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Research Article

Effect of Filler Type on the Durability of Asphalt Concrete Mixes

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Abstract

Mineral filler is the finest fraction of aggregate (smaller than 75 gm) used in the production of asphalt paving mixed. It is essential for producing a mixture that is dense, cohesive, durable, and resistant to water penetration. In spite of the fact that filler is very small proportion of the total aggregates in the mix, due to its rather high affinity for asphalt, the changes in the type of the filler can cause the paving mixture to perform satisfactorily during the design life or deteriorate rapidly under the effect of traffic and environmental impact. The objective of this study is to investigate the effect of mineral filler types (three types, limestone dust, Portland cement and hydrated lime) in the durability of asphalt concrete mixture. To achieve the objective of this study, Marshall mix design method was utilized to produce asphalt concrete mixes at their optimum asphalt content. The mixes were, then, tested to investigate their durability properties including moisture damage and fatigue characteristics. The results indicated that the mixes prepared with hydrated lime have superior resistance to moisture damage in comparison with Portland cement and lime stone dust. On the other hand, the mixes prepared with Portland cement type of filler showed better resistance to the fatigue failure of asphalt concrete pavement.

Keywords: *Asphalt concrete, Filler, Lime stone, Portland cement, Hydrated lime, Durability.*

1. Introduction

Asphalt concrete (sometimes referred to as “Hot Mix Asphalt” or simply “HMA”) is a paving material that consists of asphalt binder, aggregate and mineral filler. The asphalt binder, which can be asphalt cement or modified asphalt cement, acts as a binding agent to glue aggregate particles into cohesive mass. Because it is impervious to water, the asphalt binder also functions to waterproof the mixture. When bound by the asphalt binder, aggregate and mineral filler acts as a stone framework to impart strength and toughness to the system. Because HMA contains both asphalt binder and mineral aggregate, the behavior of the mixture is affected by the properties of the individual components and how they react with each other in the system (Albayati, 2006).

In the design of asphalt concrete mixture, it is generally agreed that a balance be obtained between a number of desirable mix properties that, inevitably, necessitates a compromise in the selection of the design asphalt cement content. These pertinent mix properties include the following:

1) Stability- resistance to deformation under load.
2) Durability- resistance to weathering.
3) Flexibility-ability to conform to long-term variations in base and subgrade elevations.
4) Fatigue resistance- ability to minimize cracking due to load repetitions.
5) Skid resistance- sufficient friction to enable a vehicle to brake to a stop within a reasonable distance under a variety of environmental conditions.
6) Fracture strength- maximum strength a mix exhibits when subjected to tensile forces.

Of particular interest is the durability which represents the resistance to stripping, i.e., the moisture damage and the fatigue resistance (Albayati, 2006).

Many studies conducted by researchers to capture the effect of filler on the performance of asphalt concrete, some of these researches focuses on the filler/asphalt ratio whereas the other concentrated on the available filler types either naturally or synthetically (like limestone dust, fly ash, Portland cement, steel slag, etc.). Asmael (2010) investigated the effect of using different types of fillers (ordinary Portland cement, lime stone powder, and waste glass powder) and contents (4%, 6% and 8% by weight of total aggregates) on Marshall properties of hot asphalt concrete mixtures. Specimens were prepared according to (SORB/R9) using the Optimum Asphalt Content (O.A.C.). The researcher found that the addition of glass powder of 6 % on the hot asphalt

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concrete mixtures leading to increase the Marshall stability by 15.5 % and 9.2 % compared with ordinary Portland cement and lime stone powder respectively. While the flow decreases by 14.5% and increased by 4.4 % compared with ordinary Portland cement and lime stone powder respectively.

