The effects of baghouse fines and mineral fillers on asphalt mix properties in the Eastern Province of Saudi Arabia

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Civil Engineering

September 1981

Abstract

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by

Hamad I. Al-Abdulwahhab

A Thesis Presented to the

FACULTY OF THE COLLEGE OF GRADUATE STUDIES

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

DHAHRAN, SAUDI ARABIA

In Partial Fulfillment of the
Requirements for the Degree of

MASTER OF SCIENCE

In

CIVIL ENGINEERING

September, 1981

Order Number 1355709

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SEPTEMBER 1981

UNIVERSITY OF PETROLEUM & MINERALS

DHAHRAN - SAUDI ARABIA

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M.S. (CIVIL ENGINEERING)

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ACKNOWLEDGEMENT

Acknowledgement is due to the University of Petroleum and Minerals for support of this research.

I wish to express my appreciation to Dr. Bassam Anani who served as my major Advisor. I also wish to thank the other members of my Thesis Committee, Dr. Abdulaziz I. Al-Mana, and Dr. T. G. Brown. I am grateful for GAC and Al-Khodary Companies who provided material and experiènce especially Mr. Anwar. Finally I would like to thank Dr. Youssef O. Al-Rasheed and Dr. Waddah Akili for speeding up this research.

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ABSTRACT

The objective of this study was to determine the effects of "Baghouse Fines" in the asphalt mixes. The analysis conducted included carrying out Marshall tests on mixes having various filler/baghouse fines ratios. Other tests to study the 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, stability, and stability loss. Asphalt mortars using different filler/baghouse fines ratio 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 controlling the effect of baghouse fines on the asphalt mixes was the percentage of carbons. It is anticipated that the results of this study will be of great help in the improvement of local mix properties.

Chapter 1

INTRODUCTION

1.1 GENERAL INTRODUCTION

Pavement systems in the Eastern Province of the Kingdom of Saudi Arabia are exposed to a multitude of severe environmental factors, mainly the excessive high temperature and high humidity. Roads usually show excessive failures at an early stage of the pavement life. Other factors contributing to the early failure are due to the extremely heavy axle loads applied to the roads of this province. There are currently no enforcements on the maximum loads permitted on an axle or the tire-pressures. Another major contributor to failure is the low quality of local materials used for the highway construction. Aggregates, for example, which are 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 greatly expand when soaked, resulting 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 and modern highways are under construction and there will still be a great need for more highways in the near future. Subsequently, a large expansion in the asphalt industry has begun. Asphalt plants are more abundant now than ever. Along with this, pollution potential for the dust emitted from the hot-aggregate elevators, plant screens, bins, hoppers, and pugmills of these plants is becoming more eminent. This dust pollution has already caused major problems in farms located near asphalt plants. An asphalt plant operating at a rate of 100-200 ton/hour will generate about 3,000 lbs of dust/hour or 50 lb/min.

1.2 STATEMENT OF THE PROBLEM

A major step in the improvement of the existing performance of roads starts with ensuring a proper mix design. It is anticipated that some failures discussed earlier are attributed to the poor design of the asphalt mixes. The existence of varied properties for local

materials requires different mix designs to be used. Fillers used in the mix design are known to affect the mix design, especially the optimum asphalt content (AC). The amount of filler used in the plant mixes will be a factor in affecting 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 existence of the large quantities of dust in the air from the asphalt plants has been of great concern to local authorities and farmers. Dust collectors have been incorporated in certain asphalt plants to ensure collection of the dust. This collected dust (or baghouse fines, as it will be referred to in this research) is being produced in large quantities from every plant, causing yet another problem such as disposal of this baghouse material.

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

1.3 OBJECTIVES

The objectives of this study are :

1) To evaluate the existing asphalt mix-designs using local aggregates.
2) To evaluate the effects of fillers and introducing baghouse fines into the asphalt mix.
3) To study various characteristics of the new asphalt mixes incorporating baghouse fines.
4) To study the effects of fillers and baghouse fines on the stability loss of the asphalt mixes.

1.4 SCOPE OF LIMITATIONS

The results of this study are applicable to mix designs using aggregates from the Dammam, Abohadryyah (AB), and Riyadh. The baghouse fines used were collected from two different sources, namely, Riyadh and AB. The Marshall test is exclusively used for the mix design.

Chapter 2

HISTORY AND BACKGROUND OF FILLERS

2.1 FILLER SIZE

The term "filler" is often used loosely to designate a mix material with a particle size distribution smaller than #4 sieve down to #200 sieve. At other times it is used for material passing #200 sieve. Specifications often define a filler as an inert mineral flour or dust having a specified particle size distribution from #10 sieve down to #200 sieve.

Richardson (1905)[1] believed that particles smaller than 0.05 mm are the most valuable particles, while particles passing #200 (0.085 mm) were called sand. A good filler should contain at least 60 percent of its weight of actual dust, preferably exceeding 70 percent. Materials which he suggested would perform satisfactorily as filler, include : portland cement, limestone, shale, and ground clay. Ground clay was believed to offer the most potential as a filler because much of natural filler

in Trinidad asphalt was clay, in addition to the high percentage of actual dust. In 1915, Richardson showed the importance of colloidal particles, although he did not indicate a size limit, but he stated that many materials enter this state with particles as large as 0.0001 mm, and some materials can be no larger than 0.000006 mm.

J.S. Miller and R.N. Traxler (1932)[2] concluded that screens are useless in the analysis of filler because particles less than 40 microns in diameter are very important. Spielman and Hughes[3] stated that the term filler is only accurately applied to a very fine dust capable of remaining in suspension in the bitumen.

In 1948, the U.S.Army Corps of Engineering[4] reported the result of their study about airfield pavement including filler This study included both laboratory stability analysis and test tracks in the field. They stated that it is essential that the filler be well graded in the material (finer than #200 sieve) and that it includes material finer than 0.01 mm in size. The following grading limits were proposed :

Grain Size	Percent Passing
0.05 mm	70 - 100
0.02 mm	35 - 65
0.005 mm	10 - 32

2.2 EXISTING THEORIES ABOUT FILLERS

Two fundamental theories have emerged regarding the function of the filler.

2.2.1 Filler Theory

The Filler Theory assumes that "the filler serves to fill voids in the mineral aggregates and thereby creates a denser mix".

This theory holds that each particle of the filler is individually coated with asphalt and that such coated particles, either discrete or attached to an aggregate particle, serve to fill the voids in the aggregate. Mixes of higher stability and density can be attained.

2.2.2 Mastic Theory

The Mastic Theory indicates that asphalt and filler combine to form a mastic which acts to fill voids and bind aggregate particles together into a dense mass. In this case, filler is in colloidal suspension. When

filler is added to asphalt, part of it will have a mechanical function where physical contact is not established, then filler and asphalt work together in the form of what can be called a binder. This finest portion of filler will be suspended in the asphalt, changing the properties of binder films. It will act as a filler within the asphalt itself, since it will replace a certain amount of asphalt in the mixture.

2.3 EFFECTS OF FILLER IN ASPHALT MIXES

2.3.1 Effect on Consistency

When filler is added to the asphalt, a marked change in the consistency of asphalt will result. This change can be inspected clearly by increasing the viscosity, penetration, and softening point of the asphalt filler mix.

Richardson[1] described the function of the filler as it acts as a part of the asphalt surface, covering aggregates for the purpose of rendering the surface more dense. This will result in a mix that is less affected by water and less liable to interior displacement for pavement. Part of this function was said to be accomplished by attraction between particles at their points of contact, with higher attraction present in fine

material than in the coarser material due to the number of contacts. The function of filler was extended by Warren[5] to include making the asphalt cement less susceptible to changes in consistency by heat in summer.

Miller and Traxler[2] noted that fillers containing large particles result in a more stable mortar than if the large particles are not present. This phenomenon was attributed to the fact that a large surface area of fine powder could adsorb more bitumen, and the portion adsorbed was the asphaltenes, which are the most rigid particles. This resulted in a lighter, more fluid oil between particles, increasing flow capabilities. Also, the large particles were believed to offer mechanical resistance fo flow which was not present in the smaller particles.

2.3.2 Effect on Void Filling

Richardson[1] stated that the only way to keep water out of an asphalt surface is to have the voids in the surface mixtures as small as possible in size, but not necessarily in volume. If the voids are entirely filled, they will easily yield to stress, causing the surface to crack and the pavement to appear soft. If the voids are not filled, water quickly enters and destroys the

pavement. The voids can be thoroughly filled without danger of movement with the introduction of filler into the asphalt, thus stiffening it as it exists between the voids. F.S. Besson[5] stated that dust was added not to reduce the voids but instead to reduce the size of the voids and increase their numbers.

M.F. Macnaghton[7] in 1924 stated that filler serves to occupy space in the coarse mineral aggregate. Therefore, the use of sand and filler was mainly for grading and particle size distribution to reduce voids and increase density and stability.

Kallas and Puzinauskas[8] indicated that minimum voids in mineral aggregate values are very significant because they indicate the condition in which the mineral particles are arranged to occupy the least volume for a given compactive effort and the corresponding volume of asphalt and air at this condition.

2.3.3 Effect on Resistance to Displacement

W. J. Emmons (1928)[9] stated that fine sand particles retained on #200 sieve are beneficial because of increased resistance to displacement resulting from the large area of contact between particles but not from finer particles.

2.3.4 Effect on Marshall Stability and Mix Strength

The U.S. Army Corps of Engineers[4] found that the stability of an asphalt mix increased by increasing the filler up to 20 percent for sand and 12 percent for asphalt concrete mixtures, while the required asphalt cement were decreased. It was noted that the effect of filler on asphalt pavement is beneficial when it has a low-quality base. On the other hand, excess filler might reduce flexibility and durability of the pavement; the best mixtures would contain as much asphalt and as little filler as possible.

McLeod in 1956[10] evaluated the effect of fillers on mixtures in terms of percent void filled with bitumen, Marshall Stability, and flow. He concluded that increasing the filler content up to 10 percent is beneficial. The bitumen content at 10 and 15 percent filler is low, causing the pavement to be brittle and therefore susceptible to ravelling and rapid deterioration.

Kallas and Krieger[11] in 1960 found out that a decrease in asphalt content to compensate for increasing densities may lead to greater pavement brittleness and a decline in pavement durability. In 1962, they found that all mineral fillers, regardless of type of concentration, increase stability or strength properties of

compacted asphalt paving mixtures when added up to a certain limit.

Kallas and Puzinauskas[7] found that by changing the concentration of filler upto a certain concentration, stability increases and optimum asphalt content decreases. As more filler is added, these tend to reverse.

2.3.5 Effect on Compaction

It was found that fillers increase compactive effects required to compact specimens to the same volume or air void content. This effect becomes more pronounced with increasing concentration of fillers. Using high-viscosity asphalt will result in the same effect.

Tunnicliff[12] has defined four different cases of filler packing, depending on asphalt content and compaction effort :

1) Loose packing where some bitumen is still at its original consistency.
2) Loose packing with maximum influence on bitumen.
3) Tight packing (plastic system).
4) Tight packing (maximum stiffening) with maximum resistance to deformation in tension. This is optimum binder content.

These situations are shown in Figure 1.

2.3.6 Effect on Water Susceptibility

Kallas and Puzinaskas[13] conducted an intensive study on eleven different mineral fillers. They believed that mineral fillers, when incorporated in the mixture, greatly increase the surface areas which must be coated with asphalt. If these surfaces are compatible and easily coated with asphalt, considerable benefits can be anticipated from the use of mineral filler. On the other hand, if these materials and their surfaces are highly susceptible to water, early failure of the pavement may result. They found that the water sensitivity of fillers to asphalt must be kept to a sufficiently low level. This can be achieved either by increasing the asphalt content or by decreasing the filler concentration in the mixture within limits that will provide satisfactory air voids, stabilities, and flow values. They also discovered that fillers containing more hygroscopic moisture exhibit higher water susceptibility.

2.4 FACTORS AFFECTING FILLER PERFORMANCE

There are many physical and chemical factors that

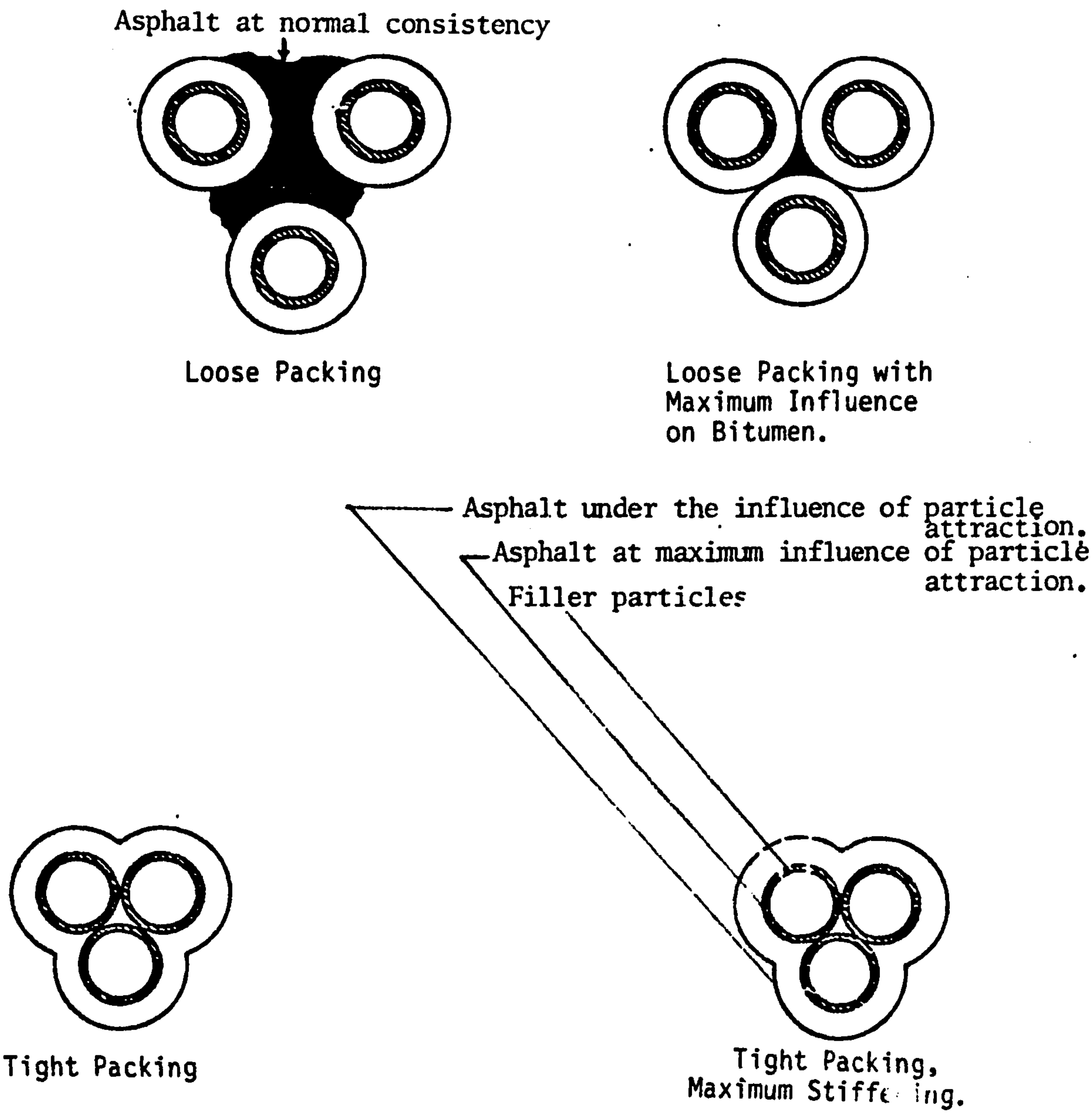

Figure 1: Different Cases of Filler Packing as Affected by Asphalt Content and Compaction Effort.

affect the performance of filler in asphaltic materials. Such factors are known to be size and gradation, specific gravity, surface area, shape, void content, and surface characteristics.

