The Effect of Combination and Addition of Some Mineral Fillers on Hot Mix Asphalt Performance

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Abstract

The using of conventional hot mix asphalt causes unnecessary road maintenance. It is necessary to use modified materials in pavement construction which could improves the performance of asphalt concrete pavement mixture.

The major objective of this research is to evaluate the effect of combination and addition of some mineral fillers on some properties of hot mix asphalt .

Hot mix asphalt specimens have been prepared with aggregate, nominal maximum size (19) mm and Al- Daurah asphalt cement (40-50). Two types of mineral fillers has been used : Portland cement and limestone dust. Percentage of Portland cement has been used in this work (6%) for binder course, limestone dust has been used in dry state with the percentage (1, 2, 3)% by weight of total aggregate as part replacer of the used filler content. Hydrated lime was used in dry state too but as locally additive with the percentage (1)% by weight of total aggregate as part replacer of the used filler content. The performance of asphalt mixtures are evaluated using Marshall test, indirect tensile test and permeability test.

It is concluded that the combination and addition of some mineral fillers to asphalt mixtures showed; the Marshall stability and indirect tensile strength are increased by (1.3,1.2) times respectively when compared with control mixtures . Permeability results are decreased by (5.5) times when compared with control mixtures .

For this research the recommended filler combination with (4% cement, 1% limestone dust and 1% hydrated lime as an additive) is the best for hot mix asphalt performance .

Keywords: Hot Mix Asphalt, Filler Combination, Filler addition, Marshall Test, Indirect Tensile Strength Test , Permeability Test .

الخلاصة

ان استخدام خلطات الرصف الاسفلتية التقليدية يتسبب في اجراءات صيانة غير ضرورية. فمن الضروري استخدام مواد معدلة في انشاء التبليط مما يحسن من اداء خلطة الرصف الاسفلتي للتبليط..

ان الهدف الرئيسي من البحث هو تقييم تأثير مزج واضافة بعض المواد المالئة على بعض خواص الخلطة الاسفلتية الحارة.

يتم تحضير نماذج من الخلطات الاسفلتية الحارة لركام بمقاس اقصى اسمي ١٤ ملم واسفلت الدورة (٤٠-٥٠) . تم استخدام نوعين من المادة المالئة هي:السمنت البورتلاندي ومسحوق حجر الكلس بنسبة ٦% لطبقة رابطة ، فقد تم استخدام مسحوق حجر الكلس بالحالة الجافة وبنسب (١،٢،٣)% من وزن الركام كبديل جزئي من المادة المالئة . اما النورة المطفأة فقد تم استخدامها بالحالة الجافة ايضا كمضاف محلي وبنسبة ١% من وزن الركام وكبديل جزئي من المادة المالئة . تم تقييم اداء الخلطات باستخدام فحص مارشال وفحص مقاومة الشد الغير مباشر وفحص النفاذية .

تم الاستنتاج بان مزج واضافة بعض المواد المالئة تؤدي الى زيادة ثبوتية مارشال ومقاومة الشد الغير مباشر بــ (1.2,1.3) مرة بالتتابع عند المقارنة بالخلطات القياسية . اما نتائج النفاذية فقد قلت بمقدار (٥,٥) مرة عند المقارنة مع الخلطات القياسية .

لهذا البحث توصية بنسبة مزج (٤% سمنت بورتلاندي ، ١% مسحوق حجر الكلس مع ١% نورة مطفأة كمضاف حيث تعتبر النسبة الافضل لأداء الخلطة الاسفلتية الحارة .

الكلمات المفتاحية: الخلطة الاسفلتية الحارة، تركيب المادة المالئة، اضافة المادة المالئة، فحص مارشال، فحص مقاومة الشد الغير مباشر، فحص النفاذية .

Introduction:

The filler, as defined, is the material passing the No.200 sieve. It has long been recognized that the filler plays a major role in behavior of the asphalt mixtures. Fillers fill voids between coarse aggregates in the mixture and alter properties of the binder, because the filler acts as an integral part of the mastic (combination of bitumen, filler, and entrapped air). The quality of mastic influences the overall mechanical performance of asphalt mixtures . [Arnodottir, 2008].

