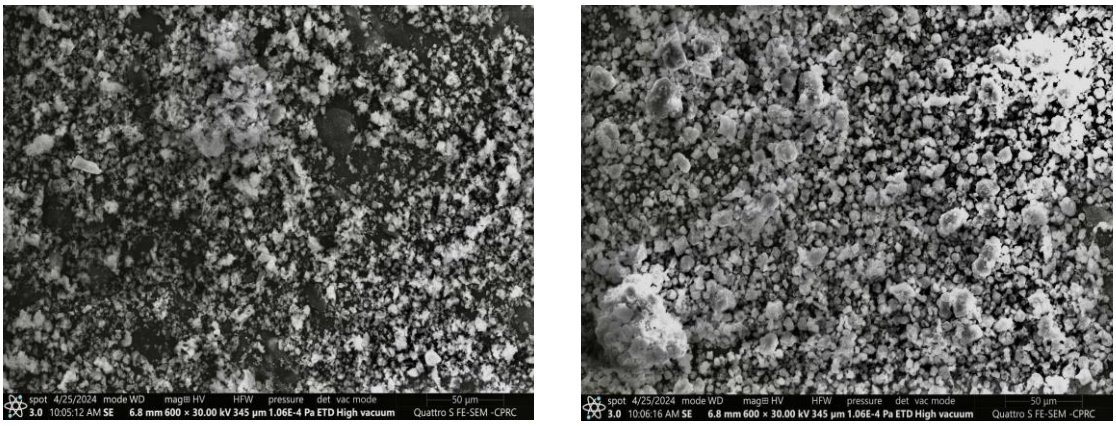


Figure 8 . IRS specimens and device, **a)**IRS specimens ,**b)**device

4. RESULTS AND DESCUSION

4.1 Field Emission Scanning Electron Microscopy (FESEM)

In order to clarify the surface morphology of the filler materials, scanning electron microscopy (SEM) was performed to display the physical and chemical interactions in mixtures. **Fig. 9** shows the two filler materials appearance. The SEM of HL presents a granular form with a rough surface texture. It differs from LS, which was shown in an irregular form with a smooth surface. These variations have a major impact on the performance and interaction of mixtures when using HL and LS as mineral fillers.



(a) (b)

Figure 9. The FE-SEM images of , **a)** HL, **b)** LS

4.2 Marshall Test

The optimal asphalt content (OAC) was obtained regarding the control mix and was applied for all combinations in this study, which is 4.9 based on the average value of maximum stability, maximum bulk density, and 4% air voids. The Marshall stability results show that replacing LS with 1.5, 2, and 2.5% HL increases the stability by 5.97, 9.38, and 14.88%, respectively. The highest rise in stability was shown at 2.5% HL content. This rise was associated with a reduction in flow values of 3.8, 9.33, and 18.36%. The bulk density of mixtures containing HL decreased somewhat as the HL content increased. The incorporation of HL implies a slight increase in the air void percentage in asphalt mixtures. These behaviours can be due to the fact that partially replacing LS with HL increases asphalt absorption since the HL particles are finer than LS, which allows them to fill void pockets and stiffen mixtures more effectively up to a limit where compaction effort will start to decrease, and the air void will increase. The bulk density reduces when the percentage of air void rises. The inclusion of HL enhanced the asphalt cement's viscosity, which was associated with increased Marshall stability. The stiffness of the mixes is expressed by the Marshall quotient (MQ). It is estimated by dividing stability by flow, and the findings indicate that the mixture's stiffness improved as the percentage of HL increased. The test findings are summarized in **Table 5** and displayed in **Fig. 10**.

Table 5. Marshall properties results.