Traxler and Miller[2] noted that mixes containing large particles result in more stable mortars than if the large particles are not present. Additional benefits usually also result in greater asphalt surface density. In this respect, the success of portland cement as a filler was believed to be caused partly by its high specific gravity.

Kallas and Puzinauskas[8] held that voids in the mineral aggregate (VMA) are affected by several properties of mineral filler, such as particle size distribution, specific surface area, surface characteristics, shape, and effect of filler on the viscosity of asphalt. They found that by changing the concentration of filler up to a certain concentration, stability increase and optimum asphalt content decrease; however, as more filler is added, these tend to reverse. They also noted that in several instances finer materials caused lower mixture viscosity than the coarser fillers at the same concentration level. They found that viscosity is an important factor in Marshall stability.

Chapter 3

DUST COLLECTOR SYSTEMS

Dust collectors have been introduced in asphalt plants to reduce the amount of solids emitted in 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 separately. Certain rules have been reinforced in some countries to guarantee that the amounts of solids emitted are not exceeding maximum limits. One example of such regulation is as follows[14] :

$$E = \frac{A}{B} \times 1.67 \times C \qquad (1)$$

where

E = amount of solids emitted in lb/min.

A = actual operating rate of production in tons/hour.

B = maximum design rate of production of plant in tons/hour, corrected to a moisture content of 5 percent.

C = actual percentage of fine material (passing #200 sieve) contained in the material processed, corrected to a moisture content of 5 percent.

The amount of solid emitted should be equal to E or 1.67 lb/min, whichever is smaller.

3.1 GENERAL TYPES OF DUST COLLECTORS

There are three general types of dust collectors in use: mechanical centrifugal separators, wet collection systems, and secondary collectors. The latter consists of two different kinds, electrostatic and fabric filters. Asphalt plants in Saudi Arabia incorporating such dust collectors are using several different types. However, due to the shortage of the water supply and electricity, most plants have adopted either the centrifugal or the fabric filter types.

3.1.1 Mechanical Centrifugal Separators

The mechanical centrifugal separators may consist of one or multiple cyclones.

3.1.1.1 Cyclonic Separator : The cyclonic separator is the system used to collect the baghouse fine from the Riyadh plant used in this study. A typical cyclonic

separator is shown in Figure 2. The main body is cylinderical, and usually has the inlet attached to it to allow air to enter tangentially. The Lower Cone Section tapers to a narrow outlet followed by an airlock. Cyclones separate particulate matter from the gas stream by utilizing the centrifugal force to draw the dust from the gas. When the gas stream enters the main body, it faces a sudden increase in the cross-section area, resulting in a reduction in velocity. Because the carrying power of air varies with the cube of the velocity, the heavier particles start to fall out. The gas stream then starts spinning in the main body, which will throw the large particles to the outer wall. The boundary layer captures the dust and allows the particles to slide down the cone of the collector. As the spinning gases enter the cone, they are drawn to the clean air outlet since this is where the fan draft exists. In order for these gases to get out the diameter must decrease, which causes an increase in the velocity, followed by a sudden change in the vertical path. Only the fine particles can make this sudden change in direction. Inertia, coupled with centrifugal force, takes dust particles to the bottom, as shown in Figure 2. Particles built up until, by shear weight, they open the discharge

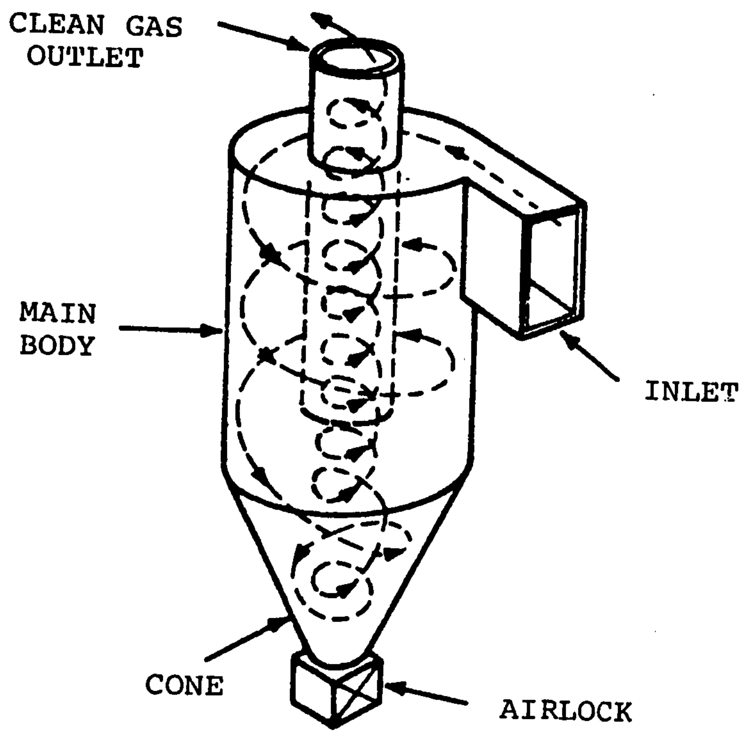

Figure 2: A typical Cyclone Separator

gate and slide out of the cyclone.

The efficiency of cyclonic collectors ranges from 80 to 90 percent. A typical efficiency curve is shown in Figure 3. A critical factor in maintaining the efficiency of such collectors is to have an effective airlock between the cone section and the atmosphere, since there is a high negative pressure in the cyclones and any leaks through the airlocking device will cause dust to be reentrained into the spinning gases, reducing the efficiency.

3.1.1.2 Multi-Clone Separators : Multi-Clone separators consist of a series of small cyclones arranged together to give an increased capacity. Centrifugal action is accomplished here by the use of stationary turbine type blades that force the rapidly flowing air to spin. A typical multi-clone separator is shown in Figure 4. The entrance of the air into the collector is slightly different from the large cyclone. The multi-cone unit utilizes axial spin vanes to impart the rotation to the air stream. The efficiency of such an arrangement can exceed 90 percent. This method of dust collecting is used in the Abohadryyah (AB) plant mix.

3.1.2 Wet Collection Separators : Wet Collection separators utilize water to trap the dust particles either

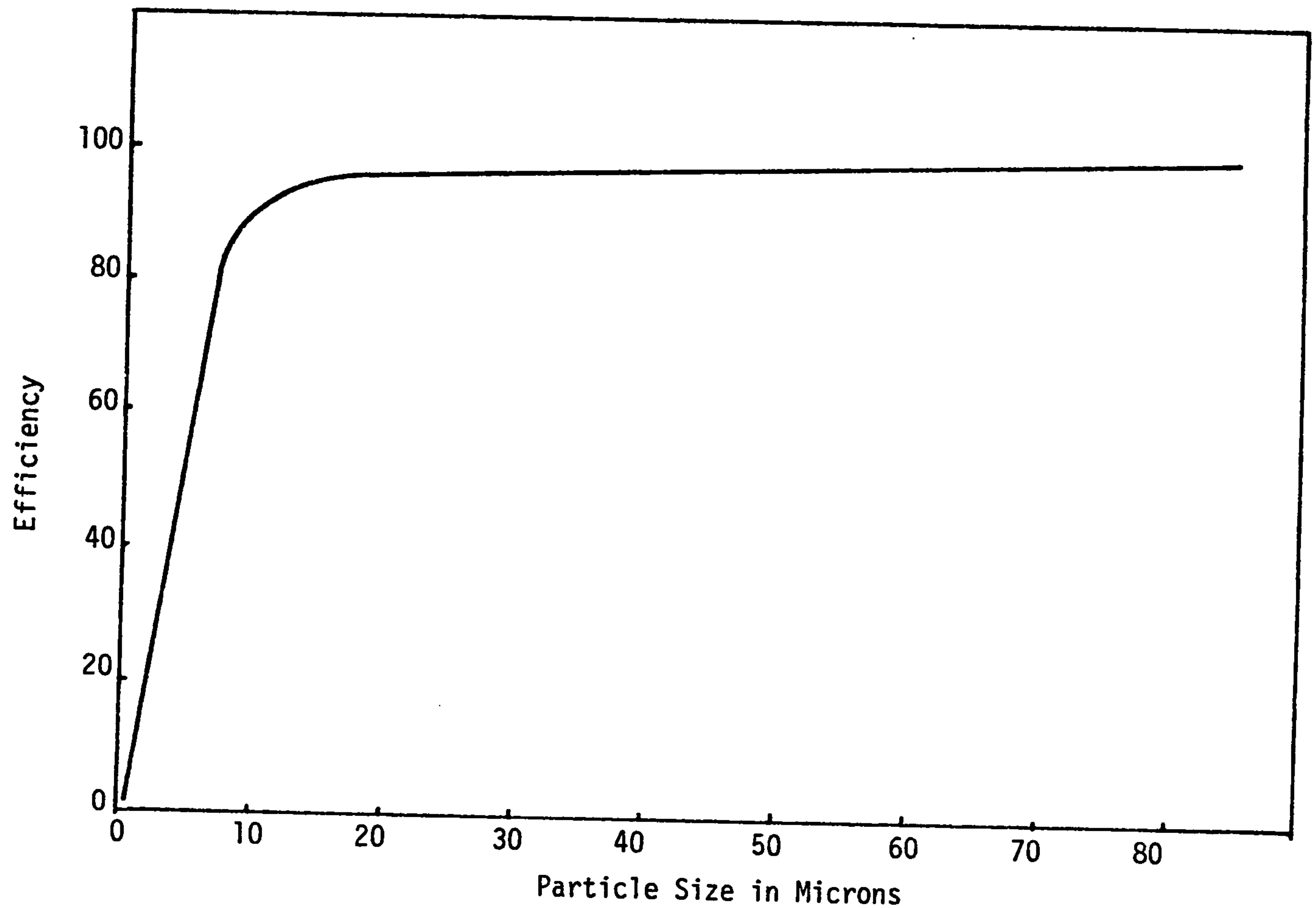

Figure 3: A Typical Efficiency Curve for Cyclonic Separators.

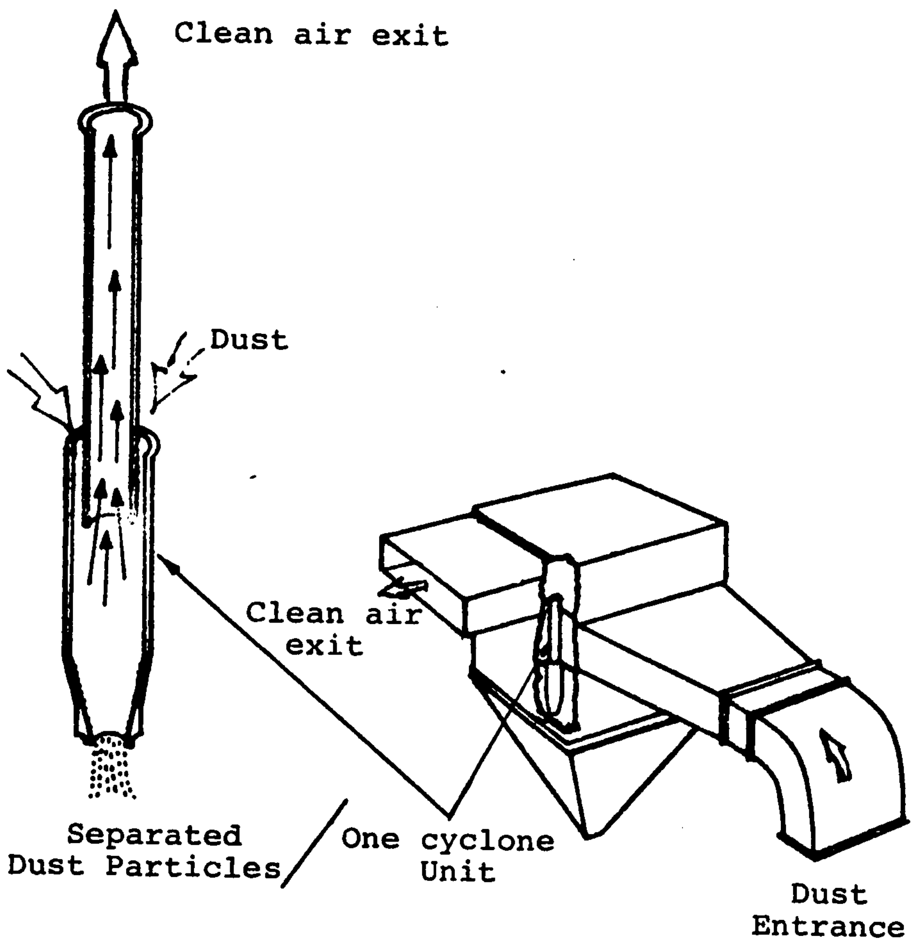

Figure 4: Multi-clone Separator.

by using a wet filter, by passing the gas stream through artificial rains from high-pressure nozzles, or by jetting the air stream below the water surface. The sludge can be changed after specific time intervals.