An interactive physico-chemical effect between the filler and the bitumen related to the fineness and surface characteristics of the filler typically influences fatigue fracture characteristics. The physico-chemical aspect is related to adsorption intensity at the filler bitumen interface, and higher surface activity significantly contributes to stronger bonds at the filler-bitumen interface. It can be inferred that the interactive role associated with the physico-chemical reaction is influenced by the type of bitumen and filler . Therefore, care must be taken to consider not only the amount of mineral filler, but also its size when evaluating whether an excessive amount of fine material is present in a mix that is being designed or controlled in the field . [Al-Khashaab, 2009].

Low voids and low stability this situation may be met with Limestone filler asphalt mixture. High voids and satisfactory stability this situation may be met with Hydrated Lime dust asphalt mix type. Satisfactory voids and satisfactory stability this case was happened with Portland cement hot mixed with the aggregates. It is the best filler type cause this mix had met all criteria successfully. [Tayh & Jabr, 2011].

The quality of mastics, the combination of asphalt binder and filler, influences the overall mechanical performance of asphalt mixtures as well as placement workability. Generally the effect of the filler is based on a volumetric filler effect or an interactive role between the filler and the bitumen due to the fineness and surface characteristics of the filler. [Chistopher, 2004].

The hydrated lime actually stiffens the asphalt film and reinforces it. Furthermore, the lime makes the HMA less sensitive to moisture effects by improving the aggregate-asphalt bond. This synergistically improves rut resistance. As the HMA ages due to oxidation, hydrated lime reduces not only the rate of oxidation but also the harm created by the products of oxidation. This effect keeps the asphalt from hardening excessively and from becoming highly susceptible to cracking (through fatigue and temperature (thermal) cracking). [Berger & Huege, 2004].

There are various benefits of adding hydrated lime in asphalt concrete mix:

- It acts as mineral filler and stiffens the asphalt binder and HMA.
- It improves fracture toughness at low temperatures.
- It favorably alters the oxidation mechanism and interacts with products of oxidation to reduce their deleterious effects.
- It changes the plastic properties of clay fines and improves moisture stability and durability.
- Above all it also has the ability to control water sensitivity and is well accepted as an antistrip to inhibit moisture damage.

Hydrated lime creates a very strong bond between the bitumen and the aggregate, preventing stripping at all pH levels. The addition of hydrated lime to HMA increases stiffness. This helps to distribute and reduce the stresses and strains within the pavement structure created by traffic loads and generally reduce permanent deformation potential. [Arambula *et al*., 2012].

Hydrated lime promotes high temperature stability, thereby increasing resistance to permanent deformation. It showed the improvements in resistance to permanent deformation, fatigue cracking and low temperature fracture. It showed that although the filler effect of lime increases low temperature stiffness, fracture toughness is also increased substantially. [Hamed, 2010].

Materials:

Material used in this study are locally available. One penetration grade (40-50) of asphalt cement is used from Daurah refinery, the physical properties and tests of asphalt cement are presented in table (1).

Table (1): Physical Properties of Asphalt Cement

Tests	Units	Penetration grade (40-50)	S.C.R.B Specification
Penetration (25 0C), 100 gm, 5sec) ASTM D-5	1/10 mm	46	(40-50)
Kinematic Viscosity at 135 0C ASTM-2170 *	cst	385	-----
Ductility (25 0C, 5 cm/min) ASTM D-113*	cm	107	>100
Flash Point ASTM D-92(Cleveland open cup)*	^{0}C	339	min. 232
Specific Gravity at 25 0C ASTM D-70 *	……	1.04	(1.01-1.05)

(*) The test was conducted Road laboratory of civil engineering Babylon and Daurah refinery.

The source of the coarse aggregate used is Al- Najaf quarry which is a crushed stone. This aggregate is widely used in the middle and south areas of Iraq for asphalt pavement. The particles tend to off white in color with angular surfaces. The fine aggregate is obtained from Karbala quarry. The fine and coarse aggregate are sieved and recombined in the proper proportions to meet the gradations required by SCRB specifications [SCRB, R/9 2003].