Mixture type	OAC (%)	Stability (kN)	Flow (mm)	MQ (kN/mm)	Density (gm/cm^3)	VTM (%)	VMA (%)	VFA (%)
0HL+7LS	4.9	10.55	3.43	3.07	2.328	3.75	16.15	76.78
1.5HL+5.5LS		11.18	3.30	3.38	2.320	4.10	16.20	74.69
2HL+5LS		11.54	3.11	3.71	2.316	4.25	16.32	73.95
2.5HL+4.5LS		12.12	2.80	4.33	2.313	4.38	16.40	73.29

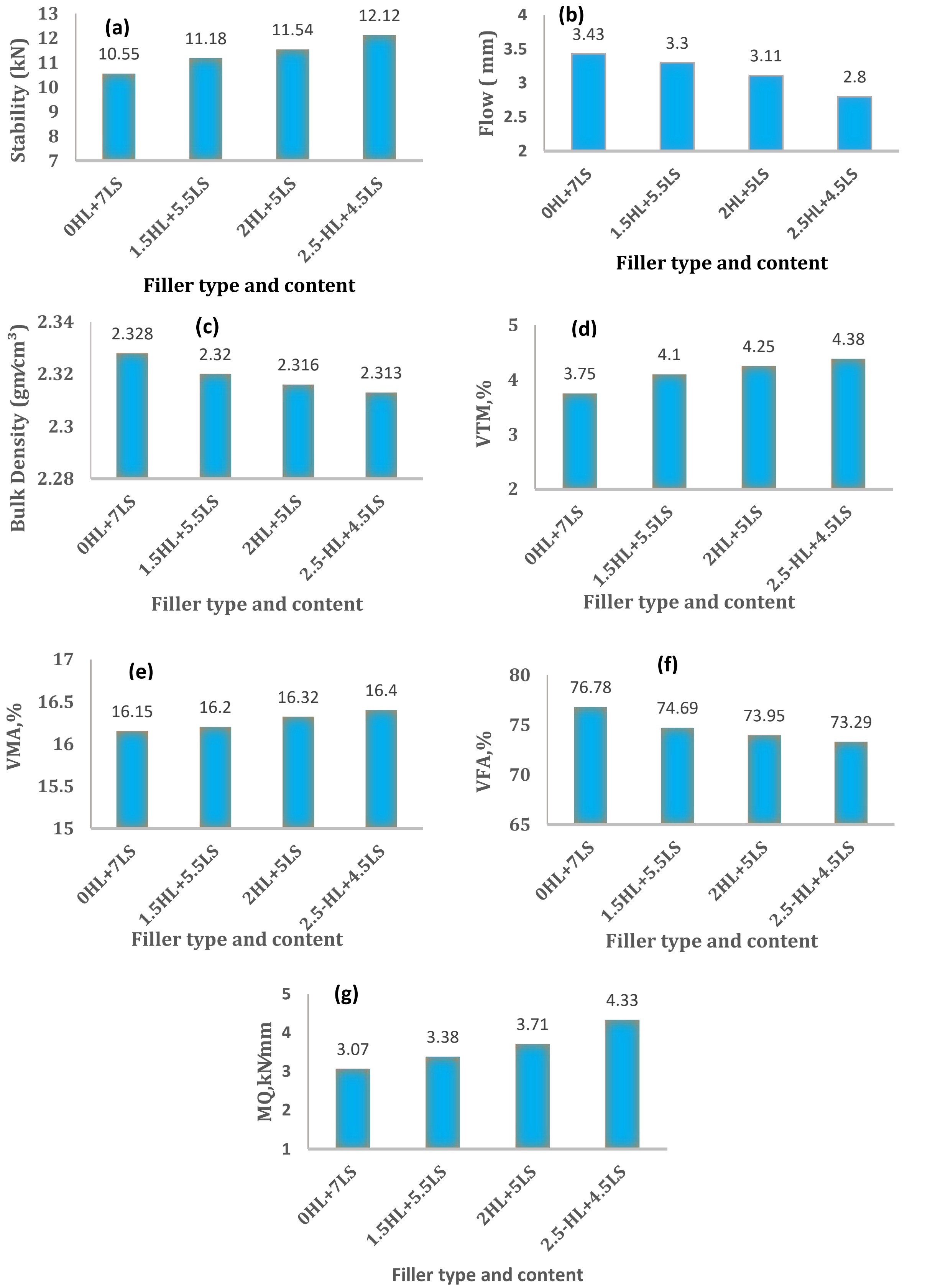


Figure 10. Impact of Filler types on Marshall characterizes: **a)** Stability, **b)** Flow, **c)** density, **d)** VTM, **e)** VMA, **f)** VFA, and g**)** Stiffness or MQ.