3.1.3 Fabric Filter Separators

The fabric filter separator utilizes fabric as the heart of the collection system in the filter. The exhaust gases are cleaned by passing the air through a fabric which captures the dust particles. The filters are narrow, long, and bag-like dressed on a steel cage. These bag-houses are arranged in several groups. The filtering process is conducted by sucking the air from the inside of the bags using a high-power turbine. This will cause gases to go through the fabric, leaving the dust on the outside of the bags, as illustrated in Figure 5. A group of bags is cleaned at a time by isolating a series of bags from the exhaust path by means of a pneumatically operated damper. The damper permits a sudden short burst of clean air from the reverse air path to enter the filter bags, resulting in a controlled shock action of the bags which breaks the dust cake on the outside of the bag, as illustrated in Figure 6.

Baghouses can be replaced when worn. They can

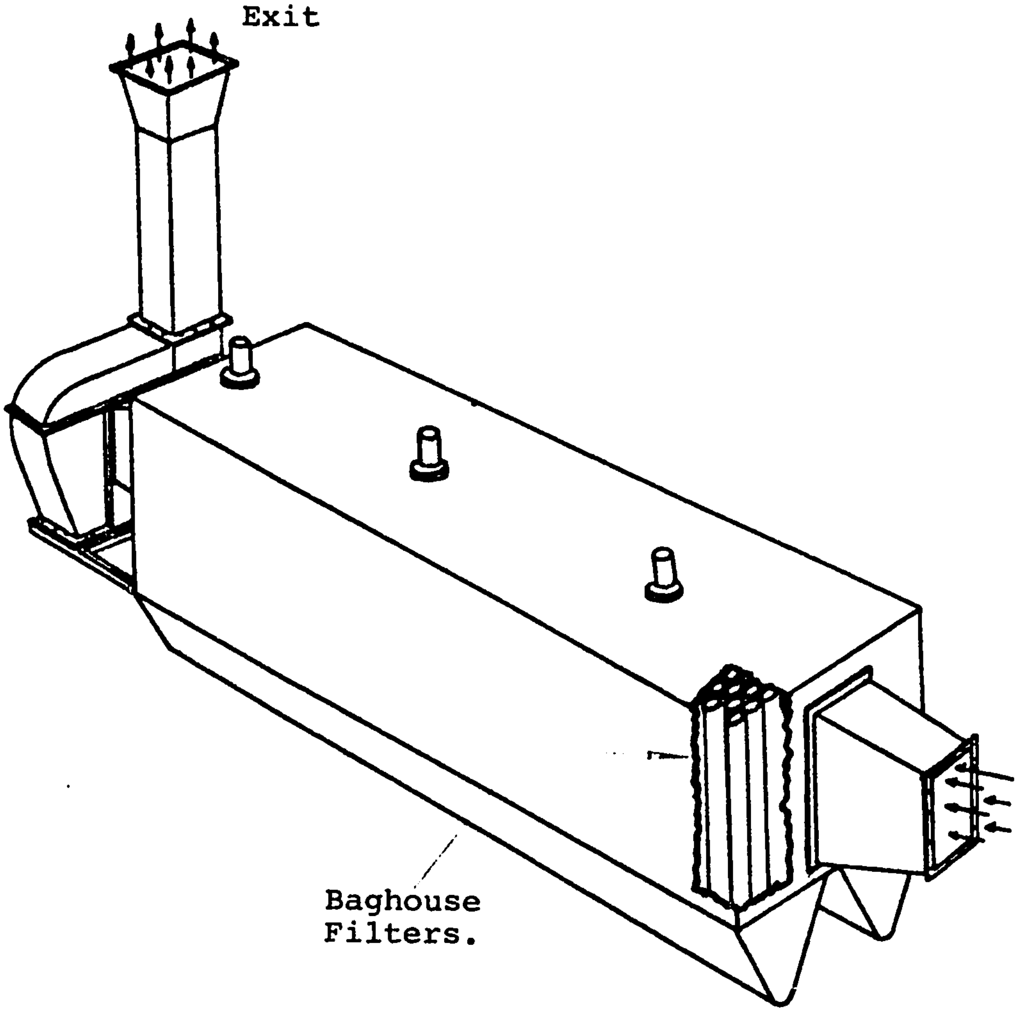

Figure 5: A Typical Fabric Filter.

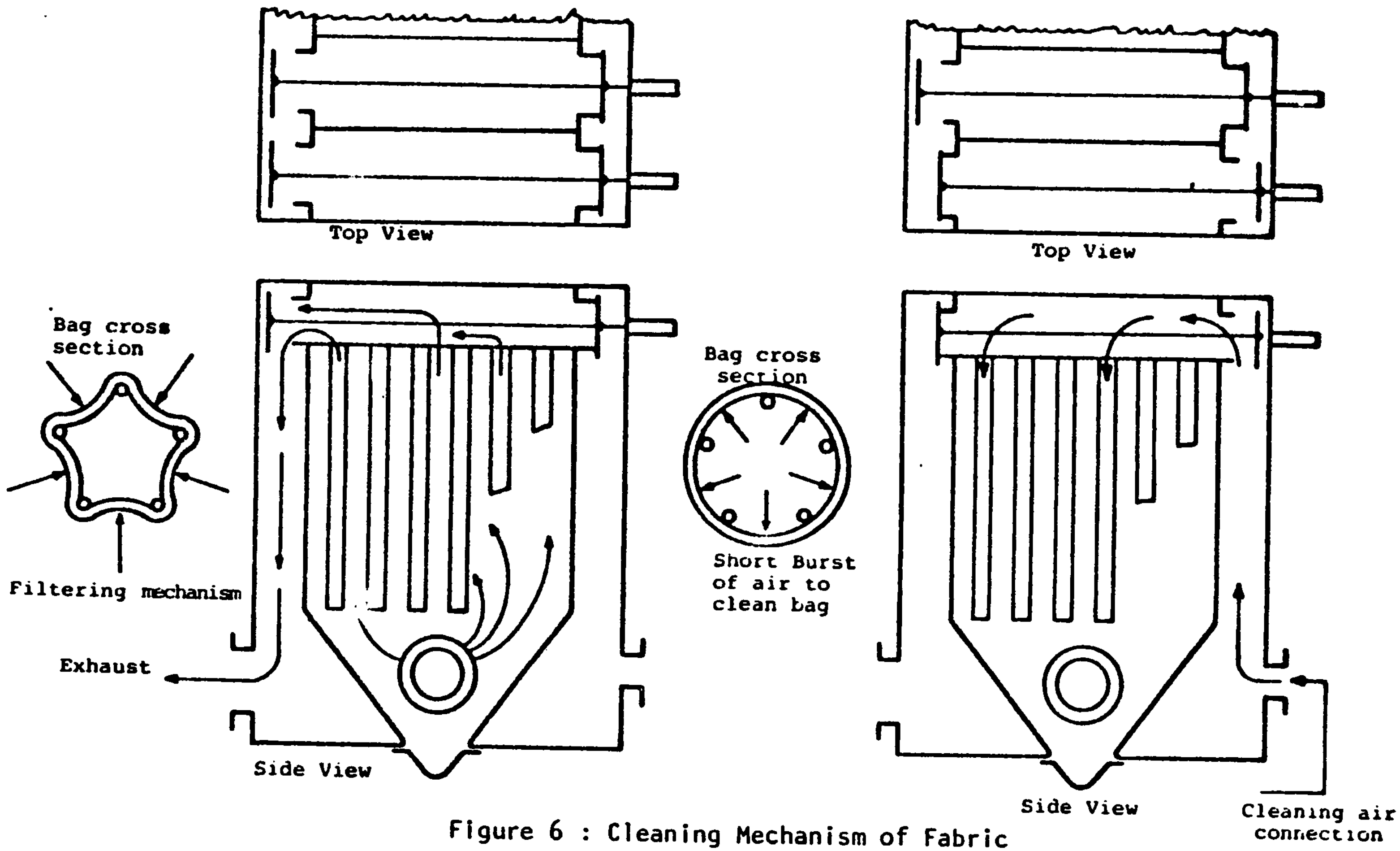

Figure 6 : Cleaning Mechanism of Fabric filter.

withstand heat upto 425^{o}F; therefore, to protect fabrics the hot bin temperature should not exceed 400^{o}F. A well-designed filter should not allow gases to hit the filter directly, which would cause the filter to wear, but should circle around it. The efficiency of the separator is approximately 99 percent. The size of trapped dust can be as small as 5 microns, or even smaller[15].

3.1.4 Electrostatic Separators[16]

This is a costly method which depends on charging dust particles by a negative (-) charge and collecting them on positively (+) charged plates to neutralize these particles. The collected particles are removed mechanically from collecting surfaces.

3.2 FUELS FOR DRYING

Fuels are used in the asphalt plants to dry the aggregates before they are mixed with the hot asphalt. The effect of the type of fuel used on the performance of the separator could be appreciable. The carbons resulting 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 AB have shown that approximately 7.0 percent of the fines are carbons resulting from the burning of diesel fuel, which is the fuel used in the plant. Excessive sulphur in the fuel can also cause damage to fabric filters.[14]

Chapter 4

MATERIAL CHARACTERIZATION

This chapter will give the results of tests to determine the characteristics of the materials used in this study, namely, asphalt, aggregates, filler, and baghouse fines.

4.1 ASPHALT

A 75-100 penetration grade asphalt was used for all mixes. Asphalt was brought from the Ras-Tanura refinery. A series of tests was performed to determine the basic properties of asphalt. Results of asphalt characterization are given in Table 1. The properties measured indicate that the asphalt meets the ASTM specifications.

4.2 AGGREGATES

Three different types of aggregates were used in this study. The first type was gravel and natural sand obtained from Riyadh, the second was limestone and natural sand obtained from Dammam, and finally limestone and

Table 1

Asphalt Properties* for "Asphalt Cement"

Penetration (100/5) at 77°F (25°C)	82
Ductility	100 cm
Flashing Point	625°F
Specific Gravity at 25°C	0.97
Softening Point (Ball and Ring)	21°C

*All tests were performed according to ASTM

natural sand from AB. The gradation of the three aggregates is shown in Table 2. As indicated, the gradation was not very different for the three sources. The maximum aggregate size for the Riyadh aggregate was ½ inch, while it was 3/4 inch for the others. The different sizes of each aggregate were blended to meet the ASTM specifications. Figure 7 gives the gradation of the blend of each aggregate as compared to those specifications.

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

4.3 FILLER

Two different fillers were used from Dammam area and from Abohadryyah. Dammam filler was used with the Dammam aggregate while Abohadryyah filler was used with both Riyadh gravel and the Abohadryyah aggregate. Filler used passed #100 sieve.

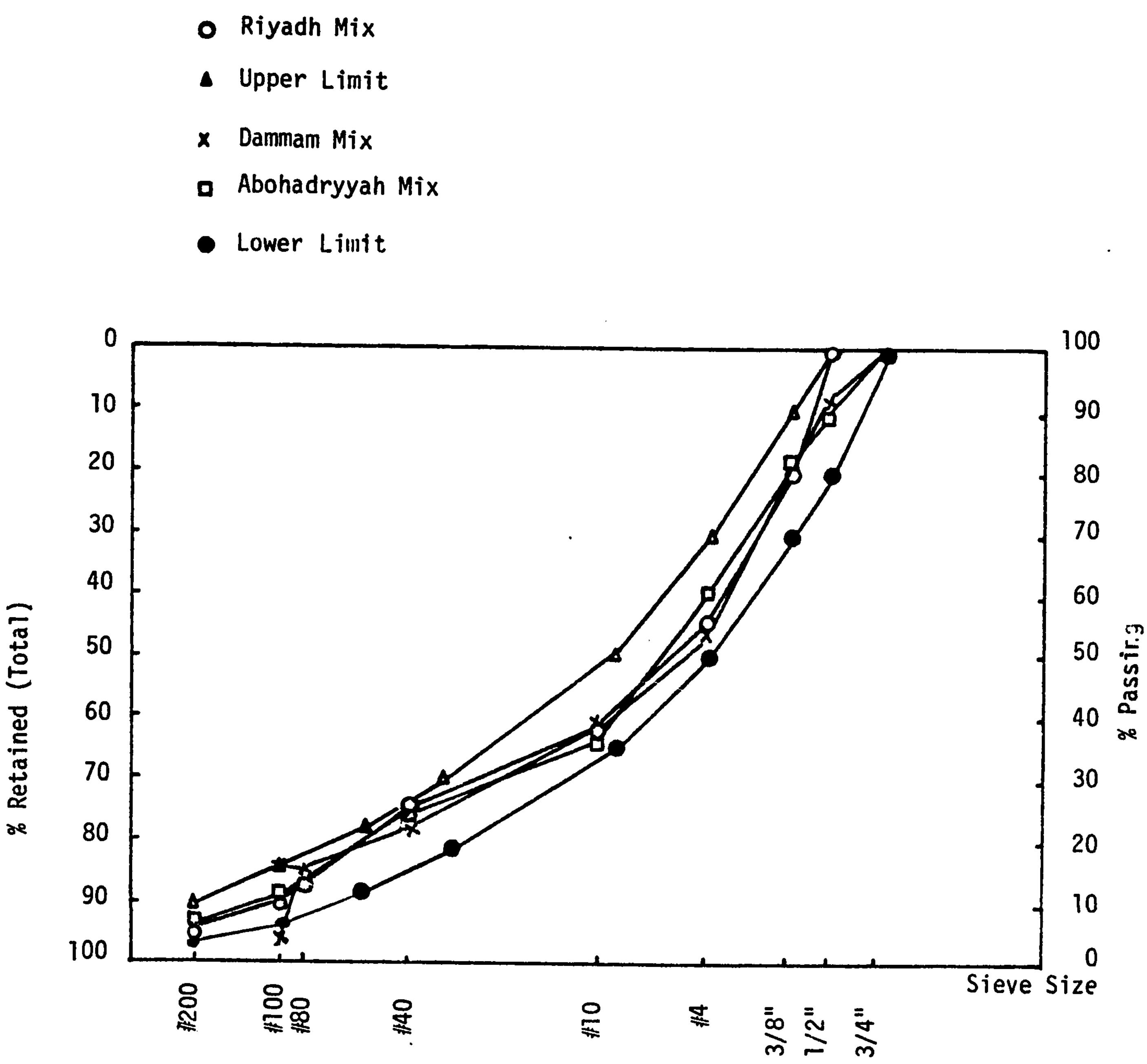

Figure 7: Gradation of the Aggregate Mixes.