Routine tests are performed on the aggregate to evaluate their physical properties.The results together with the specification limits as set by the SCRB are summarized in table (2).

The gradation of aggregate; a nominal maximum size of (19mm) is shown in Table (3). Test results show that the chosen aggregate met the SCRB specifications.

Table (2): Physical Properties of Aggregate

Property	ASTM Designation	Coarse aggregate	Fine aggregate
Bulk specific gravity	C-127 C-128	2.54	2.66
Apparent specific gravity	C-127 C-128	2.67	2.68
% water absorption	C-127 C-128	0.86	0.63
Abrasion (Los Angeles)	C-131	25 % Max 30 %	----------
Angularity	D-5821	95 %	-----------

(*) These tests were accomplished in the transportation laboratory of civil department engineering in the Babylon University.

Table (3): Asphalt mixture grading for binder course

No.	Sieve size		Specification limits for binder course (SCRB)
	Standard sieves (mm)	English sieves (in)	
1	25.0	1	100
2	19.0	3/4	90-100
3	12.5	1/2	70-90
4	9.5	3/8	56-80
5	4.75	No. 4	35-65
6	2.36	No. 8	23-49
7	300 μ□	No. 50	5-19
8	75 μ□	No. 200	3-9

In this study, Two types of mineral fillers has been used : Portland cement and limestone dust. Percentage of Portland cement has been used in this work (6%) for binder course, limestone dust has been used in dry state with the percentage (1,2,3)% by weight of total aggregate as part replacer of the used filler content. The physical properties of filler are presented Table (4).

Table (4): Physical properties of the used filler

Property	Cement	Limestone dust
Specific gravity	3.14	2.65
Finness (cm^2/gm)	3050	3180
% passing sieve No. 200	95	98

(*) These tests were accomplished in the transportation and material laboratories of civil engineering in the Babylon University.

The Hydrated lime used in this study brought from Alnoora plant in Karbala Province. Hydrated lime was used in dry state with the percentage (1)% by weight of total aggregate as part replacer of the used filler content. The physical properties of hydrated lime are presented Table (5).

Table (5): Physical properties of hydrated lime

Property	H. lime
Specific gravity	2.44
Finness (cm^2/gm)	3850
% passing sieve No. 200	100

(*)These tests were accomplished in the transportation and material laboratories of civil engineering in the Babylon University.

Tests:

Marshall Test:

Standard method of Marshall as in [ASTM D-6927] specifications is used to find the optimum asphalt content for compacted asphalt concrete specimens. Marshal apparatus and compaction apparatus are shown in plate (1). The [SCRB ,2003] specification of mix design criteria for heavy traffic roads recommends the following values for binder course, as shown in table (6).

Table (6): SCRB Specification of Mix Design

Properties	S.C.R.B Specification Limits
Marshall stability, KN	7 (minimum)
Marshall flow, mm	2 – 4
Air voids, %	3 – 5
Voids filled with asphalt, %	65 – 85
Void in mineral aggregate, %	14 (minimum)

Plate (1): Marshall Apparatus and Compaction Apparatus

The optimum asphalt content (O.A.C) of the various mixes is determined from the following Marshall curves, (stability, bulk density, flow and 4% of air voids). The optimum asphalt content for binder course (4.6) , as shown in figure (1).