(Albayati, 2012), (Little, *et al*, 2006), (Sebaaly, *et al*, 2001), (Albayati and Ahmed, 2013), and (Al-Tameemi, *et al*, 2016) have found that asphalt concretes with added hydrated lime showed a reduction of hardening age, and an increase of flexural stiffness and resilient modulus at moderate and high temperatures. These studies also found that the modified asphalt concretes had improved durability, including the ability to resist permanent deformation. Hydrated lime as a partial conventional filler substitute also displayed a significant effect on the volumetric properties of the concrete mixtures. It also was found that a high hydrated lime content corresponds with a high asphalt content for the mixtures of optimum properties. Wasilewska *et. al.*, (2017) studied the properties of fillers obtained from different sources. Five types of rocks were used as a source of the mineral filler aggregate: granite, gabbro, trachybasalt, quartz sandstone and rocks from postglacial deposits beside the limestone filler which was used as the reference material. They found that characteristics of those types of fillers are comparable with the features of limestone filler. The researcher stated that the use of other powders than limestone-based materials is an economically justified solution particularly in the countries where limestone powder is not produced. Kiflat (2013) evaluated the compatibility and resistance against rutting of asphalt concrete mixtures with respect to changes both in filler type and properties, three filler type were investigated: two silica-based fillers (fine and coarse) and fly ash. The conclusion stated by the researcher is that the silica-based filler showed better resistance against rutting than fly ash, although they required more compaction energy during construction. Also, the fine type of silica-based filler showed better resistance to rutting than the coarse type of silica-based filler.

2. Material characterization

The materials used in this work, namely asphalt cement, aggregate, and fillers were characterized using routine type of tests and results were compared with state corporation for roads and bridges specifications (SCRB, R/9 2003).

2.1 Asphalt cement

The asphalt cement used in this work is of 40-50 penetration grade. It was brought from the Dora refinery, south-west of Baghdad. The asphalt properties are shown in Table (1) below.

Table 1 Properties of Asphalt Cement

Property	ASTM designation	Penetration grade 40-50	
		Test results	SCRB specification
1- Penetration at 25°C, 100 gm, 5 sec. (0.1mm)	D-5	47	40-50
2- Rotational viscosity at 135°C (cP.s)	D4402	519	___
3- Softening Point, (°C)	D-36	51	___
4- Ductility at 25°C, 5cm/min, (cm)	D-113	>100	>100
5- Flash Point, (°C)	D-92	289	Min.232
6- Specific Gravity	D-70	1.041	___
7- Residue from thin film oven test: - Retained penetration, % of original - Ductility at 25°C, 5cm/min, (cm)	D-1754 D-5 D-113	59.5 80	> 55 > 25

2.2 Aggregate

The aggregate used in this work was crushed quartz obtained from Amanat Baghdad asphalt concrete mix plant located in Taji, north of Baghdad, its source is Al-Nibaie quarry. This aggregate is widely used in Baghdad city for asphaltic mixes. The coarse and fine aggregates used in this work were sieved and recombined in the proper proportions to meet the wearing course gradation as required by SCRB specification (SCRB, R/9 2003). The gradation curve for the aggregate is shown in Figure (1).

Routine tests were 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). Tests results show that the chosen aggregate met the SCRB specifications.

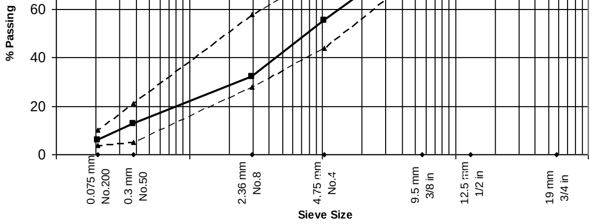


Fig.1 Aggregate Gradation

Table 2 Physical Properties of Aggregates

Property	ASTM designation	Test results	SCRB specification
Coarse Aggregate			
1- Bulk specific gravity	C-127	2.623	___
2- Apparent specific gravity	___	2.692	___
3- Water absorption, %	___	0.433	___
4- Percent wear by Los Angeles abrasion, %	C-131	18.0	30 Max
5- Soundness loss by sodium sulfate solution, %	C-88	4.3	12 Max
6- Fractured pieces, %	D5821	97	90 Min
Fine Aggregate			
1- Bulk specific gravity	C-127	2.667	___
2- Apparent specific gravity	___	2.694	___
3- Water absorption, %	___	0.809	___
4- Sand equivalent, %	D-2419	59	45 Min
5- Clay lumps and friable particles, %	C142	1.2	3 Max

2.3 Filler

Three types of filler were used for the production of asphalt concrete mixtures, these are; limestone dust, Portland cement and hydrated lime. The chemical composition as well as the physical properties of these fillers is shown in Table 3. The limestone dust and hydrated lime were supplied to the mixing plant from lime factory in Kerbala governorate, south east of Baghdad. Whereas the Portland cement supplied from Almas factory in Sulaimanya governorate, north of Iraq.