Table 2

Job Mix Formula - Sieve Analysis

Sieve Size	Percent Passing			
	Dammam	Riyadh	Abohadryyah-I	Abohadryyah-II
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
# 4	54	56.0	59.5	59.5
# 10	38	39.0	36.5	36.5
# 40	23	25.0	24.0	24.0
# 80	15	12.5	13.0	13.0
#100	4-15	10.0	10.0	10.0
#200	--	6.5	6.8	6.8
S. G. Bulk	2.54	2.62	2.57	2.57
S. G. Apparent	2.79	2.69	2.68	2.68
Percent Asphalt Absorption	0.87	0.49	1.25	1.25
Percent Water Absorption	3.1	0.9	1.9	1.9
Percent Abrasion	31.2	23.1	28.8	28.8

Hydrometer analysis was conducted on the filler as shown in Figure 8. The specific gravity of fillers was also determined using the vacuum method, as shown in Table 3. The gradation based on the hydrometer test is given in Figure 9. Determination of the plasticity index of the filler showed that the filler is non-plastic. The same conclusion was obtained from the chemical analysis to determine the amount of plastic material in the filler.

4.4 BAGHOUSE FINES

Baghouse fines are the air-born particles separated from the gas stream on a bag-like filter. Baghouse fines used in this research were brought from two different sources, namely, Riyadh and Abohadryyah. However, Abohadryyah baghouse fines were classified as two different types, according to the method of collection. The first type will be referred to as Abohadryyah baghouse fines Type 1 (AB.BH.1) and the second type will be referred to as Abohadryyah baghouse fines Type 2 (AB.BH.2).

Hydrometer analysis was performed on the different types of baghouse fines. Results are given in Table 4. It is clear that AB.BH.2 was finer than the other baghouse fines, as shown in Figure 9. It should also be

Figure 8: Hydrometer Analysis for Fillers and Baghouse Fines.

Table 3

Hydrometer Analysis for Filler Used (all Passed #100)

Grain Size	Percent Finer	
	Filler for Dammam	Filler for Riyadh and Abohadryyah
#100	100	100
#200	48	59
.05	43.3	51.0
.04	38.9	48.3
.03	34.5	40.7
.02	28.8	33.0
.01	24.0	19.4
.009	23.0	18.2
.007	19.2	15.9
.005	16.3	11.2
.003	12.4	5.3
.001	10.5	4.1
Specific Gravity	2.73	2.73
Plasticity Index	N.P.	N.P.

Table 4

Hydrometer Analysis for the Baghouses

Grain Size	Percent Finer: Riyadh Baghouse	Percent Finer: Abohadryyah Baghouse I	Percent Finer: Abohadryyah Baghouse II
#100	90.3	86.8	100
#200	59.4	60.6	99.8
.05	55.9	56.1	97.5
.04	54.7	54.6	94.8
.03	51.1	49.7	91.8
.02	47.6	40.0	86.8
.01	44.6	5.7	51.9
.009	35.7	5.4	45.9
.007	14.9	4.8	44.8
.005	--	4.8	44.0
.003	--	4.8	34.9
.001	--	4.8	15.9
Specific Gravity	2.72	2.7	2.70
Plasticity Index	N.P.	N.P.	10

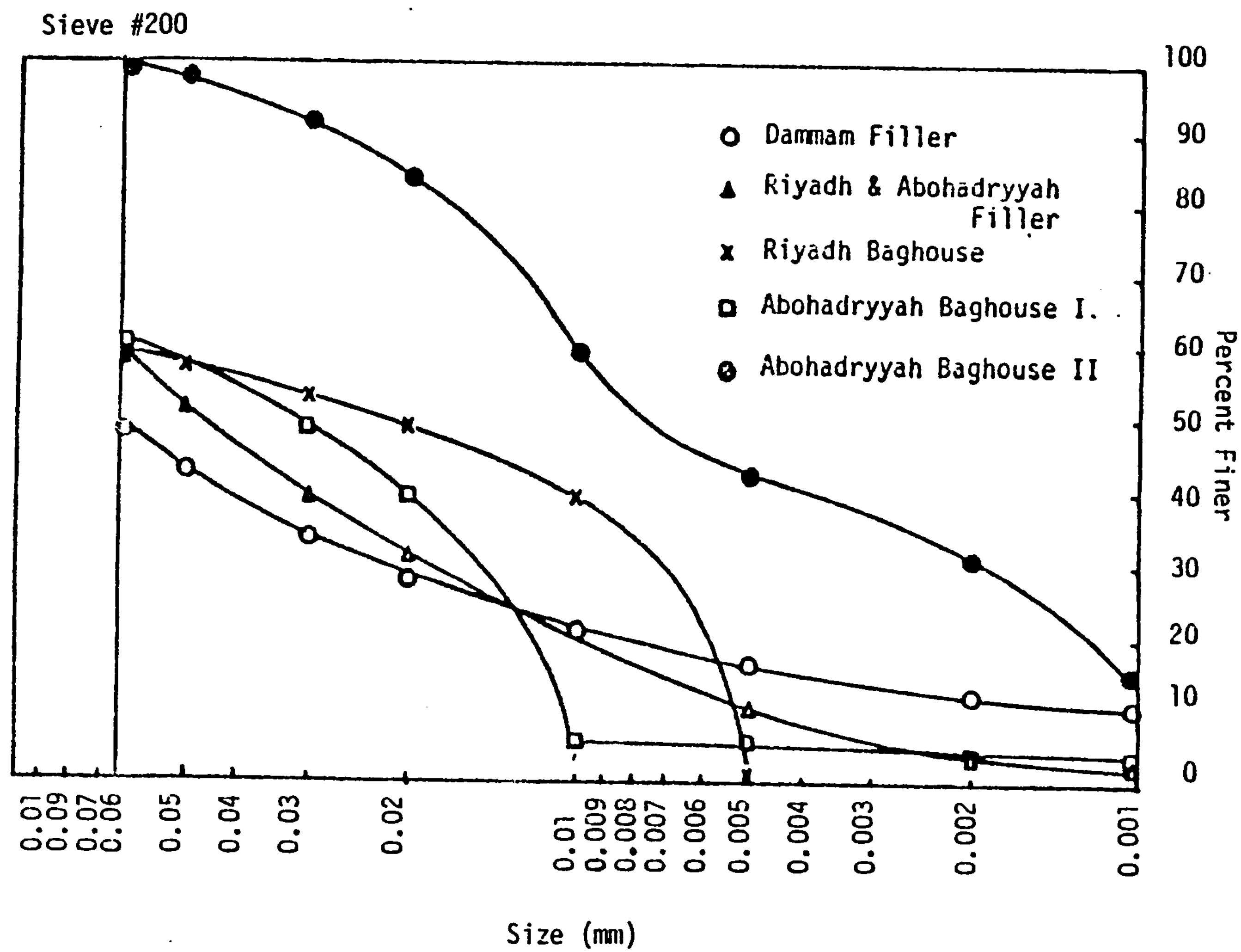

Figure 9. Gradation Analysis for Fillers and Baghouse Fines

noted that Abohadryyah baghouses fines contain some carbons due to oil burning for drying. Specific gravities were determined for the three baghouse fines. AB. BH.2 has slightly lower unit weight (by 1.1 lb/ft^3).

Plasticity-index determination on Riyadh BH and AB.BH.1 showed them to be non-plastic, while AB.BH.2 had a plasticity index of about 10.

Carbon was separated from AB.BH.1 and AB.BH.2 using a 2 percent diluted hydraulic acids. It was found that AB.BH.1. contained about 0.4 percent carbons, while AB.BH.2 contained about 7 percent carbons. Separated carbon was washed by sweet water and dried at 100°C, and then stored in a dry place. The dried samples of baghouse fines and carbon are shown in Figure 10 .

4.5 ASPHALT MORTARS

To study the effect of adding filler and baghouse fines to asphalt, a series of tests was performed on the asphalt mortars.

4.5.1 Baghouse-Filler Mortars

Baghouse fines were mixed with filler at different ratios, namely, F/BH. = 100/0, 50/50, 65/35, 80/20, and

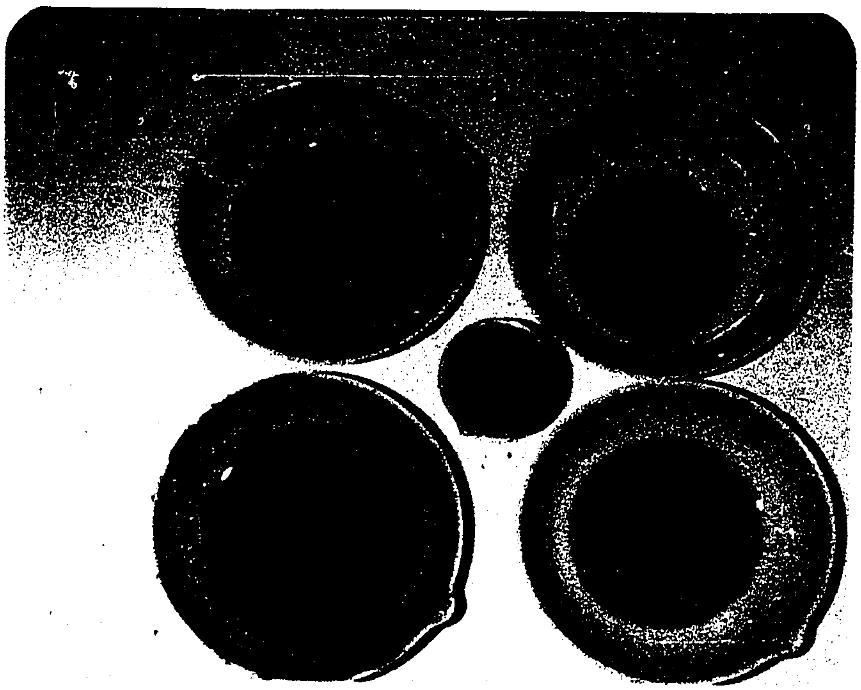

Figure 10: Dried Samples of Baghouse Fines and Carbon.

0/100. Asphalt was added to each ratio above at different percentages and penetration tests were done on the mortars. The results as presented in Figure 11*, show a linear relationship when plotting log penetration vs. F/Asphalt on a normal scale. It indicates that penetration decreases by increasing baghouse fines when log penetration vs. (F + BH)/asphalt ratio was plotted, as shown in Figure 12 . The penetration decreases as the ratio of filler and baghouse fines to asphalt increases. It is observed that using AB. baghouse fines will cause more reduction in penetration than Riyadh BH. (see Figure 13).

A softening point test was conducted on asphalt/ baghouse fines and mortars. The results are given in Figure 14. It was found that there is a tremendous increase in the softening point of AB.BH.2 mortar. This could have been caused by carbons. To investigate this, carbons were mixed at different percentages with asphalt and the softening point tests were done. The results affirmed the above assumption. The softening point was found to increase at a higher rate with AB.BH. 2. This effect is again shown in Figure 14.

It was found that as the amount of carbon increases in the filler from 0 percent up to 100 percent, the softening point vs. (filler/asphalt) ratio when plotted

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* Data used for plotting this curve and the rest of the curves are given in the Appendix.

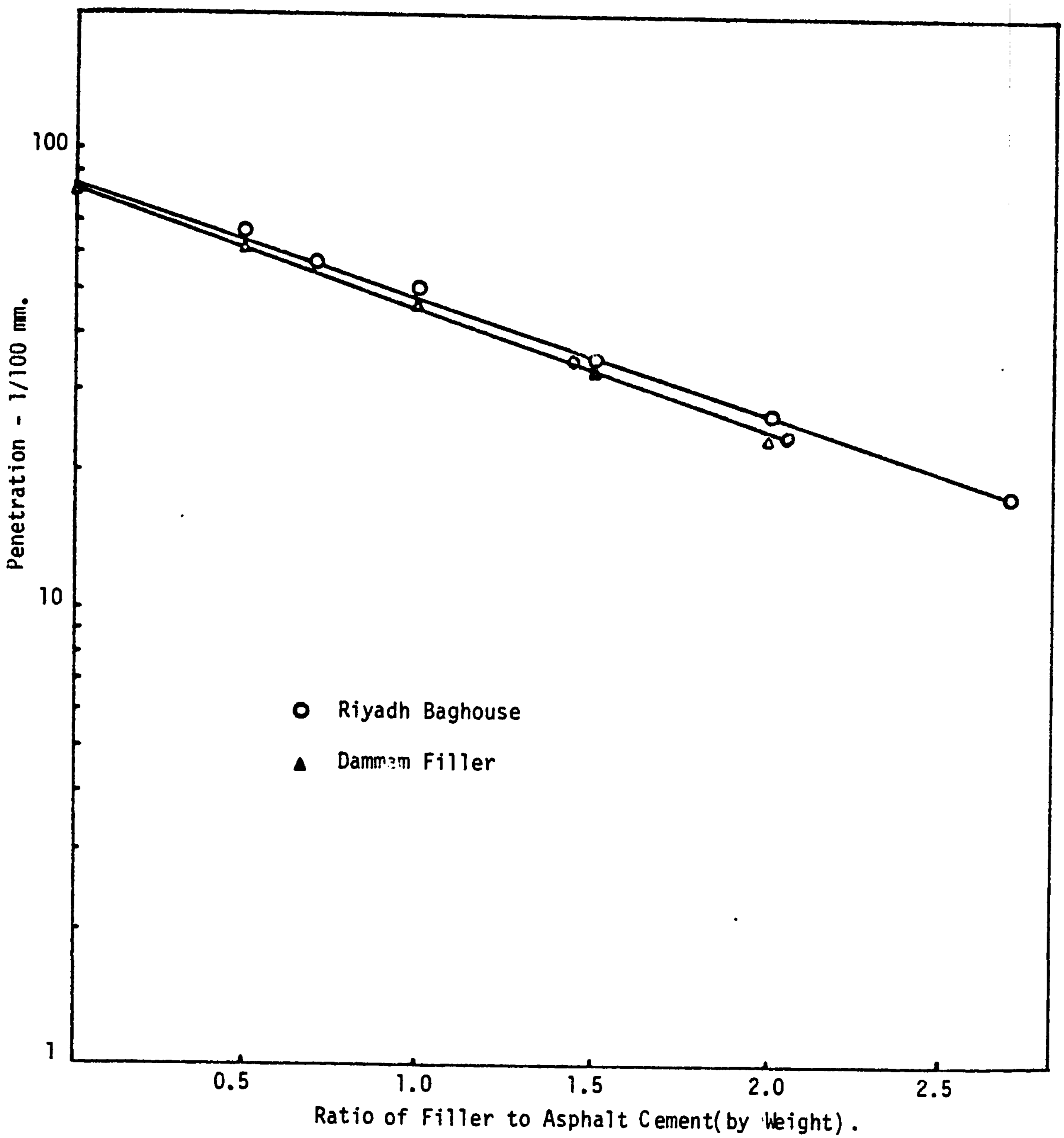


Figure 11: Penetration Test on Baghouse Fines and Filler/ Asphalt Mortars.