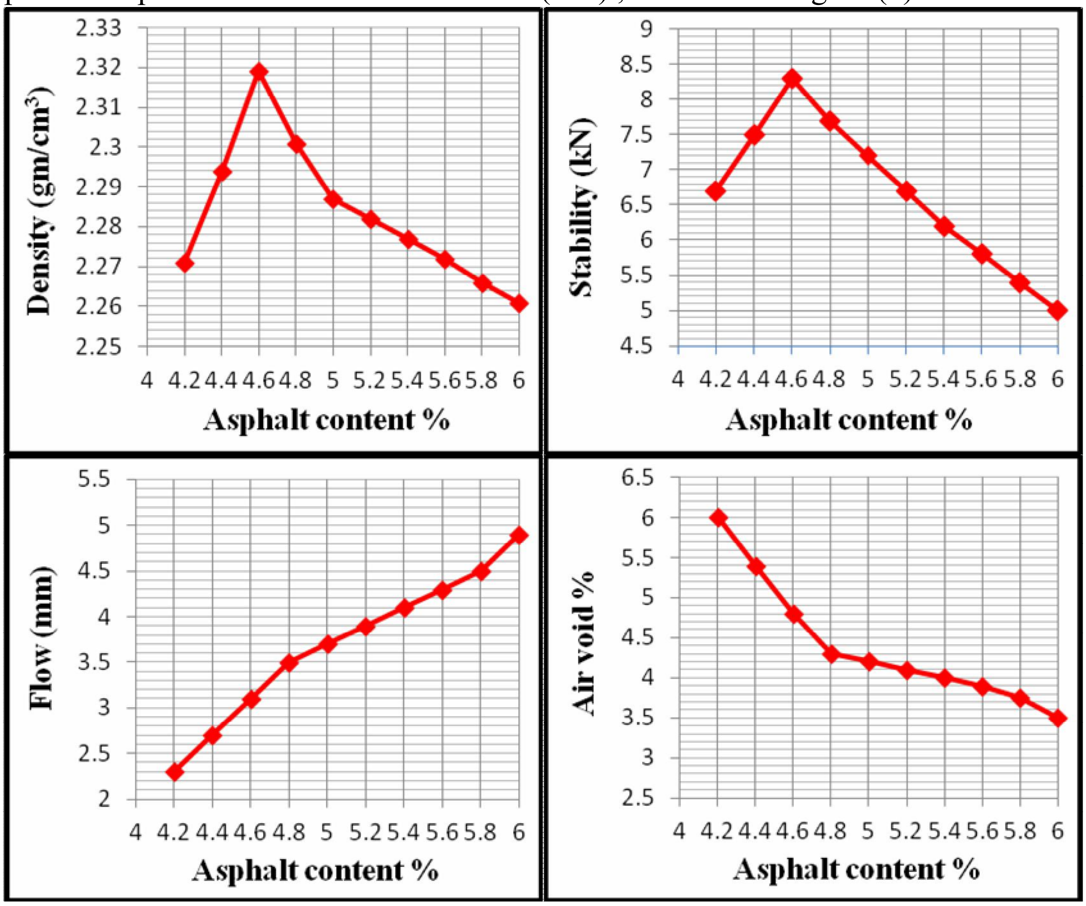

Figure (1): Marshall Mix Design Curves for Optimum Asphalt Content

Indirect Tensile Strength Test:

The indirect tensile test (IDT) is used to measure the creep compliance and strength of asphalt mixture using indirect tensile loading at intermediate temperatures. Indirect tensile testing applies a compressive load across the diametrical axis of a cylindrical specimen.

This test is used to analyze mixtures for fatigue cracking resistance. For intermediate analysis, use a test temperature 20^0C or less for fatigue cracking analyses. Lower the temperature of the environmental chamber to the test temperature with($\pm$ 0.2^0C) is achieved, allow each specimen to remain at the test temperature from 3±1hours prior to testing. In this test, the specimen is loaded at a constant deformation rate of 2 inch per minute (50 mm per minute) of vertical ram movement. The specimen is loaded until failure – peak load is measured throughout the test.

The peak load is reached when the specimen breaks in which the type of failure is categorized as :

- Clear tensile break where the specimens are clearly broken along a diametrical line, for small triangular sections close to the loading strips.
- Deformation where the Specimens are without a clearly visible tensile break line.
- Combination where the specimens are with a limited tensile break line and larger deformed areas close to the loading strips.

The type of failure recorded may be helped to understand the crack mechanism and to provide a real comparison between the testes materials.

The dimensions of the sample are 4 inch (101.6 mm) diameter and 2.5 inch (63.5 mm) height with load to failure along the diametrical plane of the sample.

