Table 5. Accident statistics for various roadways with open-graded applications.

Condition	Section	Total Accidents	Period (years)	ADT	Accidents per Million Vehicles	SN and Date
No overlay	NB I-91 (before)	69	2.5	24 500	3.09	38.7, 1974
	NB I-91 (after)	98	5	29 400	1.83	47.3, 1980
No overlay	SB I-91 (before)	98	2.5	27 000	3.98	38.5, 1975
	SB I-91 (after)	165	5	32 100	2.82	47.3, 1980
3/8-in OGFC	EB I-95 (before)	124	5 + 7 months	13 800	4.409	35.0, 1975
	EB I-95 (after)	104	2 + 10 months	14 900	6.750	47.7, 1981
1/2-in OGFC	EB I-95 (before)	69	5 + 7 months	13 600	2.490	35.0, 1975
	EB I-95 (after)	43	2 + 10 months	14 400	2.887	48.2, 1981

CONCLUSIONS

Based on the above discussion, the following general conclusions can be drawn. As a skid-resistant surface under heavy traffic, OGFCs have performed well in Connecticut for periods of up to six years. Compared with other ConnDOT mixes used for overlays, OGFC appears to be equal in terms of resistance to reflective cracking. The lateral-internal-drainage characteristics of OGFC have been shown to decrease with time. This decrease is primarily attributed to the use of winter deicing chemicals and abrasives. Due to the short lengths of the three test sections on I-91, no conclusive statements can be made regarding the effect of layer thicknesses on the performance of OGFC mats. In this connection, however, it should be pointed out that the standard ConnDOT design consisting of 0.75-in OGFC on a 2-in dense-graded surface has performed well to date.

ACKNOWLEDGMENT

The project reported in this paper was carried out with the cooperation of the Federal Highway Administration, U.S. Department of Transportation. The contents of this report reflect my views and I am responsible for the facts and accuracy of the data presented here. The contents do not necessarily reflect the official views or policies of the Connecticut Department of Transportation or of the Federal Highway Administration. The report does not constitute a standard, specification, or regulation.

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Effects of Baghouse Fines and Mineral Fillers on Properties of Asphalt Mixes

BASSAM A. ANANI AND HAMAD I. AL-ABDUL-WAHHAB

The objective of this study was to determine the effects of baghouse fines on asphalt mixes. The analysis included Marshall tests on mixes that had various ratios of filler to baghouse fines. Other tests to study these effects included stability loss, viscosity, penetration, shear-modulus, and softening point. The results of the study indicated that baghouse fines can greatly affect the properties of the mix, such as the optimum asphalt content, stability, and stability loss. Asphalt mortars that used different ratios of filler to baghouse fines exhibited varied viscosity and penetration. Stability loss, which is a main factor in the design of local mixes, was decreased drastically by the inclusion of baghouse fines. One factor that controls the effect of baghouse fines on asphalt mixes was the percentage of carbon. It is anticipated that the results of this study will be of great help in the improvement of mix properties by incorporating baghouse fines.

Pavement systems in the Eastern Province of the Kingdom of Saudi Arabia are exposed to a multitude of severe environmental factors, mainly the high temperature and the high humidity. Roads usually show excessive failures at an early stage of pavement life. Other factors that contribute to the early failure are the extremely heavy axle loads applied to the roads of this province. There is currently no enforcement of the maximum loads permitted on an axle or of the tire pressures. Another major contributor to failure is the low quality of local materials used for highway construction. For ex-

ample, aggregates used for the bituminous-concrete base course are known to be of low quality. Experience with such material has indicated excessive stripping and high absorption. Local aggregates were observed to expand greatly when soaked, which results in fracture of the aggregates. This is manifested in the roads by the excessive ravelling and existence of small cavities in the road surface caused by the deterioration of the aggregates.

Saudi Arabia is starting a new era of highway construction. Virtually thousands of miles of new, modern highways are under construction, and there will still be a great need for more highways in the near future. The asphalt industry has also begun to expand. Asphalt plants are more abundant now than ever, and the pollution potential from dust emitted from the hot-aggregate elevators, plant screens, bins, hoppers, and pug mills of these plants is becoming more eminent. This dust pollution has already caused major problems for farms located near asphalt plants. An asphalt plant that operates at a rate of 100-200 tons/h will generate about 3000 lb/h of dust, or 50 lb/min.

A major step in the improvement of the existing performance of roads is ensuring a proper mix design. It is anticipated that some of the failures discussed earlier may be attributed to the poor design of the asphalt mixes. The existence of varied properties for local materials requires different mix designs. Fillers used in the mix design are known to have an effect, especially on the optimum asphalt content. The amount of filler used in the plant mixes affects the properties of the mix produced. However, it is not possible to establish the exact amount of this filler due to the loss of fines in the form of dust from the plant.

The large quantities of dust in the air from the asphalt plants have been of great concern to local authorities and farmers. Dust collectors have been incorporated into certain asphalt plants to ensure collection of the dust. This collection dust (referred to as "baghouse fines" in this report) is produced in large quantities from every plant, which causes yet another problem--disposal of the baghouse fines.

A possible solution to the problem of disposal and regulation of the amount of fines in the mixes would be reintroduction of the baghouse fines into the mix. However, the amounts used should be determined in such quantities to ensure a properly designed mix.