Table 3 Properties of Fillers

Filler type	Chemical Composition, %						
	CaO	SiO_2	Al_2O_3	MgO	Fe_2O_3	SO_3	L.O.I
Limestone	29	10	6	16	1	0.12	37
Portland cement	54	20	6	2	1	0	17
Hydrated Lime	69	1	_	2	_	0.15	27

Table 3 Properties of Fillers, Continued

Filler type	Physical Properties		
	Specific gravity	Surface area* (m^2/kg)	% Passing sieve No. 200 (0.075)
Limestone	2.84	247	95
Portland cement	3.14	290	98
Hydrated Lime	2.43	395	99

* Blain air permeability method (ASTM C204)

3. Experimental work

The experimental work was started by determining the optimum asphalt content for all the asphalt concrete mixes using the Marshall mix design method. Then, asphalt concrete mixes were made at their optimum asphalt content and tested to evaluate the durability properties which include moisture damage and fatigue characteristics. These properties has been evaluated using indirect tensile strength and repeated flexural beam tests.

3.1 Marshall mix design

A complete mix design was conducted using the Marshall method as outlined in AI's manual series No.2 (AI, 1981) using 75 blows of the automatic Marshall compactor on each side of specimen. Based upon this method, the optimum asphalt content is determined by averaging the three values shown below:

- Asphalt content at maximum unit weight
- Asphalt content at maximum stability
- Asphalt content at 4% air voids

For each type of filler, five Marshall specimens were prepared with different asphalt content. For the mixes with limestone dust, Portland cement and hydrated lime, the following asphalt cement contents (percent by weight of total mix) were used (4.1, 4.4, 4.7, 5.0 and 5.3 percent), (4.4, 4.7, 5.0, 5.3 and 5.6) and (4.7, 5.0, 5.3, 5.6 and 5.9), respectively. The starting asphalt cement content differs for each type of filler since it was noticed earlier during the mix design that some low asphalt cement contents did not provide the proper coating for aggregate in case of Portland cement and hydrated lime mixes.

3.2 Indirect tensile test

ASTM D 4867 was utilized to assess asphalt concrete sensitivity to moisture. A total of six samples were implemented to obtain both the indirect tensile strength and also the tensile strength ratio. The samples were grouped into two categories; the first category was labeled as "reference samples" and evaluated under 25°C while the second group "treated samples" was exposed to a round of freezing and then thawing before testing them at 25°C.

All samples were produced based on Marshall criteria and compacted to air voids of 7±1%. The test presented in Fig. (2) utilized a 0.5-inch-wide steel plate that was shaped over the specimen width to be used for applying the load. The vertical compressive force acting along the diameter of the samples, as shown in Fig. (2), was applied at a pace of (50.8mm/min) until the splitting of the samples occurred. Eq. (1) shown below was utilized to compute the indirect tensile strength while Eq. (2) is employed to obtain the tensile strength ratio:

$$ITS = \frac{2P}{\pi t D} \qquad (1)$$

$$TSR = \frac{ITS_c}{ITS_d} \qquad (2)$$

Where:
ITS_c , ITS_d = Indirect tensile strength for reference samples and treated samples respectively.
P = Ultimate applied load.
t = Thickness of specimen.
D = Diameter of specimen.

Fig.2 ITS testing

3.3 Flexural Beam Fatigue test

Within this study, third-point flexural fatigue bending test was adopted to evaluate the fatigue performance of asphalt concrete mixtures using the pneumatic repeated load system, this test was performed in stress-controlled mode with flexural stress level varying from 5 to 30 percent of ultimate indirect tensile strength applied at the frequency of 2 Hz with 0.1s loading and 0.4s unloading times and in rectangular waveform shape. All tests were conducted as specified in SHRP standards at 20°C (68°F) on beam specimens 76 mm (3 in) x 76 mm (3 in) x 381 mm (15 in) prepared according to the method described in (Al-khashaab, 2009). In the fatigue test, the initial tensile strain of each test has been determined at the 50th repetition by using (Eq.3) shown below and the initial strain was plotted versus the number of repetition to failure on log scales, collapse of the beam was defined as failure, the plot can be approximated by a straight line and has the form shown below in (Eq. 4).