In the road laboratory of civil engineering, university of Babylon Marshall apparatus is used to conduct this test by replacement the device head with two metal bracket 0.5 inch (12.5 mm) width, as shown in plate (2).

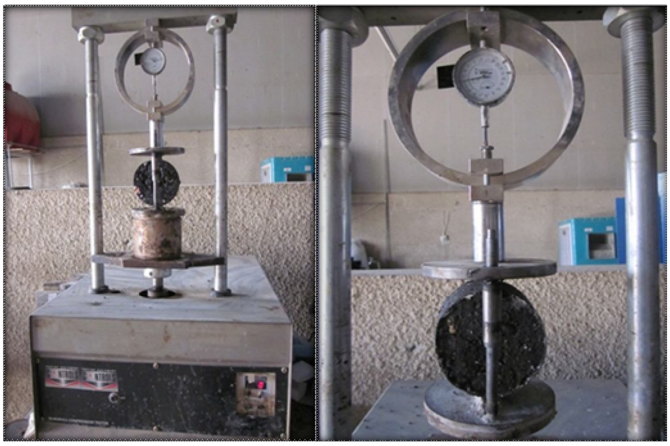

Plate (2): Process of Converting Marshall Test to Measure the Indirect Tensile Test

The indirect tensile method is used to develop tensile stresses along the diametric axis of the test specimen. The horizontal tensile stress at the center of the test specimen is calculated to determine the indirect tensile strength by doubling the peak load (P) and then dividing it by the diameter (d) of the sample and the thickness (t) of the sample using the following eq. (1).

$$\sigma = \frac{2 * P}{\pi * t * D} \qquad \text{eq. (1)}$$

Where:

σ = Tensile strength (Mpa).

P = Peak load (N).
t = Thickness of specimen (mm).
d = Diameter of specimen (mm).

Permeability Test:

The fact that the durability of asphalt concrete is compromised when a pavement has a high air void content has been recognized for many years. Not only do void spaces allow air to enter and oxidize the asphalt cement, but water can also enter and cause freeze-thaw and stripping damage. [Harris, 2007]

It must be realized that void levels greater than the target average requirement of 7.0 percent will likely produce high permeability.

It can be concluded that the new permeability design system is resulting in surface mixtures that can be constructed with an average low permeability. VDOT's Materials Division should continue the current permeability specification requiring a maximum permeability of 150×10^{-5} cm/sec to ensure the construction of asphalt mixtures with low permeability .

A falling head permeability test patterned after conventional soils testing was performed using apparatus currently under development. The Lab Permeability apparatus is shown in Plate (3) .

Plate (3): The setup of lab permeability apparatus

The apparatus consists of a metal cylinder with a flexible membrane on the inside of the cylinder to which air pressure can be applied. The cylinder has removable plastic plates at the top and bottom that can be sealed. The top plate has a hole with a graduated cylinder for the introduction of water, and the bottom plate has an outlet hole and valve for the water to flow out.

The attached graduated cylinder was filled with water, and the permeameter was tilted and tapped gently to remove air bubbles. Water was then allowed to flow through the specimen by opening the valve on the bottom of the permeameter. The graduated cylinder was refilled to the top mark (approximately 800-cm head), the valve was opened, and the time required for the water to reach the lower mark (approximately 200-cm head) was recorded. The coefficient of permeability was computed according to the following formula. Three tests on the same specimen were performed and averaged. The coefficient of permeability, k, is determined using the following eq (2) :

$$k = \frac{al}{At} In(h_1 / h_2) \qquad \text{eq. (2)}$$

Where:
K = coefficient of permeability, cm/s;
a = inside cross-sectional area of the buret, cm^2;

L = average thickness of the test specimen, cm;
A = average cross-sectional area of the test specimen, cm^2;
t = elapsed time between hi and h_2, s;
h_1 = initial head across the test specimen, cm;
h_2 = final head across the test specimen, cm.