4.3 Tensile Strength Ratio

HL partial addition improves the asphalt mixture's resistance to moisture, as shown in **Table 6** and **Fig. 11**. HL significantly increases both unconditional and conditional ITS. Consequentially, the TSR value also enhanced; the greatest increment in TSR value was at 2.5% HL content. The maximum TSR value was increased by 7.29% above the control mix that was prepared with LS as the only filler; the results are in agreement with **(Aljbouri and Albayati, 2024)**.

Table 6. TSR test results.

Mixture type	Unconditional ITS (kPa)	Condition ITS (kPa)	TSR (%)
Control Mix	1146	922	80.45
1.5HL+5.5LS	1227	1023	83.37
2HL+5LS	1317	1121	85.11
2.5HL+4.5LS	1411	1218	86.32

The enhancement in water resistance of the mixture resulted from the effective blending of HL particles with the viscous elements subjected to oxidative aging, which reduced the process when exposed to moisture. On the other hand, HL particles have a high surface area; therefore, their ability to stiffen the asphalt matrix (asphalt cement and filler) is improved, leading to improved resistance to the tensile stress mobilised within a plane perpendicular to the diametral loading axis **(Behbahani et al., 2020; Al-Marafi, 2021; and Albayati et al., 2022)**.

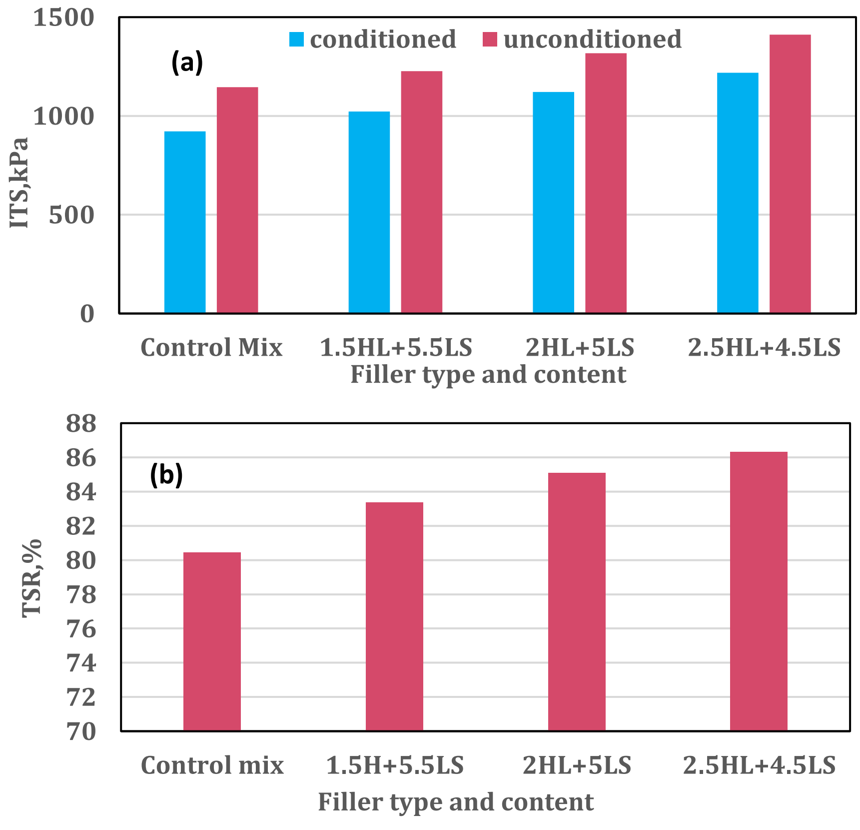


Figure 11. Impact of filler(types and content) on, **a)** ITS, **b)** TSR.