The objectives of this study can be summarized as follows:

1. To evaluate the existing mix designs that use local aggregates,
2. To evaluate the effects of introducing baghouse fines into the asphalt mix,
3. To study various characteristics of the new asphalt mixes that incorporate baghouse fines, and
4. To study the effects of baghouse fines and filters on the stability loss of the asphalt mixes.

The results of this study are applicable to mix designs that use aggregates from the Damman, Abohadryyah, and Riyadh. The baghouse fines used were collected from two different sources, namely, Riyadh and Abohadryyah. The Marshall test was used exclusively for the mix design.

DUST COLLECTOR SYSTEMS

Dust collectors have been introduced in asphalt plants to reduce the amount of solids emitted into the air. The main function of such a collector is first to separate the dust from the gas stream in the plant and then to collect this fine material. Certain rules have been reinforced in some countries to guarantee that the amounts emitted do not exceed maximum limits. Currently no such regulations exist in Saudi Arabia.

There are three general types of dust collectors in use: mechanical centrifugal separators, wet collection systems, and secondary collectors. The last consists of two different kinds: electrostatic filters and fabric filters. Asphalt plants in Saudi Arabia that incorporate such dust collectors use several different types. However, due to the shortage of water and electricity, most plants have adopted either the centrifugal or the fabric-filter types. The cyclonic separator was used to collect the baghouse fines used in this study from the Riyadh plant.

Dust collected from the Abohadryyah plant consists of two distinct types. The first, referred to here as AB.BH.1, is collected by using multiclone separators. These consist of a series of small cyclones arranged together to give an increased capacity. The second type of dust, referred to here as AB.BH.2, is collected by using the fabric-filter separators (1). These separators use fabric filters as the heart of the collection system. The exhaust gases are cleaned by passing the air through a fabric that captures the dust particles. The filters are narrow, long, and baglike, dressed on steel cages. These baghouses are arranged in several groups. The filtering process is conducted by sucking the air from the inside of the bags by using a high-power turbine. This will cause gases to go through the fabric and leave the dust on the outside of the bags.

Fuels are used in the asphalt plants to dry the aggregates before they are mixed with hot asphalt. The effect of the type of fuel used on the performance of the separator could be appreciable. The carbon that results from burning certain fuels will increase the amount of fines that the dust collectors must remove. This might result in clogging the bags in the fabric-filter separator.

Baghouse fines collected from Abohadryyah have shown that approximately 7.0 percent is carbon from the burning of diesel fuel, which is the fuel used in the plant. Excessive sulfur in the fuel can also cause damage to fabric filters (2).

MATERIAL CHARACTERIZATION

This section gives the results of tests to determine the characteristics of the material used in this study, namely, asphalt, aggregates, fillers, and baghouse fines.

Asphalt

Asphalt that had a 75-100 penetration grade was used for all mixes. It was brought from the Ras-Tanura refinery. A series of tests was performed to determine the basic properties of the asphalt. Results of asphalt characterization are given below. The properties measured indicate that the asphalt meets the specifications of the American Society for Testing and Materials (ASTM):

Property	Amount
Penetration (100/5) at 77°F	82
Ductility (cm)	100
Flash point (°F)	625
Specific gravity, 77°F	0.97
Softening point (ball and ring) (°F)	70

Aggregates

Three different types of aggregate were used in this study. The first type was gravel and natural sand obtained from Riyadh, the second was limestone and natural sand from Damman, and finally limestone and natural sand from Abohadryyah. The gradation of the three aggregates is shown in Table 1. As indicated, the gradation was not very different for the three sources. The maximum size for the Riyadh aggregate was 1/2 in, whereas it was 3/4 in for the others. The different sizes of each aggregate were blended to meet the ASTM specifications. Figure 1 gives the gradation of the blend of each aggregate as compared with ASTM specifications.

Specific gravity was determined for each aggregate type when no appreciable difference was observed. However, absorption tests indicated that Abohadryyah aggregates had high absorption values when compared with Riyadh aggregates, which clearly showed very low absorption. Abrasion tests indicated a similar trend. Results of these tests are given in Table 2.

Table 1. Job-mix formula: sieve analysis.

	Aggregate (% passing)			
Sieve Size	Damman	Riyadh	Abohadryyah 1	Abohadryyah 2
3/4 in	100	-	100	100
1/2 in	92	100	91.5	91.5
3/8 in	81	80.0	82.5	82.5
No. 4	54	56.0	59.5	59.5
No. 10	38	39.0	36.5	36.5
No. 40	23	25.0	24.0	24.0
No. 80	15	12.5	13.0	13.0
No. 100	4-15	10.0	10.0	10.0
No. 200	-	6.5	6.8	6.8

Figure 1. Gradation of aggregate mixes.