Correct the calculated permeability so that for 68^o F (20^0C), k20, by multiplying *k* by the ratio of the viscosity of water at the test temperature to the temperature of water at 68^o F (20^0C) ,RT, using the following eq (3) :

$$K_{corrected} = R_T K \qquad \text{eq.(3)}$$

Test Results and Discussion:

Marshall Test:

Stability is an important property for the asphalt mixture in the binder course design. It shows the ability to resist shoving and rutting under traffic. Almost the stability treated asphalt concrete mixtures and regardless of filler type and (% of filler combination or addition) is higher than the control asphalt concrete mixtures .

An air void in the mixture is an important parameter because it permits the properties and performance of the mixture to be predicated for the service life of the pavement.

- The results of all mixtures agree the Iraqi specification (section R_9) for stability flow & % air voids .
- For control mixtures, the using of cement as filler provides better performance than that of limestone dust due to difference in chemical composition .
- The best combination was (1% limestone dust, 5% cement) for stability while other combination (2% limestone dust , 4% cement) & (3% limestone dust , 3% cement) still agree the Iraqi specification but with lower values .
- The addition of hydrated lime leads to decrease slightly the stability but within the Iraqi specification range but decrease significantly the % air voids that may be high fineness of hydrated lime additive.

The results of Marshall test are shown in table (7), figure (2) and figure (3) :

Table (7) : Marshall test results

Type of Mixture	Stability (KN)	Flow (mm)	Stiffness (kN/mm)	Bulk Density (gm /cm^3)	Air Void %
6% Cement (Control)	10.7	3.4	3.147	2.314	4.6
6% L.D (Control)	9.3	2.6	3.577	2.306	4.8
5% Cement & 1% L.D	13.0	3.1	4.193	2.321	4.3
4% Cement & 2% L.D	10.7	3.4	3.147	2.313	4.6
3% Cement & 3% L.D	8.7	3.3	2.636	2.305	4.7
4% Cement , 1% L.D & 1% HL	11.1	3.6	3.083	2.327	3.8
3% Cement , 2% L.D & 1% HL	10.4	3.8	2.737	2.330	3.5
2% Cement , 3% L.D & 1% HL	9.1	3.7	2.459	2.336	3.4