$$\varepsilon_t = \frac{\sigma}{E_s} = \frac{12h\Delta}{3L^2 - 4a^2} \qquad (3)$$

$$N_f = k_1(\varepsilon_t)^{-k2} \qquad (4)$$

Where:
$\mathcal{E}_t$ = Initial tensile strain.
σ = Extreme flexural stress.
E_s = Stiffness modulus based on center deflection.
h = Height of the beam.
Δ = Dynamic deflection at the center of the beam.
L = Length of span between supports.
a = Distance from support to the load point (L/3).
N_f = Number of repetitions to failure.
k_1 = Fatigue constant, value of N_f when $\mathcal{E}_t$ =1.
k_2 = Inverse slope of the straight line in the logarithmic relationship.

4. Test results and discussion

4.1 Marshall Properties

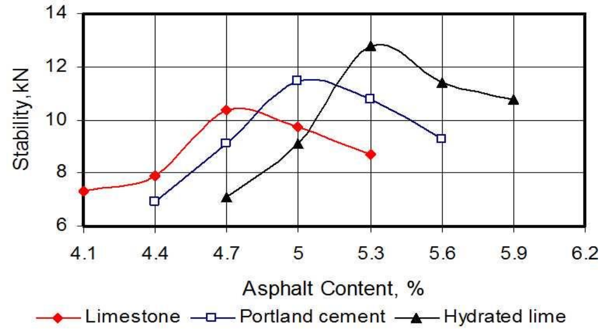
Based on the Marshall design procedure outlined in paragraph (3.1), the variations of asphalt cement content were plotted against each of the Marshall properties to calculate the optimum asphalt content (OAC) and the results are shown in the figure (3) below. After calculating the OAC, a new set of Marshall specimens were prepared at the OAC and the results were presented in table (4) below.

Examinations of the presented data suggest that the mixes with hydrated lime filler possess the highest optimum asphalt cement content (5.3 %), whereas the optimum asphalt cement contents for the mixes with Portland cement and limestone are (5%) and (4.7 %), respectively. Logically, this can be attributed to the fine grain size of the hydrated lime filler in comparison with the Portland cement as well as limestone fillers.
The stability results indicate that all the specimens satisfy the minimum stability requirement presented in the SCRB specification (8 kN). The stability value for limestone mix was lower than that of Portland cement and hydrated lime by 10.6 percent, and 23.7 percent, respectively. The highest stability value (12.8 kN) belong to hydrated lime mix.

Based on the Marshall flow values, the mix with limestone dust has the highest value in comparison with Portland cement and hydrated lime mixes, the flow value for hydrated lime mix is lower than that of Portland cement and Limestone by (6 percent) and (10 percent), respectively. This could be attributed to the higher air voids value for the mixes with hydrated lime as compared to Portland cement and Limestone mixes. Nevertheless, all the flow values that belong to different types of filler satisfy the requirement for the SCRB specification flow requirement (2-4 mm).

Table 4 Marshall Properties of mixes at optimum asphalt content

Filler Type		Limes-tone	Portland cement	Hydrated lime	SCRB Specification
Marshal Properties	OAC, %	4.7	5.0	5.3	4-6
	Stability, kN	10.35	11.45	12.80	Min. 8
	Flow, mm	3.3	3.2	3.0	2-4
	Density, gm/cm³	2.333	2.338	2.343	—
	Air Voids, %	4.13	3.98	3.88	3-5
	VMA, %	14.7	14.9	15.3	Min. 14