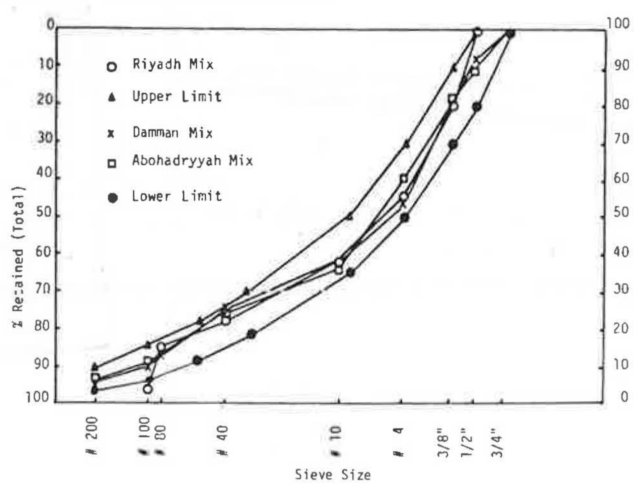


Table 2. Job-mix formula: other tests.

	Aggregate			
Property	Damman	Riyadh	Abohadryyah 1	Abohadryyah 2
Specific gravity				
Bulk	2.54	2.62	2.57	2.57
Apparent	2.79	2.69	2.68	2.68
Asphalt (%)	0.87	0.49	1.25	1.25
Absorption				
Water (%)	3.1	0.9	1.9	1.9
Abrasion (%)	31.2	23.1	28.8	28.8

Fillers

Two different fillers were used--one from the Damman area and one from Abohadryyah. Damman filler was used with the Damman aggregate, whereas Abohadryyah filler was used with both the Riyadh gravel and the Abohadryyah aggregate. Fillers used passed the No. 100 sieve.

Hydrometer analysis was conducted on the fillers. The specific gravity of the fillers was determined by using the vacuum method. The gradation based on the hydrometer test is given in Table 3 and Figure 2. Determination of the plasticity index showed that the fillers are nonplastic. The same conclusion was obtained from the chemical analysis to determine the amount of plastic material in the filler.

Baghouse Fines

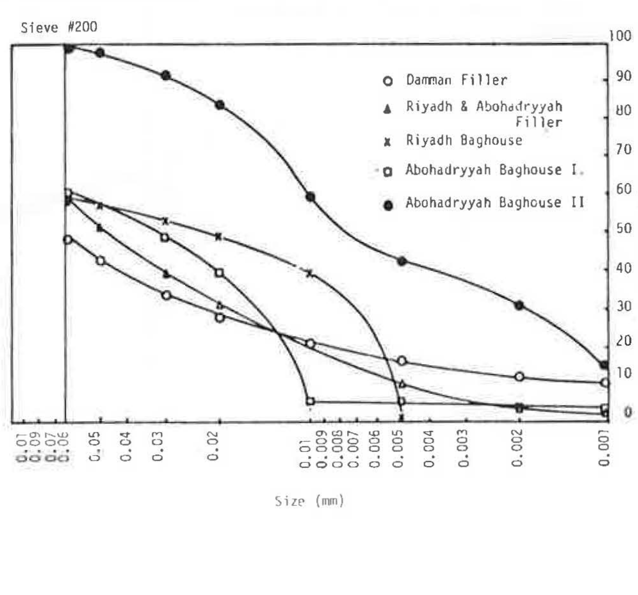
Baghouse fines are the airborne particles separated from the gas stream on a baglike filter. Hydrometer analysis was performed on the different types of baghouse fines; the results are given in Table 4. It is clear that AB.BH.2 was finer than the other baghouse fines, as shown in Figure 2. It should also be noted that Abohadryyah baghouse fines contain some carbon from oil used in the drying process. Specific gravities were determined for the three baghouse fines. AB.BH.2 has a slightly lower unit weight (by 1.1 lb/ft^3).

Table 3. Hydrometer analysis of fillers.

	Filler (% finer)	
Sieve and Grain Size	Damman	Riyadh and Abohadryyah
No. 100	100	100
No. 200	48	59
0.05	43.3	51.0
0.04	38.9	48.3
0.03	34.5	40.7
0.02	28.8	33.0
0.01	24.0	19.4
0.009	23.0	18.2
0.007	19.2	15.9
0.005	16.3	11.2
0.003	12.4	5.3
0.001	10.5	4.1

Note: Specific gravity for both fillers was 2.73; both fillers were nonplastic.

Figure 2. Gradation analysis for fillers and baghouse fines.



Plasticity-index determinations on Riyadh baghouse fines and AB.BH.1 showed them to be nonplastic, whereas AB.BH.2 had a plasticity index of about 10. Carbon was separated from AB.BH.1 and AB.BH.2 by using a 2 percent diluted acid. It was found that AB.BH.1 contained about 0.4 percent carbon, whereas AB.BH.2 contained about 6 percent carbon. Separated carbon was washed by using sweet water, dried at 100°C, and then stored in a dry place for further analysis.

ASPHALT MORTARS

To study the effect of adding filler and baghouse fines to asphalt, a series of tests was performed on the asphalt mortars. Baghouse fines (BH) were mixed with filler (F) at different ratios, namely, F/BH = 100/0, 50/50, 65/35, 80/20, and 0/100. Asphalt was added to each of these ratios at different percentages, and penetration tests were done on the mortars. Figure 3 indicates that penetration decreases as the percentage of baghouse fines increases when log penetration versus the ratio of filler to baghouse fines was plotted. The penetration decreases as the ratio of filler to baghouse fines increases. It was observed that using Abohadryyah baghouse fines will cause more reduction in penetration than using Riyadh baghouse fines (Figure 4).