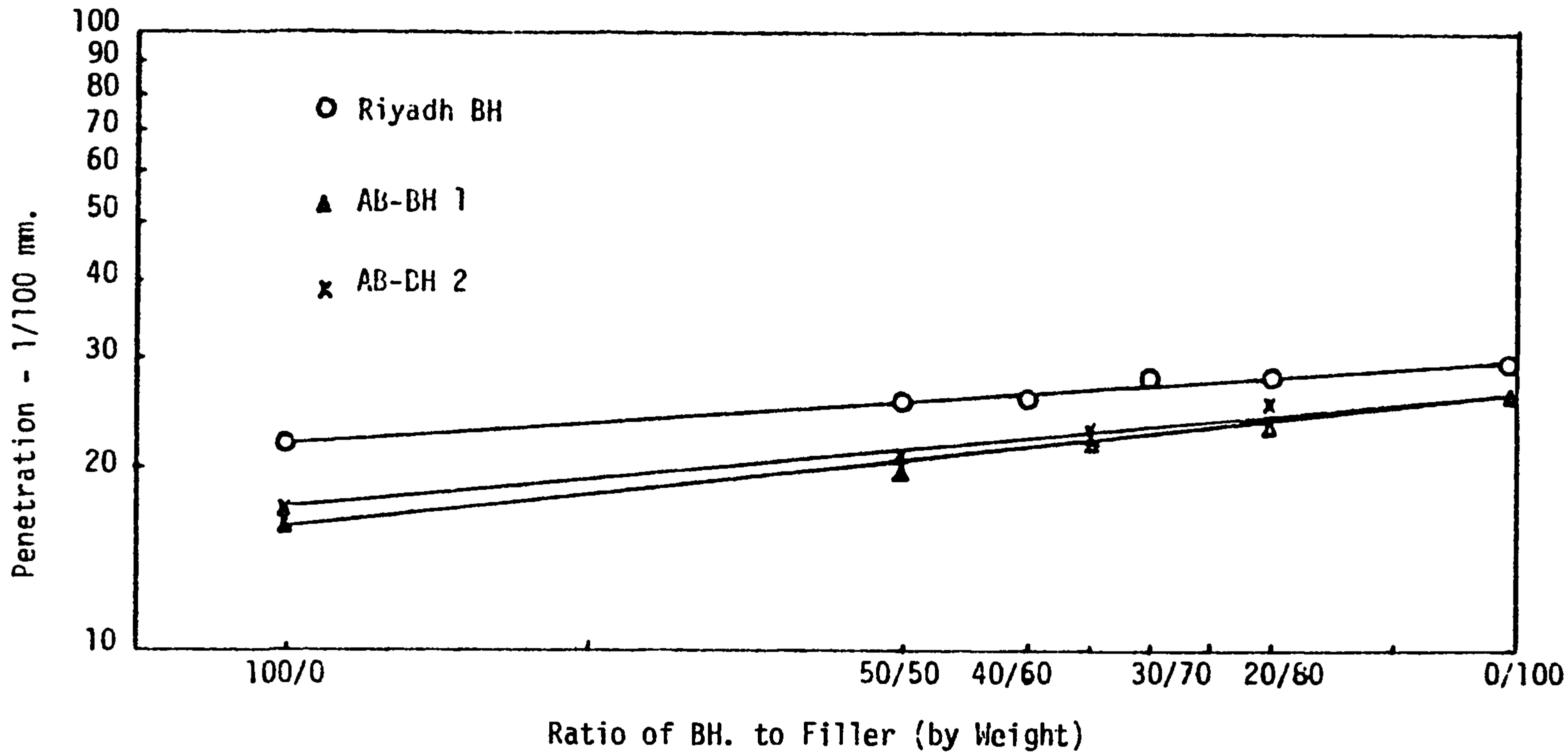


Figure 12 : Penetration Test on (BH / F)/Asphalt Mortar

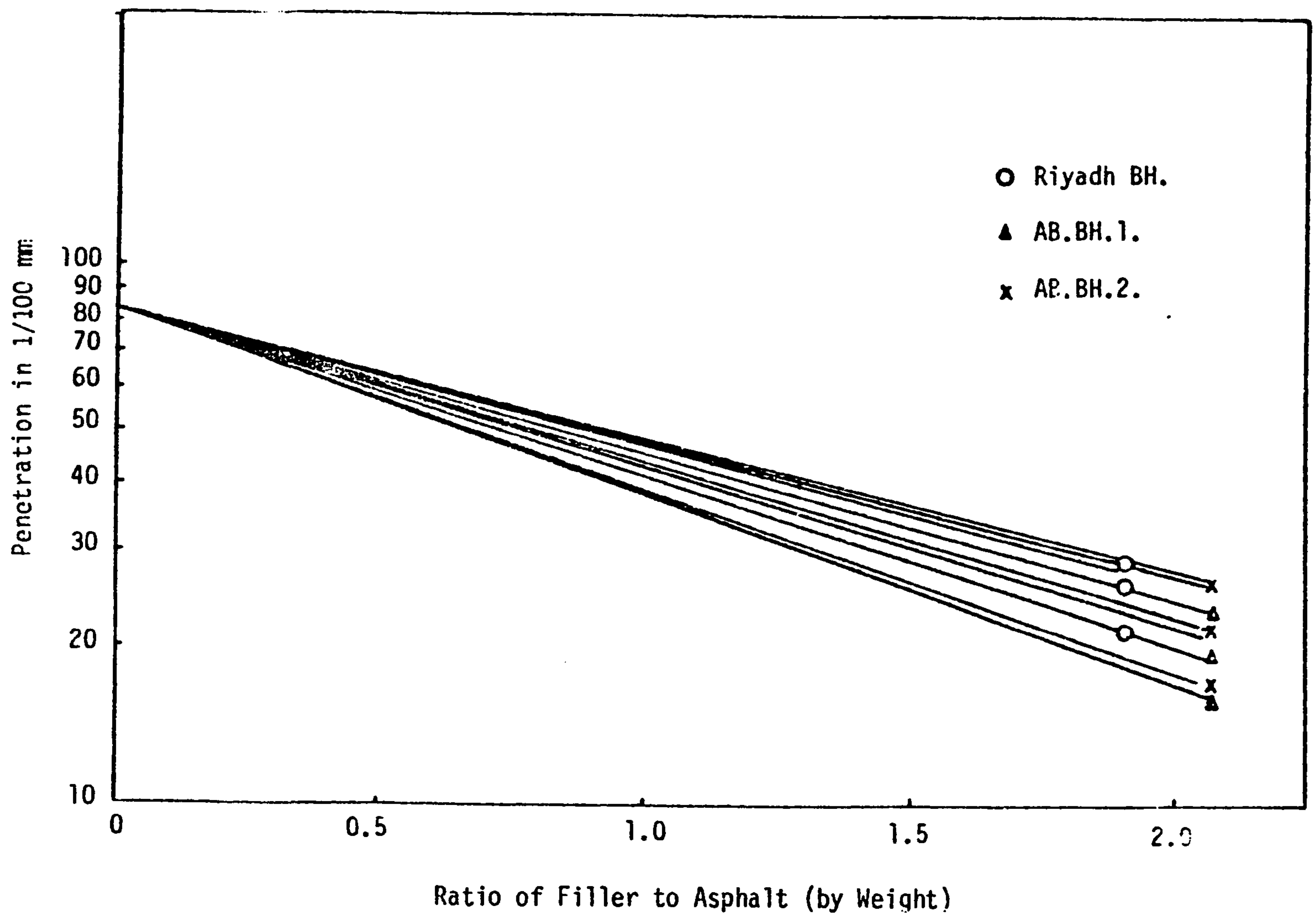


Figure 13: Penetration Test on (BH + F)/Asphalt Mortar

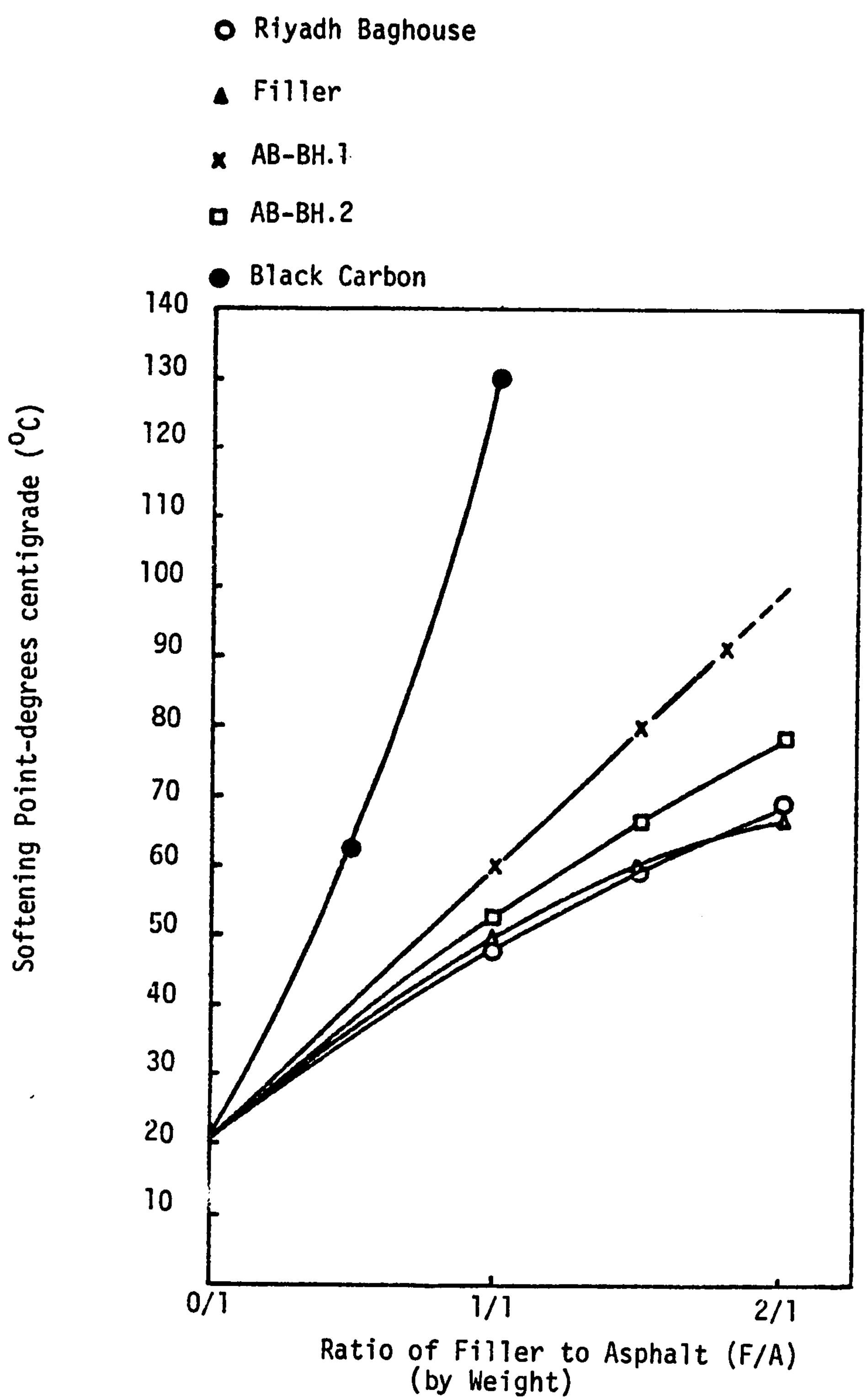


Figure 14: Softening Points for Asphalt/Baghouse and Filler Mortar.

on linear scale moved from a concave curve downward to a concave curve upward, as shown in Figure 14.

This was investigated further using a sliding-plate Rehometer, shown in Figure 15. 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 are given in Figures 16 and 17. The results indicate that shear modulus and viscosity for baghouse fines are higher than those for filler. Moreover, as the quantity of carbon increases in the baghouse fines, the viscosity and the shear modulus increase, especially at a ratio (filler/asphalt) of around 2. This analysis gave a high value for carbon mortars, as was shown in Figures 16 and 17.

4.5.2 Filler/Asphalt Mortars

To study the effect of filler on asphalt, a penetration test on asphalt-filler mortars was performed. Test results indicated that the mortar penetration decreased by increasing filler percentage. A drop of penetration from 82 at (filler/asphalt) = 0 to 21 at (filler/asphalt) = 2 was indicated, as shown in Figure 11. Results on viscosity, shear modulus, and softening points are indicated on the corresponding figures for baghouse fines.