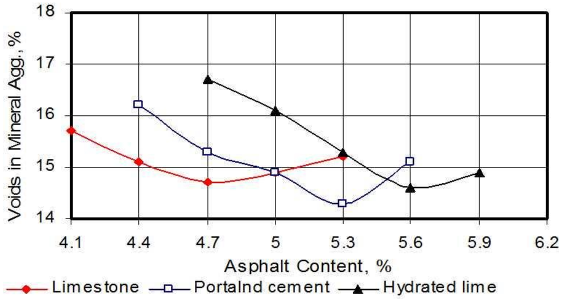
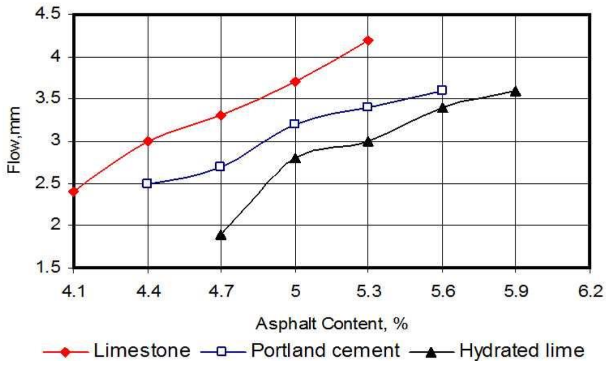
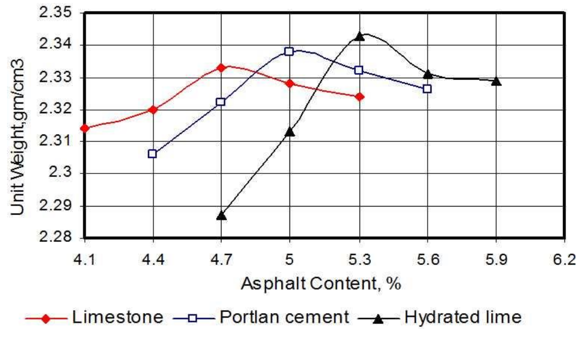
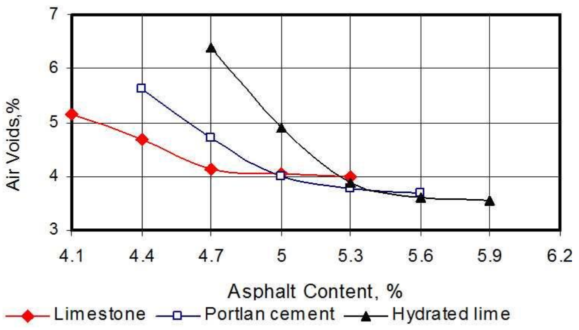


Fig.3 Marshall properties plots







In view of density results, generally the mixes with hydrated lime filler have higher density than mixes prepared with the Portland cement and limestone, this could be attributed to the ability of the fine grains of hydrated lime as compared to other type of fillers to infiltrate onto the voids pockets and hence increase the mass of the unit volume. As demonstrated in the filler type trend with air void values, which exactly has the same trend as per the flow, the average air void values for hydrated lime mixes is the lowest one (3.88 percent) followed by the Portland cement and then limestone dust. All the air voids values for mixes with different type of fillers are within the range of SCRB specification requirement (3-5 percent). Based on the voids in mineral aggregate (VMA) results, the mixes with limestone dust have had the lowest value (14.7 percent) as compared to the mixes with Portland cement and hydrated lime fillers. These results indicate that the compaction level achieved by this type of filler is better and the high spaces to be accommodated by asphalt cement. All the VMA values are satisfy the requirement of SCRB specification (Min. 14 percent).

4.2 Moisture Susceptibility

Based on the data shown in Table (5) and Figure (4), it appears that the examined filler types have influence on the moisture susceptibility of the asphalt concrete mixes. It's obvious that the hydrated lime mixes less susceptible to moisture damage than mixes with Portland cement and limestone filler. The average tensile strength ratio (TSR) for the hydrated lime mixes (94 percent) is higher than that of Portland cement and limestone filler by approximately 7 and 10 percent, respectively. Reminding that the minimum acceptable limit for the TSR is 80 percent, it's clear that the all the mixes satisfy the specification requirement for this type of damage but the mixes with hydrated lime filler is superior in this regard. The indirect tensile strength results for both control and conditioned mixes approximately linearly proportional to the filler type with constants of proportionality of +71.3 for the former and +105.3 kPa per change in filler type from limestone to Portland cement and then hydrated lime. These findings beside that related to tensile strength ratio shown in figure (4) confirm that the resistance to moisture induced damage is enhanced in asphalt concrete pavement contained hydrated lime. The obtained results are comparable with (Albayati, 2018).