A softening-point test was conducted on asphalt/baghouse fines and mortars. The results are given in Figure 5. It was found that there is a tremendous increase in the softening point of AB.BH.2 mortar, which could have been caused by carbon. To investigate this, carbon was mixed at different percentages with asphalt and the softening-point tests were done. The results affirmed the above assumption. The softening point of asphalt mixed with carbon was found to increase at a higher rate than that with AB.BH.2. This effect is again shown in Figure 5.

The effect of carbon was investigated further by using a sliding-plate rheometer. The same mortars were tested for shear modulus and viscosity. The spacing of the two plates for the test was 6 mm and the temperature for testing was 25°C. The results, given in Figures 6 and 7, indicate that shear modulus and viscosity for baghouse fines are higher than those for the fillers. Moreover, carbon causes an increase in the viscosity of asphalt. Carbons that have a tremendous surface area cause a rapid increase in asphalt viscosity. It is quite difficult

Table 4. Hydrometer analysis of baghouse fines.

Sieve and Grain Size	Baghouse Fines (% finer)		
	Riyadh	Abohadryyah 1	Abohadryyah 2
No. 100	90.3	86.8	100
No. 200	59.4	60.6	99.8
0.05	55.9	56.1	97.5
0.04	54.7	54.6	94.8
0.03	51.1	49.7	91.8
0.02	47.6	40.0	86.8
0.01	44.6	5.7	51.9
0.009	35.7	5.4	45.9
0.007	14.9	4.8	44.8
0.005	-	4.8	44.0
0.003	-	4.8	34.9
0.001	-	4.8	15.9

Note: Specific gravity was 2.72 for Riyadh BH, 2.7 for AB.BH.1, and 2.70 for AB.BH.2. The first two were nonplastic; AB.BH.2 had a plasticity index of 10.

Figure 3. Penetration test: log penetration versus ratio F/BH.

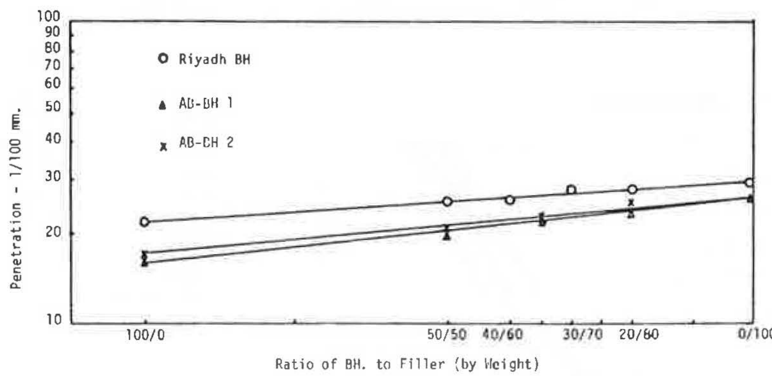


Figure 4. Penetration test: log penetration versus ratio F/asphalt.

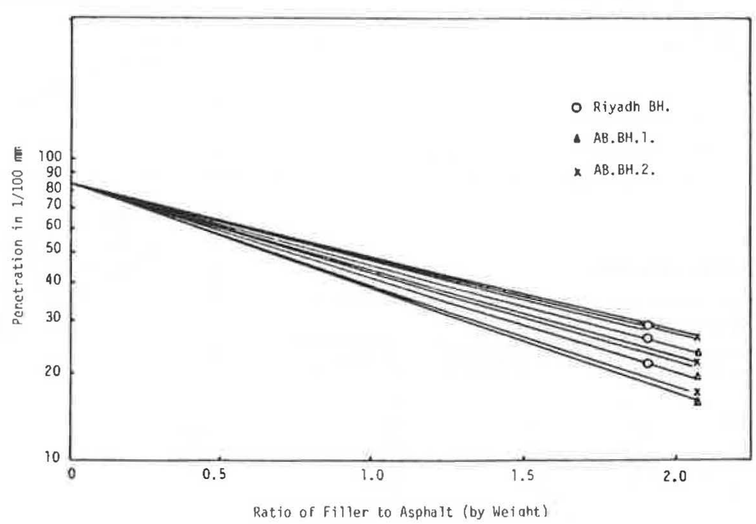


Figure 5. Softening points for asphalt/baghouse fines and filler mortars.

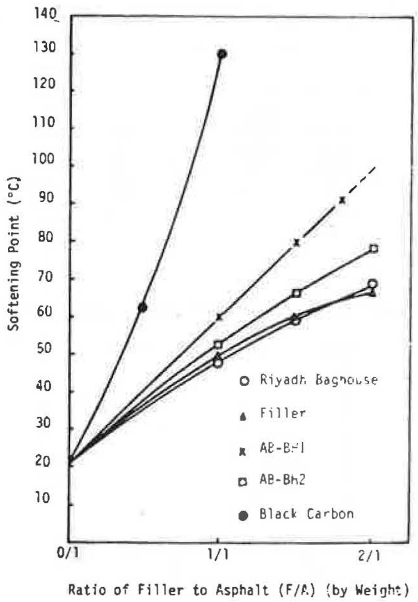


Figure 6. Shear modulus from rheometer analysis.