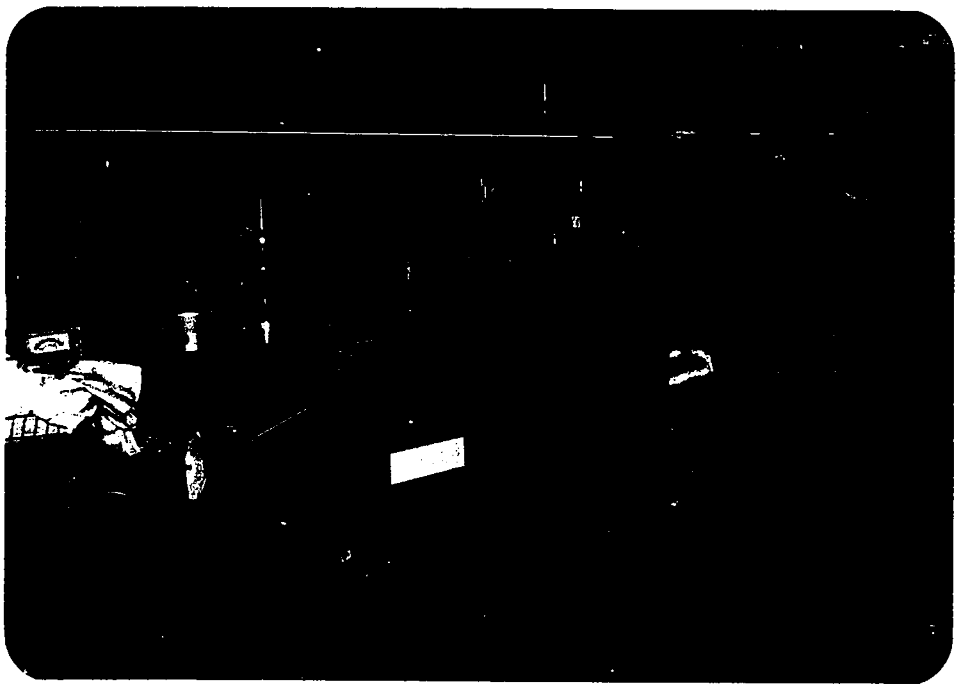


Figure 15: Sliding-Plate Rehometer

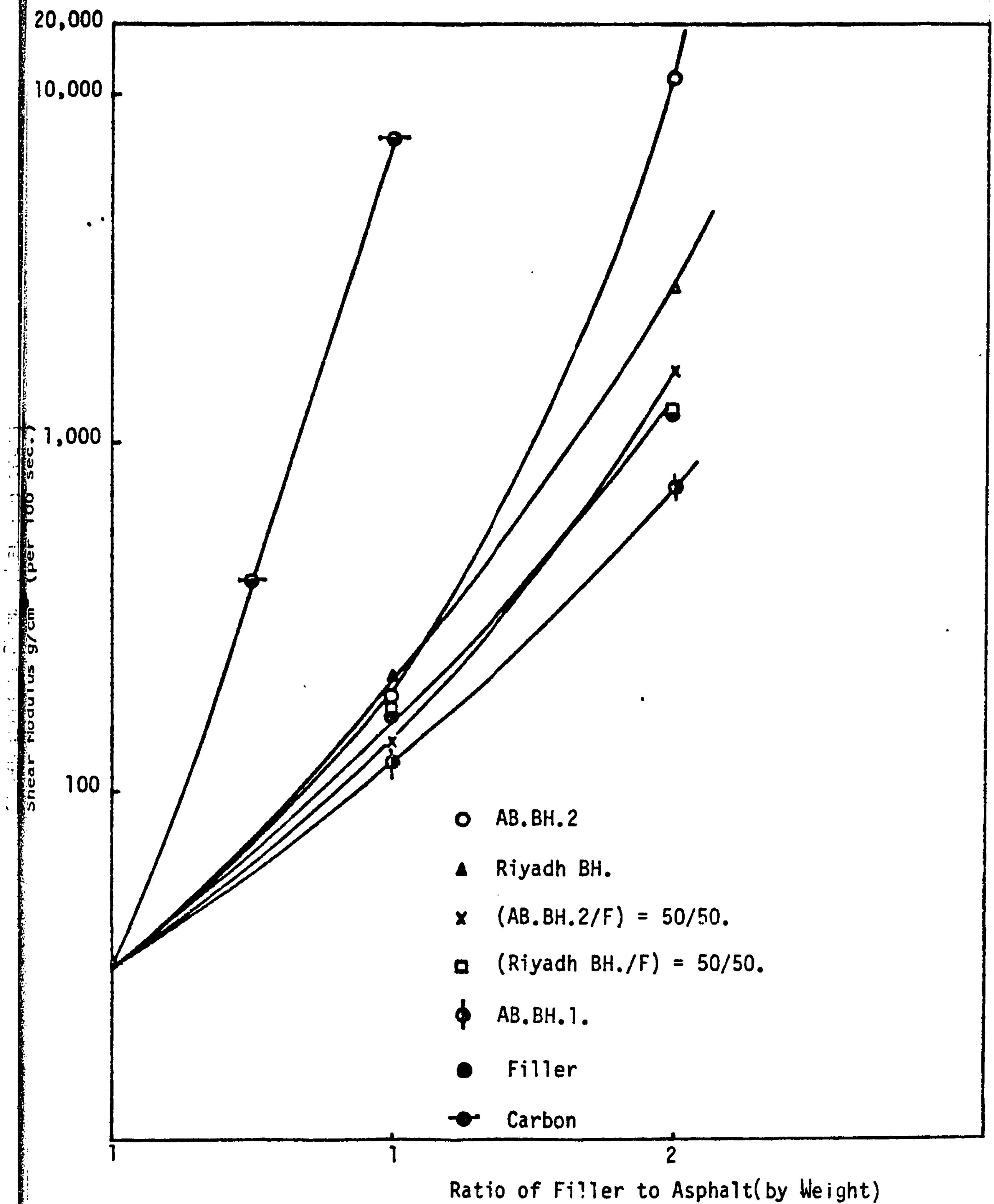


Figure 16: Shear Modulus from Rehometer Analysis.

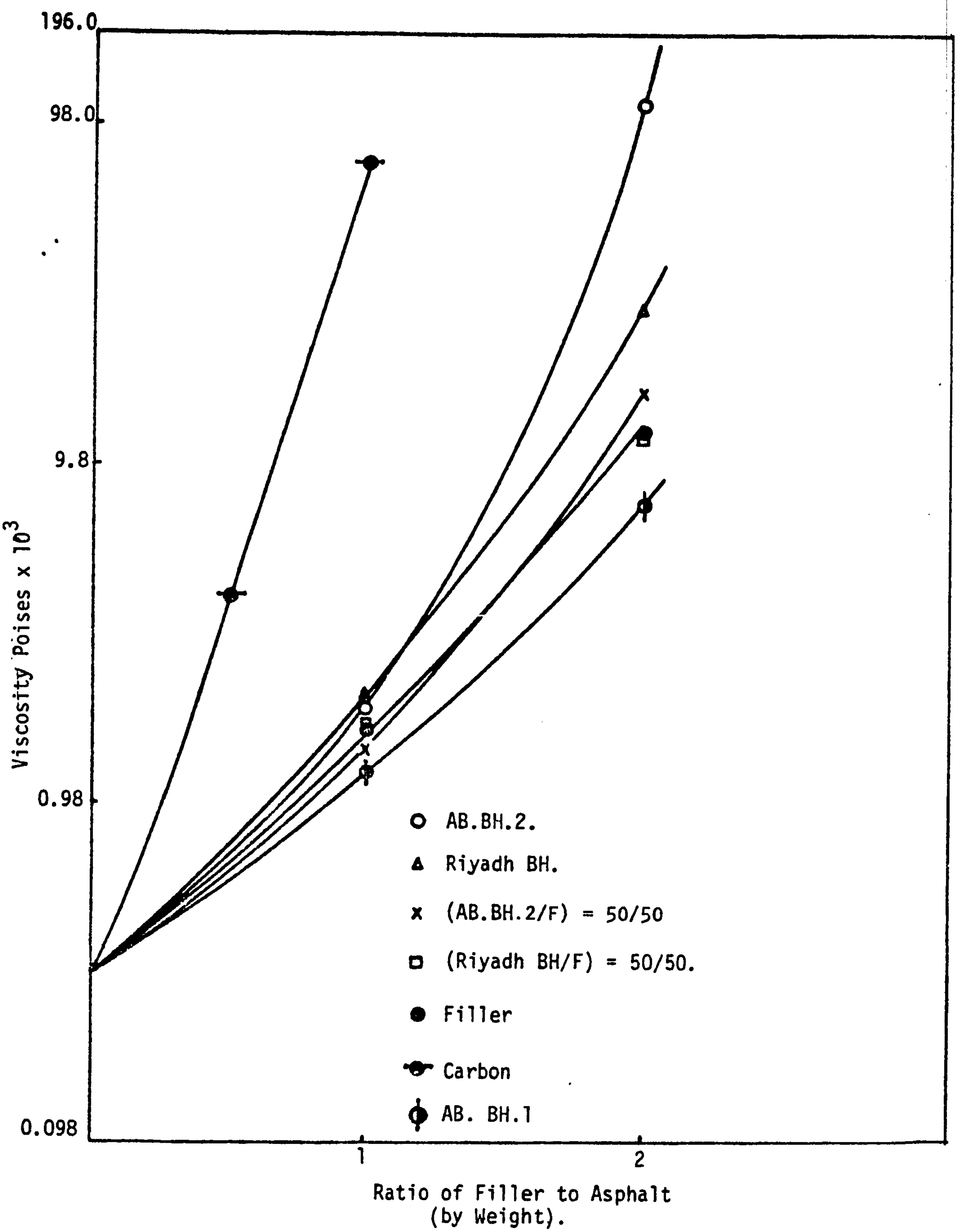


Figure 17: Viscosity Evaluation by Rehometer Analysis.

Chapter 5

EFFECT OF FILLER AND BAGHOUSE FINES ON 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. Usually, three samples were repeated for the same mix to ensure reproducibility of results.

5.1 MIXING PROCEDURE

Each aggregate sample was blended for each specimen separately according to the mix formula. Aggregates were placed in an oven at a temperature of 320°F for at least eight hours to assure hot and dry aggregate.

Asphalt was heated up to 275°F prior to mixing. Pre-heated asphalts were avoided. Excess heated asphalt was disposed of to avoid veriability in the asphalt properties. Cox and Sons self-heating mixers were used

where heating was done by electrical lamps. This mixer has a capacity of two samples at a time, as shown in Figure 18. Asphalt was added to the hot aggregate and placed in position to be mixed for at least three minutes. Standard Marshall molds, 4 in. diameter, 2½ in. high, were heated in an oven up to 270°F. The aggregate, when thoroughly mixed, was placed in the mold and compacted. The compaction effect of 50 blows was used for mixes with Riyadh and Dammam aggregates. Mixes with AB. aggregates were compacted using 75 blows. This was necessary due to the low quality of the AB. aggregates. Compacted molds were left to cool down for at least four hours before extraction. Specimens were left to cure at room temperature for 24 hours before testing.

5.2 VOLUMETRIC RELATIONSHIPS

Bulk specific gravity was determined according to ASTM specifications by weighing specimens in air; in water; and drying the surface, and again weighing in air. Then bulk specific gravity G_{bulk} was determined according to the following formula :

$$G_{bulk} = a/(c - b) \qquad (2)$$

where G_{bulk} = bulk specific gravity

a = weight dry in air

b = weight in water

c = weight surface-saturated dry in air

Bulk specific gravity for the aggregate was used in the analysis. Correction for asphalt absorption was also used to find the effective asphalt content, which was later used to find the maximum theoretical specific gravity.

5.3 TESTING PROCEDURE

Two types of tests were used. The Marshall Test was done first on specimens after they had soaked for 30 minutes in a $60^{o}C$ water bath. The second test was the evaluation of water susceptibility of each mix. This test was conducted by immersing compacted specimens in a controlled water bath at $60^{o}C$ for 24 hours. Stability was measured and stability loss was determined. It was believed that this test was more severe than the conditions existing in the field.

5.4 EFFECT OF FILLER AND BAGHOUSE FINES ON MIX DESIGN

5.4.1 Effect of Dammam Filler

Dammam aggregate is known to cause some problems in the field because of its low content of chalk. To investigate

b = weight in water

c = weight surface-saturated dry in air

Bulk specific gravity for the aggregate was used in the analysis. Correction for asphalt absorption was also used to find the effective asphalt content, which was later used to find the maximum theoretical specific gravity.

5.3 TESTING PROCEDURE

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

5.4 EFFECT OF FILLER AND BAGHOUSE FINES ON MIX DESIGN

5.4.1 Effect of Dammam Filler

Dammam aggregate is known to cause some problems in the field because of its low content of chalk. To investigate

what effects Dammam filler have on mix properties, filler was added at different percentages to the mix. These corresponded to 4, 8, 10, 12, and 15 percent of the weight of the aggregates. Initially, specimens were compacted using 50 blows on each side.

Results of the tests shown in Figure 19 indicate that as the percentage of filler increases in the mix, then the specific gravity of the mix will increase. The same trend was also observed for percentage of void filled in the mix, as shown in Figure 20. However, the percentage of air voids in the mix will decrease by increasing filler content. For an asphalt content of 6 percent, for example, the percentage of air voids dropped from 3.8 percent corresponding to a filler percentage of 4.0 to approximately 1.6 percent at filler percentage of 15.0, as shown in Figure 21.