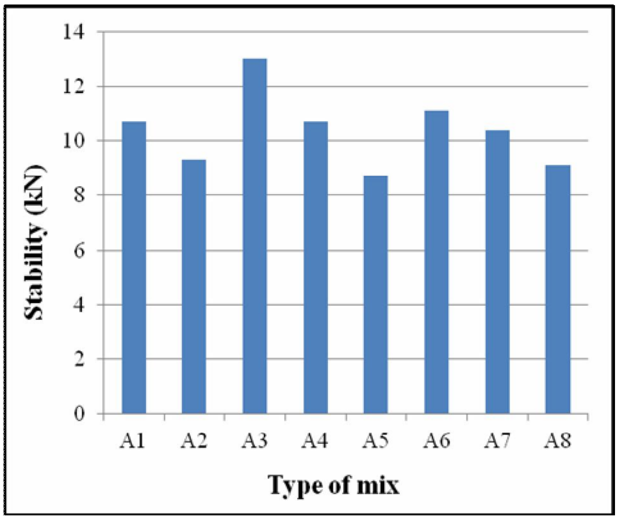

Figure (2) : Effect of type of mix on stability

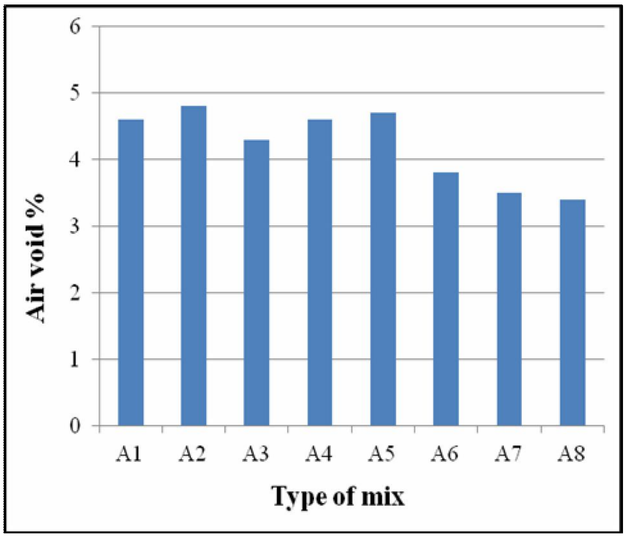

Figure (3) : Effect of type of mix on air void

Where:
A1: 6% Cement (Control)
A2: 6% limestone dust (Control).
A3: 5% Cement & 1% limestone dust .
A4: 4% Cement & 2% limestone dust .
A5: 3% Cement & 3% limestone dust .
A6: 4% Cement , 1% limestone dust & 1% hydrated lime.
A7: 3% Cement , 2% limestone dust & 1% hydrated lime.
A8: 2% Cement , 3% limestone dust & 1% hydrated lime.

Permeability Test :

- According to the Florida Department of Transportation (FDOT) the critical permeability value for the falling head permeater method is 125×10^{-5} cm/sec .
- The results of all mix except (control with 6% limestone dust)agree the mentioned specification .
- The using of cement as filler provide better permeability performance than that of limestone dust.

- The results of all mixes for all % of combination seems the same trends that may be the chemical composition of cement which contribute to less flow through path particles.
- While the using of hydrated lime as an additive , decrease significantly the permeability value. That ma be due to chemical composition & high fineness which contribute to less flow through paths particles. The results of permeability are shown in table (8) and figure (4):

Table (8) : Permeability test results

Type of Mixture	a (cm^2)	L (cm)	A (cm^2)	t (sec)	h_1 (cm)	h_2 (cm)	K (10^{-5}) (cm/sec)	T (^0C)	R_T	$K_{corrected}$ (10^-5) (cm/sec)
6% Cement (Control)	10.75	6.4	78.54	300	15	8.5	165.8	25	0.889	147.4
6% L.D (Control)	10.75	6.6	78.54	300	15	7.5	208.7	25	0.889	185.5
5% Cement & 1% L.D	10.75	6.3	78.54	300	15	10.2	110.0	25	0.889	97.8
4% Cement & 2% L.D	10.75	6.7	78.54	300	15	10.0	124.0	25	0.889	110.2
3% Cement & 3% L.D	10.75	6.4	78.54	300	15	9.1	148.0	25	0.889	129.8
4% Cement , 1% L.D & 1% HL	10.75	6.3	78.54	300	15	13.8	24.0	25	0.889	21.3
3% Cement , 2% L.D & 1% HL	10.75	6.7	78.54	300	15	14.1	19.0	25	0.889	16.9
2% Cement , 3% L.D & 1% HL	10.75	6.5	78.54	300	15	14.4	12.1	25	0.889	10.8

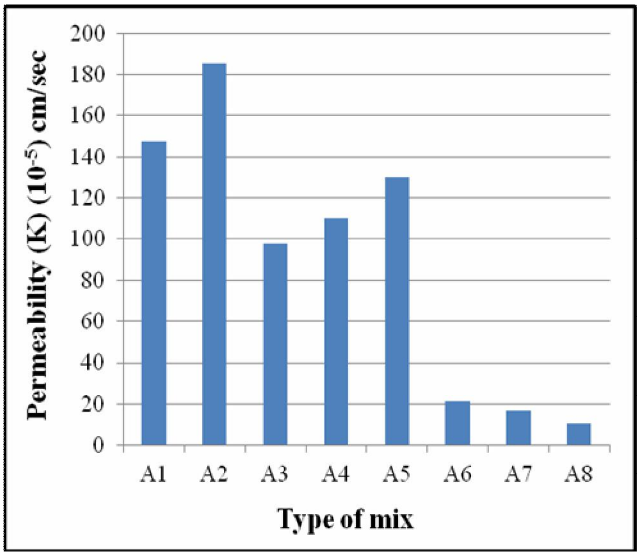

Figure (4) : Effect of type of mix on permeability

Indirect Tensile Strength :

The evaluation of tensile strength for asphaltic concrete mixture is important due to fact that the pavement will be exposed to various traffic loading and climatic condition . This is partially due to the fact in service pavement during service .These conditions cause tensile stresses to be developed within the pavement and as a result two types of cracks may be exhibited : one resulting from traffic loading , called fatigue cracking , while the other resulting from climatic conditions, called thermal or shrinkage cracking. As mentioned previously, one testing temperature has been conducted to evaluate the resistance of mixtures at (20 ^{0}C) . In tensile stress state, the mixture strength depends on the cohesion element (asphalt) in resisting stresses .