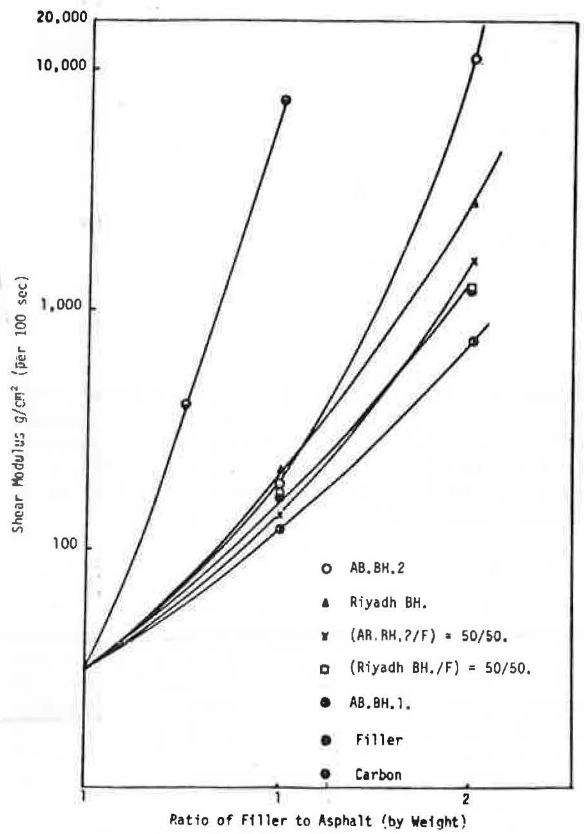
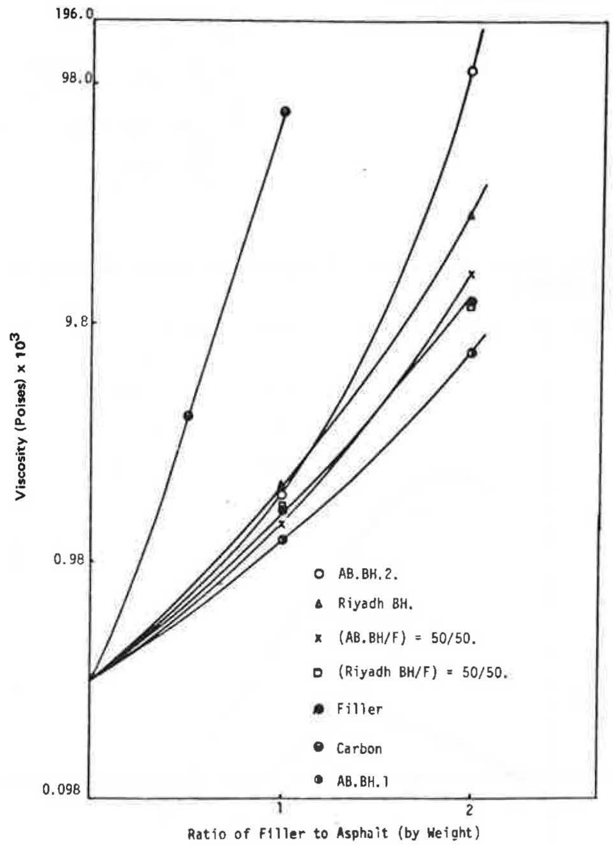


Figure 7. Viscosity evaluation by rheometer analysis.



to mix asphalt with carbon at a ratio of filler to asphalt content of 1.5 by weight because this gives a very dry mix. The effect of filler on asphalt was also determined. Results for viscosity, shear modulus, and softening points are given in Figures 5-7.

MIX DESIGN

To investigate the effect of filler and baghouse fines on the mix design, the Marshall method was used because of its wide acceptability, simplicity, and correlation with the field performance. At least three samples were repeated for each mix to ensure reproducibility of results.

Two types of tests were used. First the Marshall test was done on specimens after they had soaked 30 min in a 60°C water bath. The second test was the evaluation of the water susceptibility of each mix. This test was conducted by immersing compacted specimens in a controlled water bath at 60°C for 24 h. Stability was measured and stability loss was determined. It was believed that this test was more severe than the conditions that existed in the field.

Effect of Filler on Mix Properties

Damman aggregate is known to cause some problems in the field because of its chalk content. To investigate what effect Damman filler has on mix properties, different percentages of filler were added to the mix. These corresponded to 4, 8, 10, 12, and 15 percent of the weight of the aggregates. Initially, specimens were compacted by using 50 blows of the Marshall hammer on each side.

Stability was determined for the different levels of filler content by two different methods. The Marshall stability results for samples that were soaked 30 min are given in Figure 8. They indicate that an increase in the percentage of filler in the mix will increase the stability. However, no results are given for the stability of mixes soaked 24 h. This is due to the total collapse of the specimens. Another group of specimens was compacted by using 75 blows and tested for 30-min and 24-h stability. After the 24-h soaking, samples were still compact. The stability loss S_L is defined as follows:

$$S_L = S_{30} - S_{24} \qquad (1)$$

Table 5. Stability-loss analysis for Damman filler (compacted by 75 blows).