Stability was determined for the different levels of filler content by two different methods. The Marshall stability results for samples which were soaked for 30 minutes are given in Figure 22. They indicate that an increase in the filler percentage in the mix will increase the stability. However, no results are given for the stability of mixes soaked for 24 hours. This is due to the total collapse of the specimens. Another group of

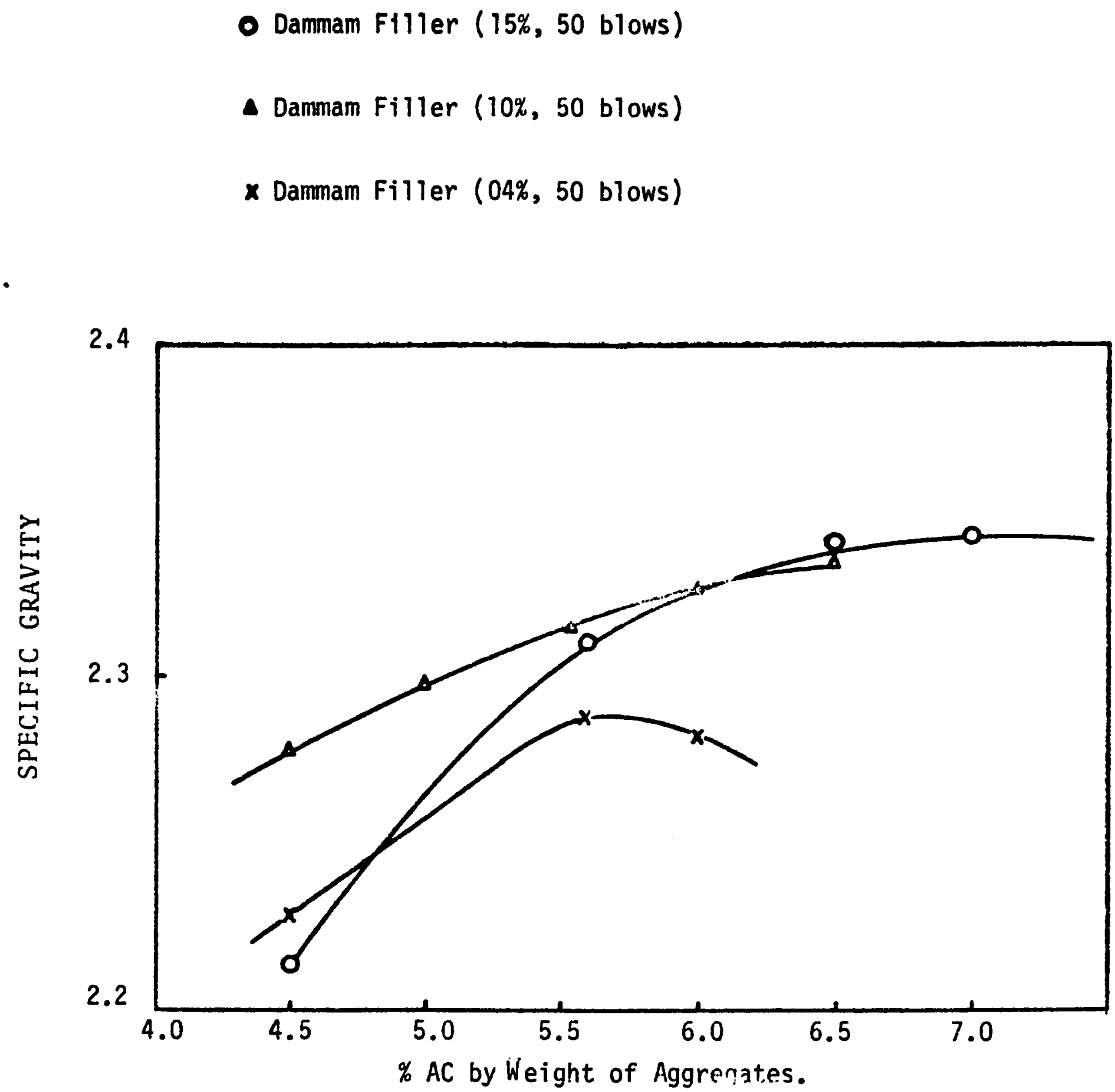


Figure 19: Specific Gravity vs. Asphalt Content for Different Percentages of Filler Content for Dammam Filler.

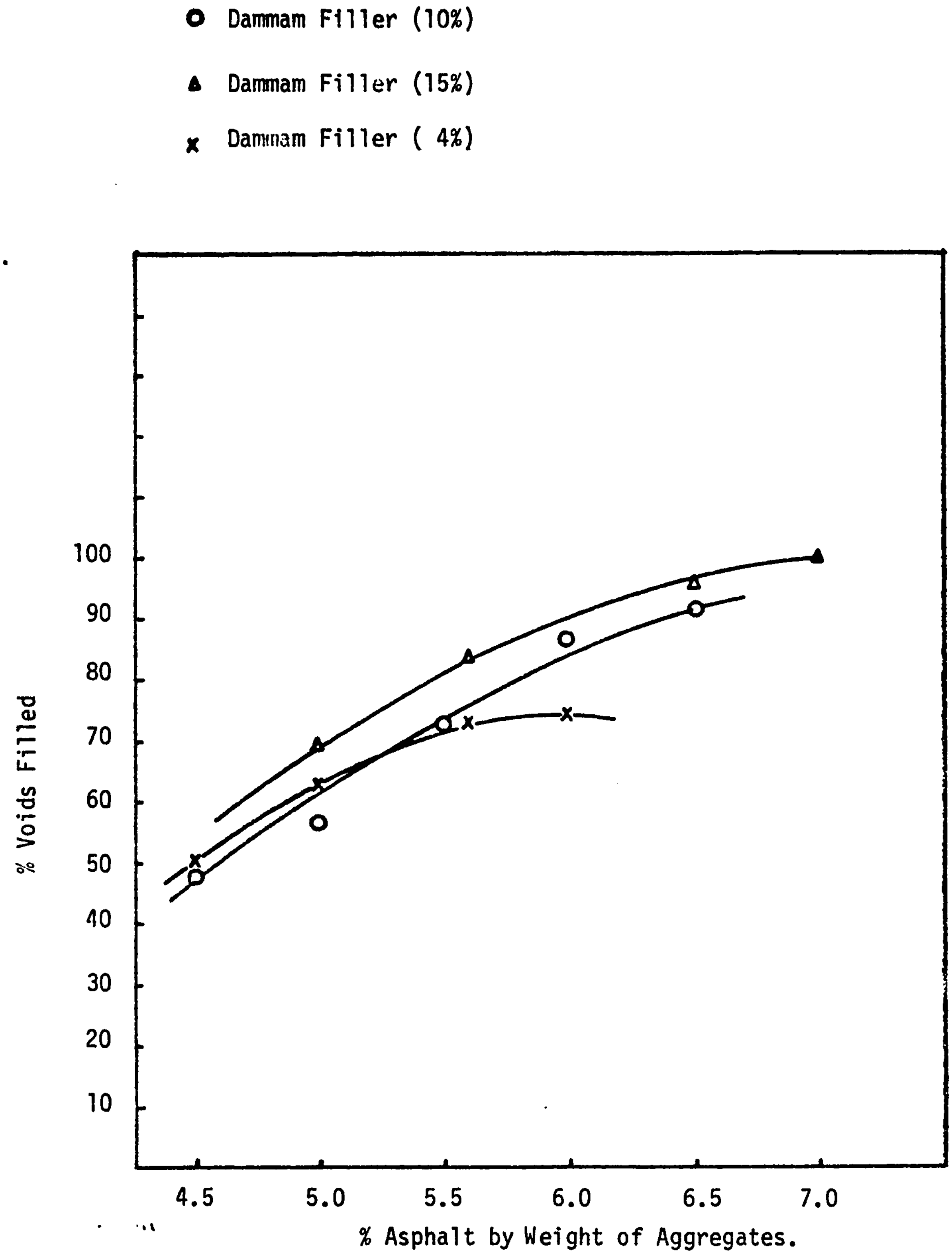


Figure 20: Percent of Air Voids Filled vs.Asphalt Content for Different Percentages of Filler Content for Dammam Filler.

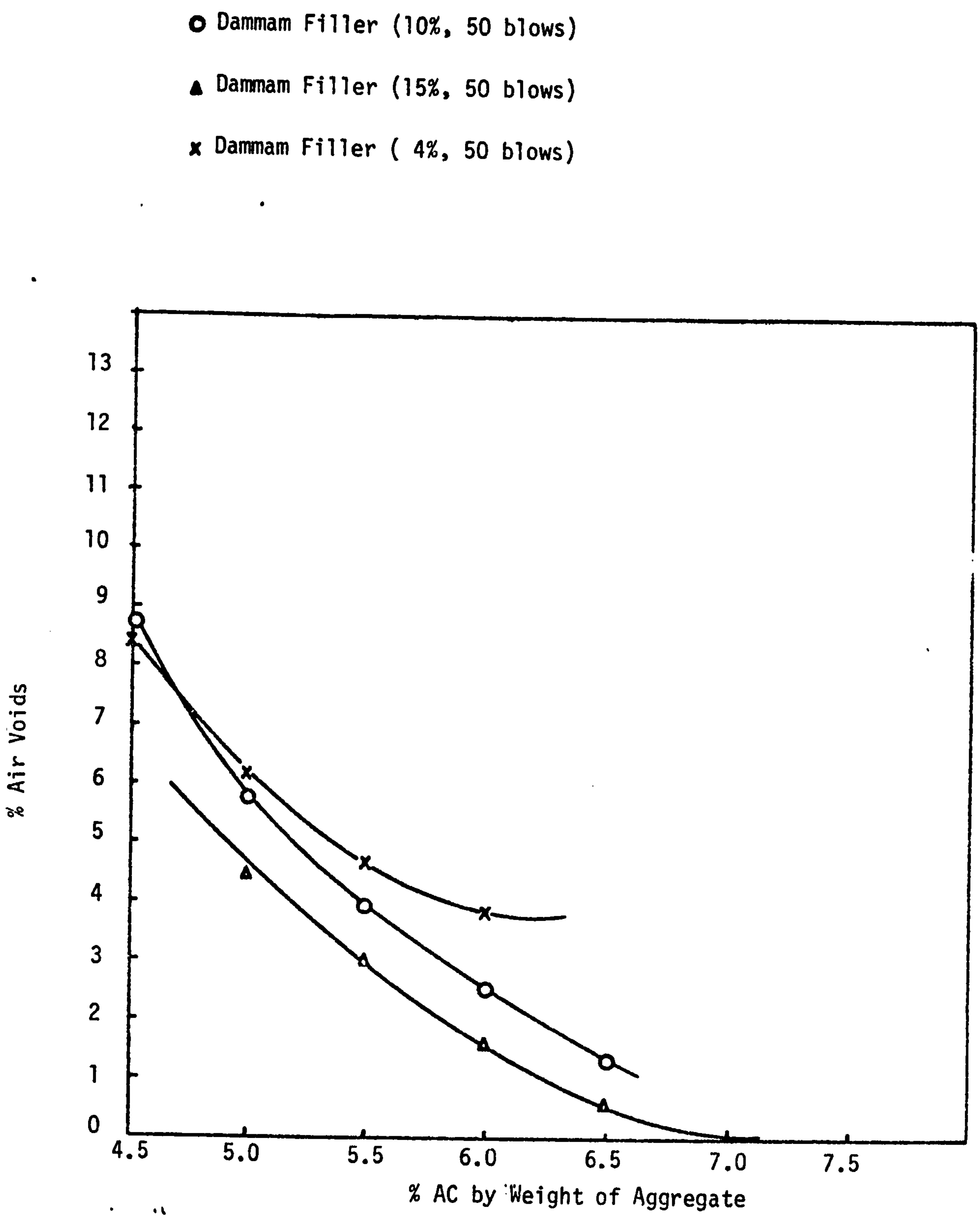


Figure 21: Air Voids Filled vs. Asphalt Content for Different Percentages of Filler Content for Dammam Filler.

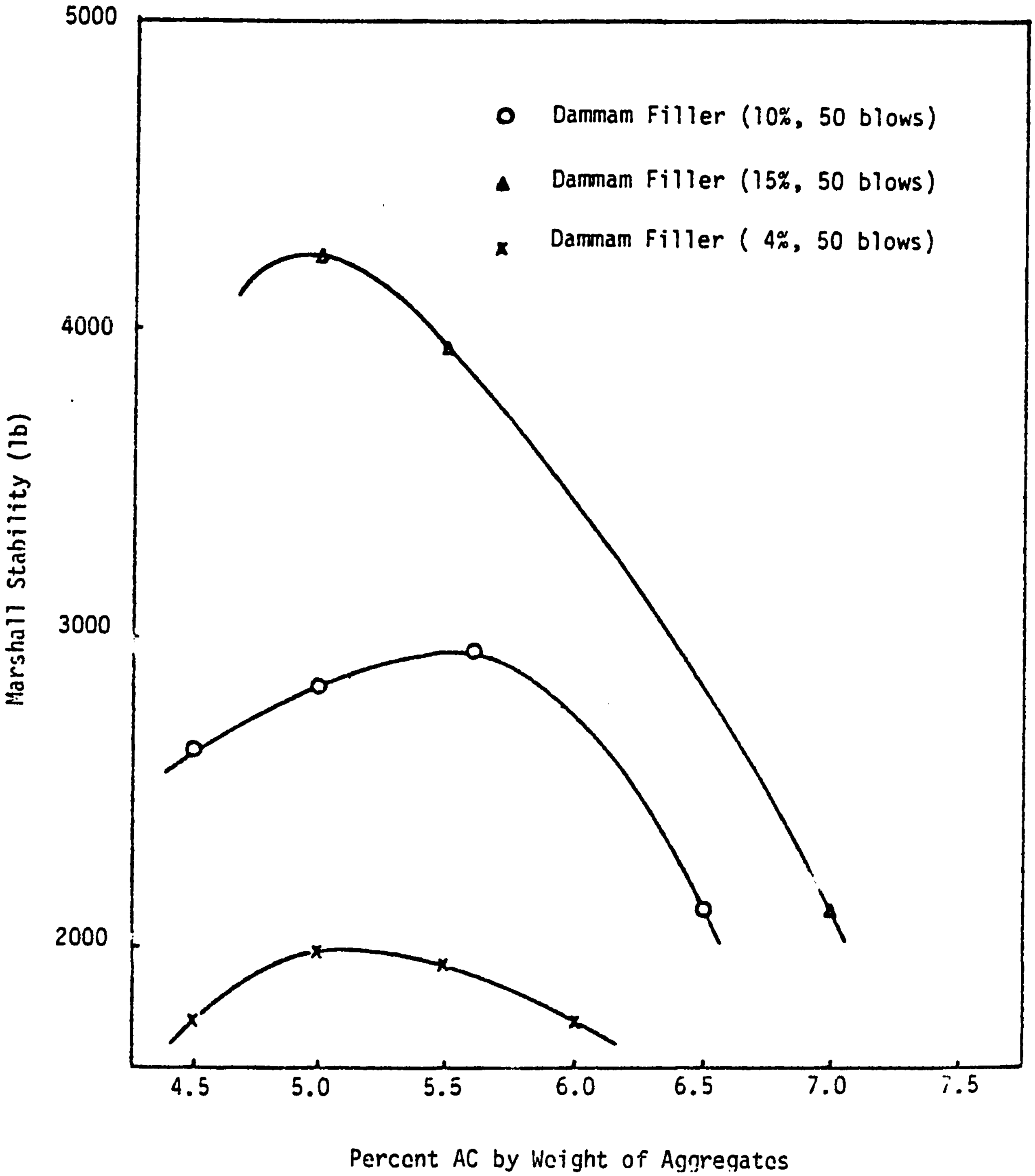


Figure 22 Stability vs. Asphalt Content for Different Percentages of Filler Content for Damman Filler

specimens were compacted using 75 blows and tested for 30-minute and 24-hour stability. After the 24-hour soaking, samples were still compact. Figure 23 shows samples after the 24-hour soaking for 50 and 75 blows. The stability loss, S_L, is defined as :

$$S_L = S_{30} - S_{24} \qquad (3)$$

where

S_{30} = stability of 30-minute soaked sample, lbs.