- For control mixes, the using of cement as filler provide better performance than that of limestone dust due to difference chemical composition .
- The results of all % of filler combination seems higher value than control once for indirect tensile strength .
- The addition of hydrated lime leads to slightly decrease in indirect tensile strength but still with better performance than control mix . The results of indirect tensile strength test are shown in table (9) and figure (5) :

Table (9) : Indirect tensile strength test results

Type of Mixture	*Thickness(mm)*	*Maximum Load (kN)*	*Tensile Strength(kPa)*
6% Cement (Control)	65	19.3	1.89
6% L.D (Control)	٦٦	18.4	1.77
5% Cement & 1% L.D	٦٣	22.3	2.25
4% Cement & 2% L.D	٦٧	20.1	1.91
3% Cement & 3% L.D	٦٤	19.5	1.94
4% Cement , 1% L.D & 1% HL	٦٦	21.1	2.03
3% Cement , 2% L.D & 1% HL	٦٥	20.6	2.02
2% Cement , 3% L.D & 1% HL	٦٣	18.7	1.89

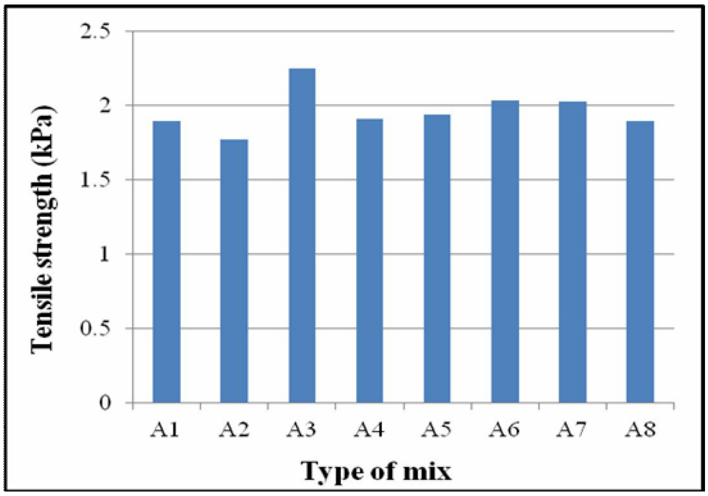

Figure (5) : Effect of type of mix on tensile strength

Conclusions :

- The filler as defined in this study is the material passing No. 200 sieve which play physicochemical role on HMA behavior .
- For stability test as an indication on rutting problem, using cement as filler provide better performance than that of limestone dust. While the best combination was (1% limestone dust, 5% cement) which increased stability value of 1.3 times. The addition of (1% hydrated lime) for HMA mixture with filler combination slightly decreased the stability value of 1.15 times and decreased significantly the % air voids of 1.25 times .
- For permeability test as an indication on moisture damage problem, using cement as filler provide better performance than that of limestone dust. The use of (1% hydrated lime) as an additive to HMA with filler combination decreased significantly the permeability value of 5.5 times.
- For indirect tensile strength test an indication on fatigue cracks., Also the using of cement as filler provide better performance than that of using limestone dust. The best combination (1% limestone dust, 5% cement) with or without hydrated lime addition increased the indirect tensile strength value of 1.2 times.
- The use of limestone dust as partial replacer of cement or hydrated lime as additive was better for cost estimation of the HMA.
- Almost The best recommended percentage of filler combination and addition was (4% p. cement + 1% limestone dust and 1% hydrated lime as an additive).

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