4.4 Index of Retained Strength

Findings indicated that increasing the dry and wet compressive strength values resulted from partially replacing LS with HL. This led to a corresponding rise in the value of IRS. At a percent of 2.5, the best results were obtained; the largest increase in the IRS value was 9.81% above the control mix. However, all mixes were within the permissible limit recommended by **(SCRB/R9,2003)**, which is 70%.

Due to the same reasons that were found in the TSR test, the partial replacement of LS with HL increased the asphalt mixture's resistance to moisture-induced compressive strength, which raised the IRS and improved moisture resistance. The test outcomes are displayed in **Table 7.** and **Fig. 12.**

Table 7. IRS test results.

Mixture type	Dry Compressive Strength (kPa)	Wet Compressive Strength(kPa)	IRS (%)
Control mix	5983	4451	74.39
1.5HL+5.5LS	6591	5110	77.52
2HL+5LS	7255	5775	79.60
2.5HL+4.5LS	7385	6033	81.69

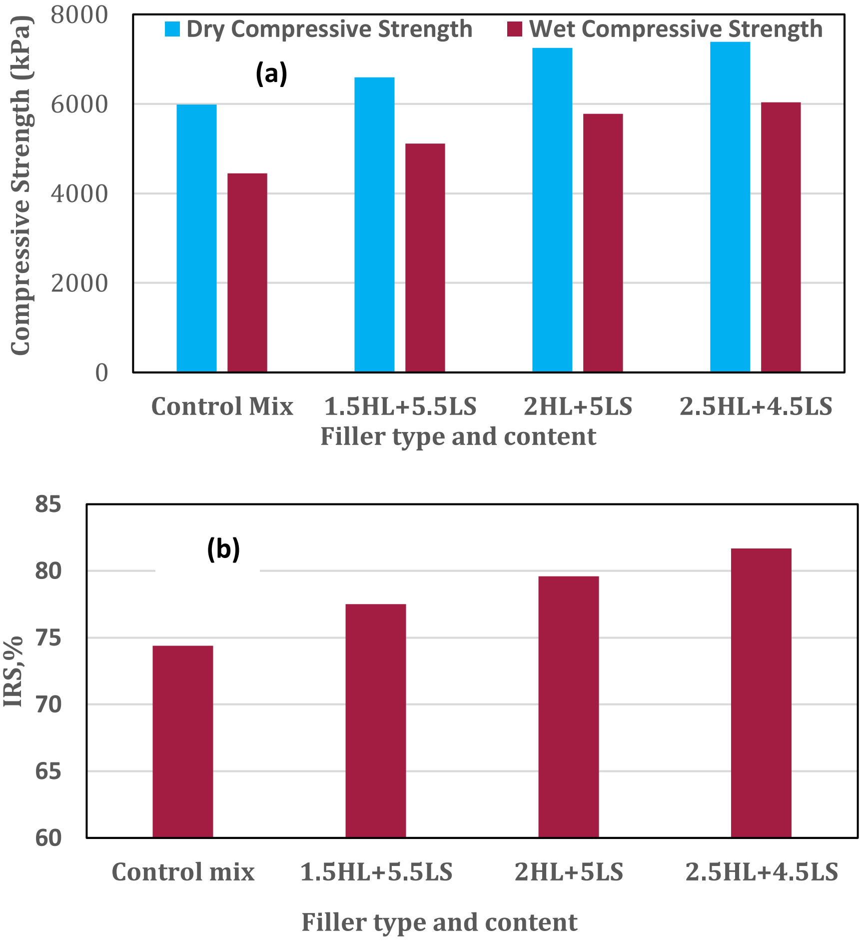


Figure 12. Impact of filler (types and content) on, a) Compressive strength, b) IRS.