Item	Filler (%)							
	4	4	4	8	10	10	15	15
Aggregate asphalt content (%)	5.0	5.6	6.0	5.6	5.6	6.5	5.6	6.0
Marshall stability (lbf), 30 min at 60°C	2500	2900	2650	3337	3430	3200	4050	3800
Flow	10.0	12.0	14.0	14.0	14.5	16.0	13.0	15.0
Marshall stability (lbf), 24 h at 60°C	1364	1753	1250	613	355	1230	Collapse	500
Flow	22.0	16.0	22.0	25.0	34.0	25.0	Collapse	34.0
Stability loss (%)	45.0	39.5	52.0	81.0	89.0	61.0	100	86

Figure 8. Marshall stability versus asphalt content for different percentages of Damman filler.

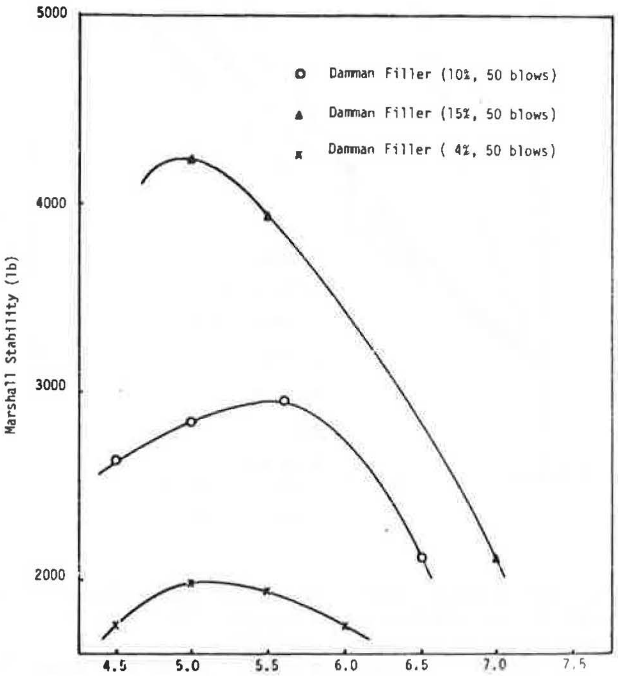
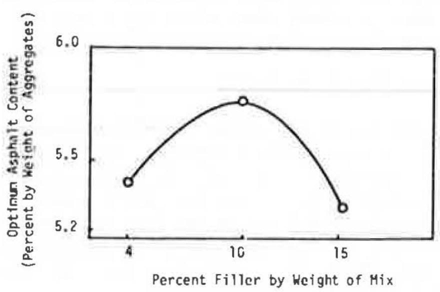


Figure 9. Optimum asphalt content versus percentage of Damman filler.

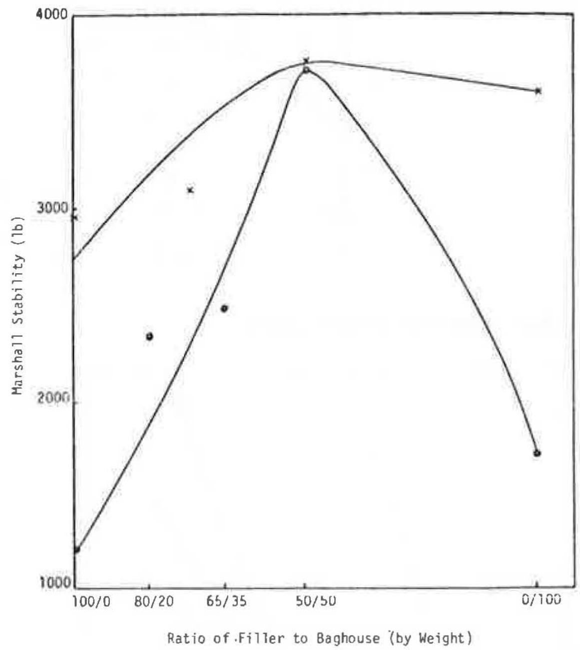


where S_{30} is the stability of the 30-min soaked sample in pounds, S_{24} is the stability of the 24-h soaked sample in pounds, and the percentage of stability loss is defined as follows:

$$\text{Percent } S_L = S_L/S_{30} \tag{2}$$

Stability results for Damman filler are shown in Table 5. It is clear that filler content has a direct relation to stability loss. By increasing filler from 4 to 15 percent, stability loss increases from 39 to 100 percent (for the same mix).

Figure 10. Marshall stability versus ratio F/BH for Riyadh mix.



Calculations show that the optimum asphalt content varies by varying the percentage of filler. Figure 9 indicates that the optimum asphalt content increases while the filler content increases to a maximum value of 10 percent. After that, the optimum asphalt content starts to decrease.

Effect of Baghouse Fines on Mix Properties

Riyadh baghouse fines affected stability positively. Increasing the amount of baghouse fines in the filler increased the stability up to a maximum value at an F/BH ratio of 50/50 and then the stability decreased, as illustrated in Figure 10. Optimum asphalt content increased slightly by the addition of baghouse fines and then decreased to a minimum ratio of F/BH of 50/50. Percentage of air voids varied in a short range.

When Abohadryyah baghouse fines were added to the mix, a slight reduction in stability resulted. As the amount of baghouse fines increased, stability decreased until it reached the minimum at a ratio of F/BH of 0/100 as shown in Figures 11 and 12. Air voids and percentage of air voids filled varied in a wide range (wider than that for Riyadh baghouse fines).