Table 5 Moisture susceptibility test results

Filler type	ITS, kPa		TSR, %
	Control	Conditioned	
Limestone	1042	865	83
Portland cement	1180	1039	88
Hydrated Lime	1256	1181	94

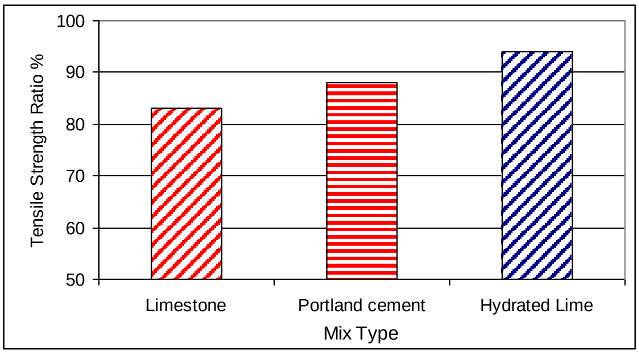


Fig.4 Effect of hydrated lime content on tensile strength ratio

4.3 Fatigue Performance

The fatigue characteristic curves for all mixtures are presented in Fig. 5. The fatigue parameters k_1 and k_2 are shown in Table 6. Values of k_1 and k_2 can be used as indicators of the effects of filler type on the fatigue characteristics of a paving mixture. The flatter the slope of the fatigue curve, the larger the value of k_2. If two materials have the same k_1 value, then a large value of k_2 indicates a potential for longer fatigue life. On the other hand, a lower k_1 value represents a shorter fatigue life when the fatigue curves are parallel, that is, k_2 is constant. As per the presented data in table 6, the mix with Portland cement filler has the lowest value of k_1 (1.24E-09) in comparison with the hydrated lime and the limestone dust. The highest k_2 value belong to the Portland cement, the k_2 value for the mix with Portland cement is higher than that of hydrated lime and limestone fillers by 13.9 and 21.3 percent, respectively. Collectively, the above results beside that presented in Fig. 5 revealed that the mixes with Portland cement type of filler has the ability to perform superior in resisting the fatigue failure of asphalt concrete pavement. The average number of load repetitions per the stress levels to cause a fatigue failure of mixes with Portland cement is 1.36 and 1.2 times that of limestone and hydrated lime fillers, respectively.

Table 6 Fatigue test results

Filler type	Limestone	Portland cement	Hydrated Lime
k_1	2.621E-07	1.24E-09	3.85E-08
k_2	2.66	3.38	2.91

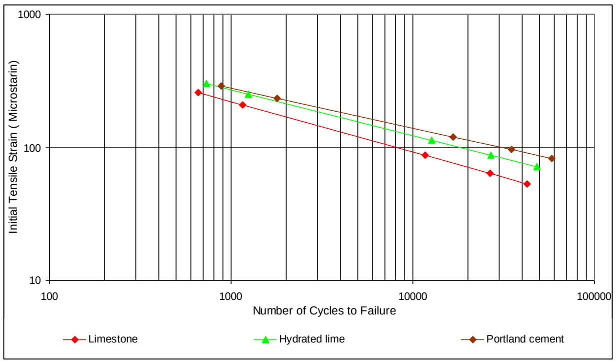


Fig.5 Effect of Filler types on fatigue performance

Conclusions

According to the presented works in this research and within the limitation of test program and the materials used, the following salient conclusions can be drawn.

1) The Marshall properties at optimum asphalt cement content showed that the mixes with three types of examined filler types (limestone dust, Portland cement and hydrated lime satisfy the requirement of the local SCRB specification.
2) Mixes with hydrated lime filler possess the highest optimum asphalt cement content (5.3 %), whereas the optimum asphalt cement contents for the mixes with Portland cement and limestone are (5%) and (4.7 %), respectively.
3) The highest Marshall stability value (12.8 kN) belong to hydrated lime. The stability value for limestone mix was lower than that of Portland cement and hydrated lime by 10.6 percent, and 23.7 percent, respectively.
4) Although All the air voids values for mixes with different type of fillers are within the range of SCRB specification requirement (3-5 percent), but the average air void values for hydrated lime mixes is the lowest one (3.88 percent) followed by the Portland cement and then limestone dust.
5) The hydrated lime mixes less susceptible to moisture damage than mixes with Portland cement and limestone filler. The average tensile strength ratio (TSR) for the hydrated lime mixes (94 percent) is higher than that of Portland cement and limestone filler by approximately 7 and 10 percent.

6) The mixes with Portland cement type of filler has superior resistance to the fatigue failure of asphalt concrete pavement. The average number of load repetitions per the stress level to cause a fatigue failure of mixes with Portland cement is 1.36 and 1.2 times that of limestone and hydrated lime fillers, respectively.

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