5. CONCLUSIONS

This study assessed the impact of filler types on moisture damage in mixtures using HL and LS as fillers. According to the laboratory work, the following findings were reached:

1. As compared with the control mix that was prepared with LS as the only filler, Marshall stability increased through replacing LS with 1.5, 2, and 2.5% of HL, with the optimum increase at 2.5% HL of 14.88%.
2. HL addition reduces Marshall flow; the significant reduction was 18.36% at 2.5% of HL compared with the control mix.
3. The replacement of LS by HL slightly decreased the density of the mixture. The air voids increased with the maximum increasment of 4.38 at 2.5% of HL. However, air void values were within the permitted standard limits of 3–5%.
4. The mixtures containing HL as a filler had better moisture damage resistance based on the increase in TSR of 3.63%, 5.79%, and 7.29% for 1.5%, 2%, and 2.5% HL, respectively. Furthermore, all mixtures exceeded the 80% minimum recommended value of TSR.
5. The IRS also increased by (4.2, 7, and 9.81%) for 1.5%, 2%, and 2.5% HL, respectively, over the control mix.
6. The use of filler(HL) considerably improved the mixture's resistance against moisture damage. since HL plays a role as an anti-stripping additive, which enhances the bond between aggreagate and asphalt.

NOMENCLATURE

Symbol	Description	Symbol	Description
D	The specimen's diameter	VMA	Voids in mineral aggregate
HL	Hydrated lime	ITS	Indirect Tensile Strength
IRS	Index of Retained Strength	TSR	Tensile Strength Ratio
LS	Limestone dust	VFA	Voids filled with asphalt
t	The specimen's thickness	P	Ultimate load failure
VTM	Voids in total mixture		

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Credit Authorship Contribution Statement

Noor N. Adwar: Writing – original draft. Amjad H. Albayati: Writing – review & editing, Validation, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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تأثير انواع المادة المالئة على ضرر الرطوبة للخلطات الاسفلتية

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الخلاصة

تعتبر المادة المالئة في خليط الأسفلت مكونًا أساسيًا لأنها تلعب دورًا مهمًا في تقوية وتصلب الأسفلت. يمكن أن تؤدي التغييرات في نوع المادة المالئة إلى أداء افضل للخلطات الاسفلتية خلال العمر التصميمي أو إلى التدهور السريع عند أخذ التأثيرات المرورية والبيئية بعين الاعتبار. الهدف من هذه الدراسة هو تقييم تأثير أنواع المادة المالئة مثل غبار حجر االكلس (LS) والجير المطفأ (HL)على خواص مارشال وضرر الرطوبه للخلطات الاسفلتية. تم في هذه الدراسة استخدام ثلاث نسب مختلفة من الجير المطفأ كبديل جزئي من حجر الكلس وهي: 1.5، 2، 2.5 % وزناً من الركام، إلى جانب الخلطة المرجعية المحضرة بغبار حجر الكلس بنسبة 7% وزناً من الركام للطبقة السطحية. تم استخدام طريقة مارشال للحصول على المحتوى الإسفلتي الأمثل والخواص الحجمية للخلطات الإسفلتية. تم استخدام المحتوى الأسفلت الأمثل لتحضير الخلطات الخرسانية الإسفلتية، والتي تم اختبارها بعد ذلك لمقاومة أضرار الرطوبة باستخدام قوة الشد غير المباشرة (ITS) ومؤشر قوة الانضغاط (IRS) . وقد لوحظ أن استبدال جزءِ من غبار حجر الكلس بالجير المطفأ من شأنه أن يحسن مقاومة أضرار الرطوبة. تم التحقق من ذلك حيث أن الحد الأقصى للزيادة في نسبة قوة الشد (TSR) وجد أنها 7.29% عند 2.5% من HL، والحد الأقصى للزيادة في مؤشر قوة الانضغاط (IRS) وجد أنها 9.81% عند نفس نسبة HL.

الكلمات المفتاحية: ضرر الرطوبة، الجير المطفأ، حجر الكلس، مقاومة الشد، مقاومة الانضغاط.