The effect of baghouse fines on the optimum asphalt content was determined. Figure 13 shows that optimum asphalt content was increased in AB.BH.1 up to the maximum at a ratio of F/BH of 50/50 and then decreased (the opposite of the effect from using Riyadh baghouse fines). Optimum asphalt content in-

Figure 11. Marshall stability versus ratio F/BH for AB·BH·1.

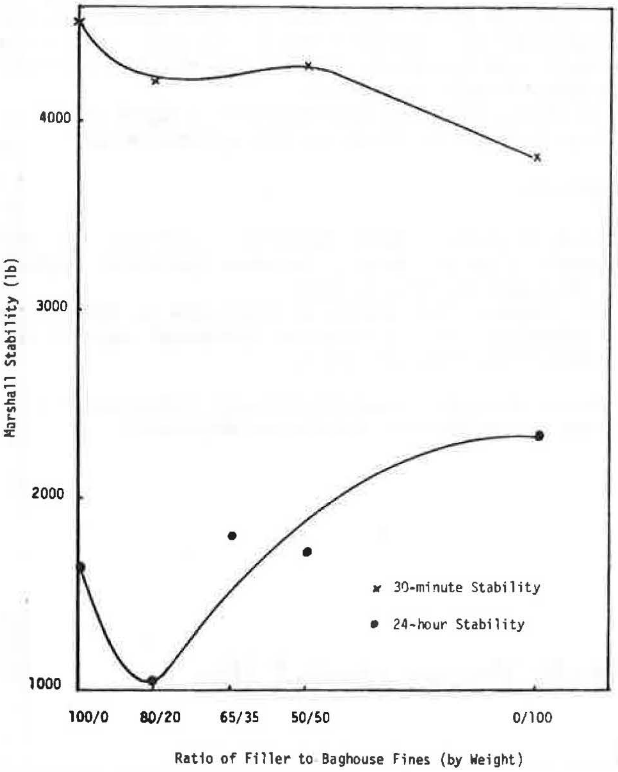


Figure 12. Marshall stability versus ratio F/BH-2 for AB·BH·2.

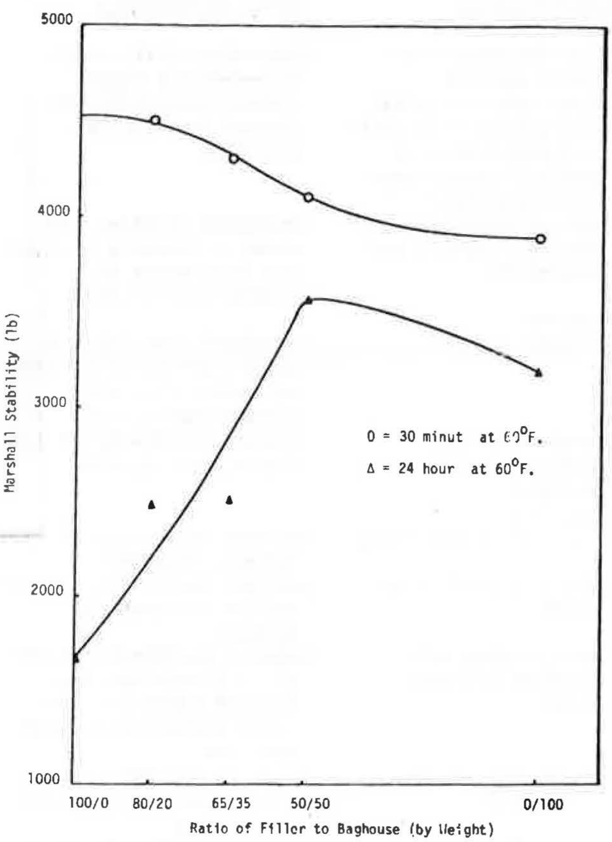


Figure 13. Optimum asphalt content versus ratio F/BH.

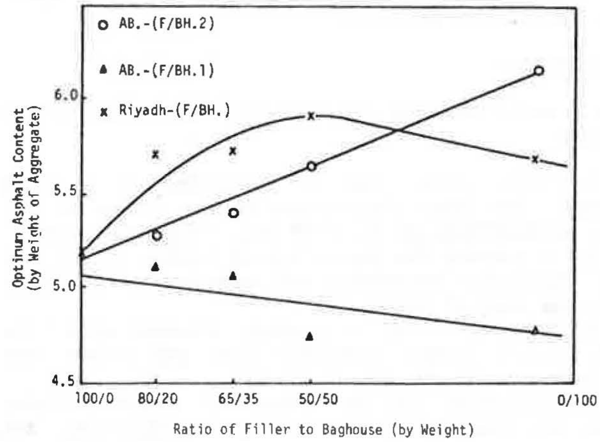
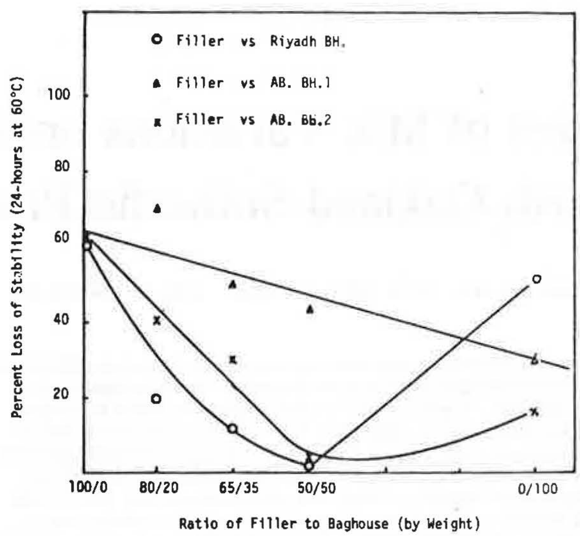


Figure 14. Stability loss versus ratio F/BH.



creased linearly by addition of AH.BH.2, which was due to the presence of carbon.

It was found that Riyadh baghouse fines can decrease the stability loss tremendously and can even prevent it. By increasing the amount of baghouse fines in the filler, stability loss decreased gradually to approximately 2.0 percent at a ratio of F/BH of 50/50. In fact, some of the specimens showed higher stability after 24 h than after 30 min. By adding more baghouse fines, stability loss increased. At a combined ratio of 50/50, an ideal filler is obtained that requires the minimum optimum asphalt content and gives the highest stability and lowest stability loss. Adding AB.BH.1 to the mix caused a linear reduction in stability loss from 62 to 30 percent. The same trend was noted for AB.BH.2, in which stability loss was decreased from 62 to 4 percent at a ratio of F/BH of 50/50 and then increased to 15 percent at a ratio of F/BH of 0/100.

Stability loss at a ratio of F/BH of 0/100 for AB.BH.2 was lower than that for AH.BH.1, which in turn was lower than that for Riyadh baghouse fines, as shown in Figure 14. This effect was caused by carbon fines, which exist in AH.BH.2 at 6 percent concentration, whereas the concentration is only 0.5 percent in AB.BH.1 and zero for Riyadh baghouse

fines. It is believed that carbon fines increase the resistance of asphalt to the effects of water and temperature variation.

CONCLUSIONS

The conclusions for this study are summarized as follows:

1. Filler affects the mix properties to a large extent. The lower percentages of the filler in the mix, as specified by the ASTM E11, should be used.
2. Decreasing the percentage of filler in the mix and increasing compaction and asphalt content will decrease loss of stability.
3. Baghouse fines, if properly blended with filler, should reduce stability loss and affect the optimum asphalt content of the mix.
4. Increasing the percentage of baghouse fines will increase the viscosity, shear strength, and softening point of the mortar.
5. Presence of larger percentages of carbon in the baghouse fines will have a major effect on the performance of baghouse fines in the mix. This will decrease the stability loss of the mix and increase the optimum asphalt content.
6. Mixes that use approximately a 50/50 ratio of filler to baghouse fines are the optimum mixes.

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Effect of Mix Variations on Asphalt Pavement Life: North Oakland-Sutherlin Project

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An increase in construction and short-term pavement performance problems has been noted in the Pacific Northwest and throughout the United States during the past five years. Several reasons have been suggested by others to explain this sudden change, such as recent variations in asphalt properties and new developments in paving technology. By using the data and construction materials from projects built in 1978-1979, the Oregon Department of Transportation and Oregon State University initiated a laboratory study to determine the relationship between asphalt-concrete mix performance and mix compaction, asphalt content, and percent passing the 2-mm and 0.075-mm (Nos. 10 and 200) sieves. Conventional and dynamic tests were run on laboratory-compacted samples to determine mix stiffness, fatigue life, and permanent deformation characteristics. By using the fatigue data generated as an example, pay-adjustment factors were developed by comparing the performance of mixes prepared at the design optimum with that of mixes from specifications. It was found that fatigue life is primarily affected by the level of compaction of the mix. Test results indicate that there is an optimum asphalt content for fatigue and that gradation slightly affects fatigue life. The most critical pay-adjustment factors for fatigue are presented. Additional work is being completed to combine the fatigue and permanent deformation test results.

Several changes in highway materials and in asphalt paving technology have occurred in recent years. New asphalt sources have been developed that introduce changes in asphalt properties. New equipment has been developed that affects mixing (drum mixers, more efficient dust-collector systems), storage (mix storage silos), and compaction (vibratory compactors). In the same period, economic constraints have resulted in increased use of lower-quality aggregate. As a result, there has been an increase in construction or short-term performance problems throughout the Pacific Northwest (1). The impact of such changes on the mix properties is, however, difficult to evaluate. The main changes observed and their expected influence on the mix behavior are summarized below:

Change Observed	Impact on Pavement
Asphalt:	
Wide difference between asphalt temperature-viscosity curves from various suppliers, increased temperature susceptibility	Compaction difficulty, slow-setting mixes, reduced resistance to thermal and fatigue cracking
Reduced compatibility between asphalt and aggregate	Increased reveling, reduced resistance to damage from water and freeze-thaw effects
Aggregate:	
Reduced quality	Increased raveling, reduced resistance to damage from water and freeze-thaw effects
Single stockpile, elimination of plant screens	Reduced uniformity of gradation, segregation
Equipment:	
Use of dust collector	Reduced uniformity of gradation, flushing
High mix production rate	Reduced uniformity of gradation and asphalt content
Lower mixing and laydown temperatures	Reduced uniformity of asphalt viscosity, increased moisture, reduced asphalt-aggregate adhesion
Use of vibratory compactors	Breakage of aggregates, low compaction from improper use
Use of drum mixers	Incomplete coating of aggregate