S_{24} = stability of 24-hour soaked sample, lbs.

and the percent stability loss, % S_L, is defined as :

$$\% S_L = \frac{S_L}{S_{30}} \qquad (4)$$

Stability results for Dammam filler are shown in Table 6. It is clear that filler content has a direct relation to stability loss. By increasing filler from 4 percent to 15 percent, stability loss increases from 39 up to 100 percent (for the same mix).

Calculations show that the optimum asphalt content* varies by varying the filler percentage. Figure 24 indicates that the optimum asphalt content increases while increasing the filler content to a maximum value of 10 percent. After that, the optimum asphalt content

* Selected according to Table 5.

TABLE - 5

OPTIMUM ASPHALT CONTENT SELECTION *

	CRITERION	
1	Marshall Stability	Maximum (> 1500 lb)
2	Specific Gravity	Maximum
3	% Air Void	(3% - 5%) (4% average)
4	% Void Filled	70% - 80% (75% average)
5	Flow 1/100"	10 - 18

*Optimum asphalt content were selected to be the average of the asphalt content at the first four criterions and then checked to satisfy the acceptable limits for flow values.

a) 50 Blows

b) 75 Blows

Figure 23: Dammam Samples After 24-Hours Soaking, for Different Compaction Efforts

Table 6

Stability Loss Analysis for Dammam Filler (75 Blows)

Percent Filler	4			8	10		15	
Percent Asphalt (of aggregate)	5.0	5.6	6.0	5.6	5.6	6.5	5.6	6.0
Marshall Stability (lb) (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 (lb) (24 hours at 60°C)	1364	1753	1250	613	355	1230	Collapse	500
Flow	22.0	16.0	22.0	25.0	34.0	25.0		34.0
Percent Loss	45.0	39.5	52.0	81.0	89.0	61.0	100	86

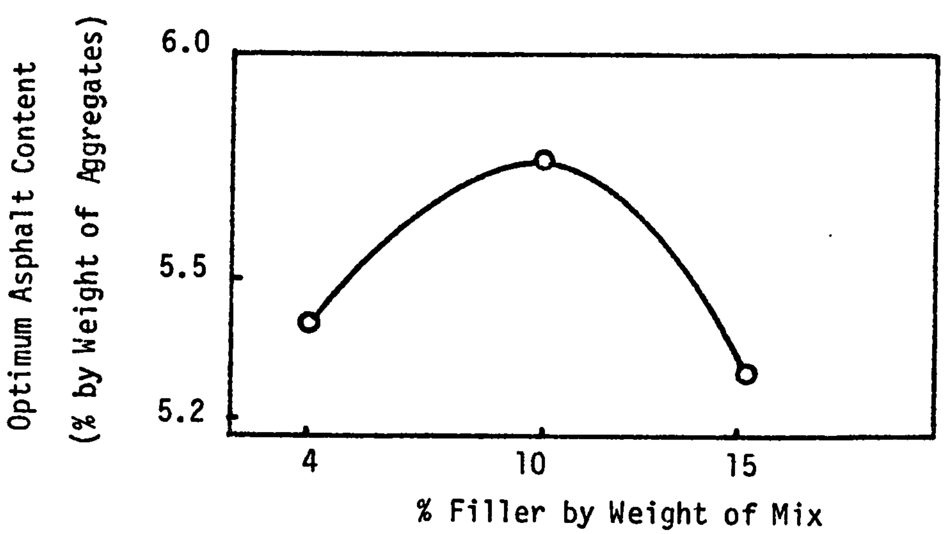


Figure 24: Optimum Asphalt Content Vs. Filler Percentage for Dammam Filler.

will start to decrease. The variation of flow values with percentage of asphalt content for different filler content is given in Figure 25. The flow values for all mixes is within acceptable limits (8-20).

5.4.2 Effect of Riyadh Baghouse Fines on Mix Design

Riyadh baghouse fines were added to the filler to form a combined filler at different proportions (filler/ baghouse fines = 100/0, 50/50, 35/65, 20/80, and 0/100). The combined filler was introduced in the mix at a ratio of 10 percent by weight of aggregate.

Optimum asphalt contents were determined for specimens compacted using 50 blows and immersed for 30 minutes corresponding to different F/BH. ratios. Figure 26 shows this relationship and indicates that the minimum optimum asphalt content is 4.75 corresponding for F/BH. ratio of 50/50. Increasing the percentage of the baghouse fines beyond this did not affect the asphalt content.

The 30-minute Marshall stability vs. asphalt content for the different F/BH. ratio are given in Figure 27. The maximum stability for each F/BH. ratio was obtained and the results are given in Figure 28. It can be seen that the maximum stability occurred at an F/BH. ratio of 50/50. To evaluate the stability loss, the 24-hour stability was

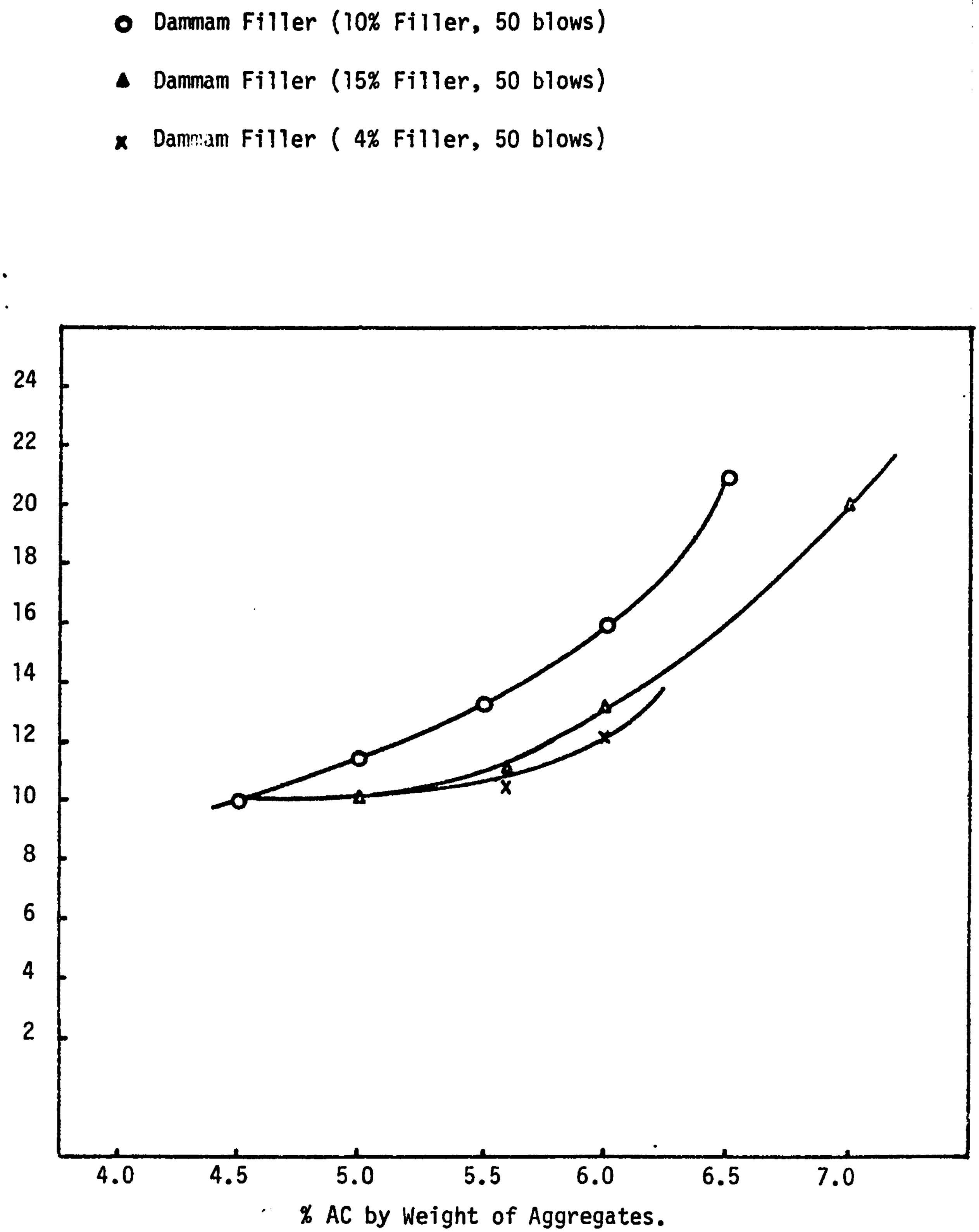


Figure 25: Flow vs. Percent Asphalt Content for Different Percentages of Filler Content for Dammam Filler.

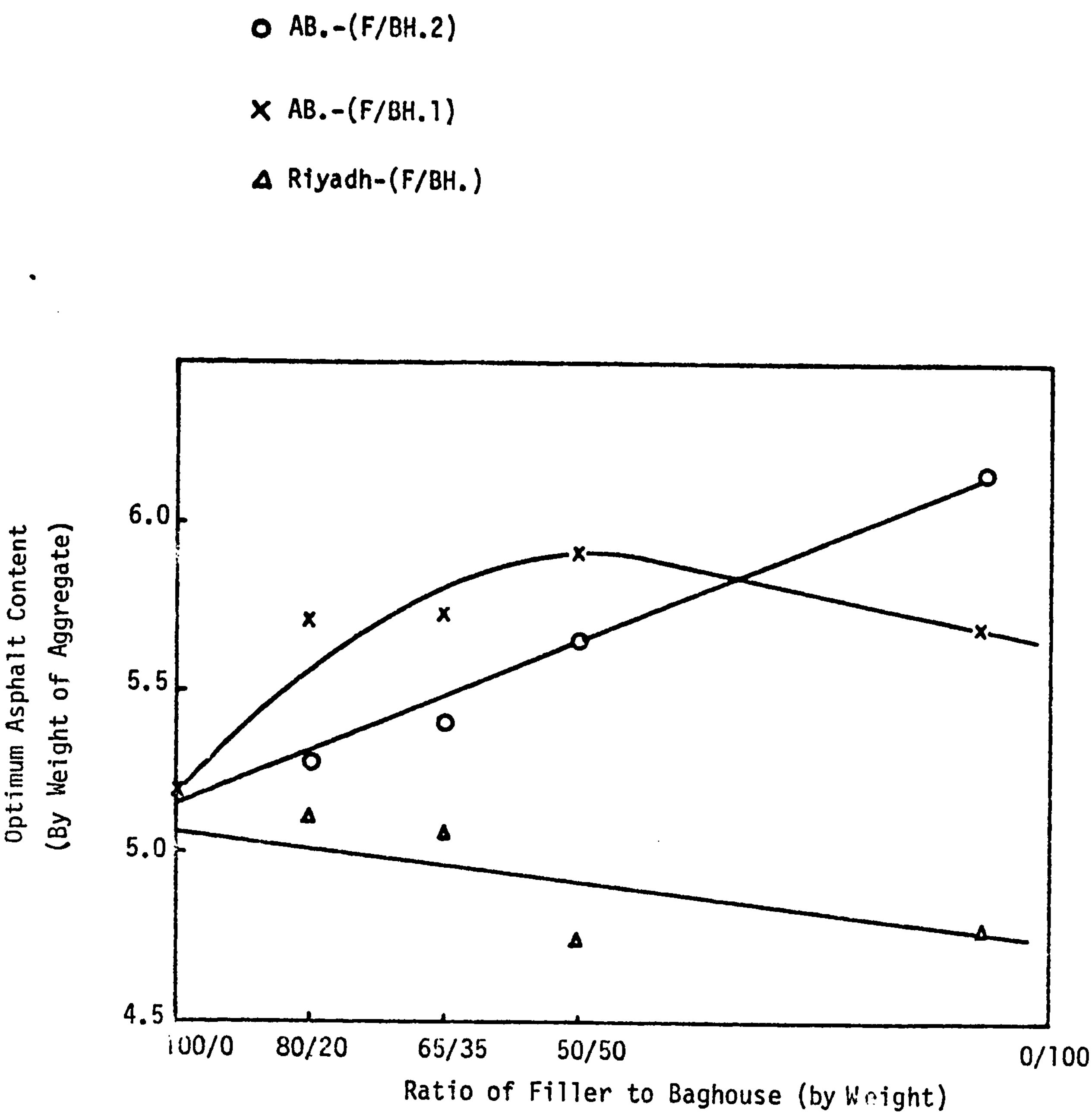


Figure 26: Optimum Asphalt Content vs. Filler/BH. Ratios.

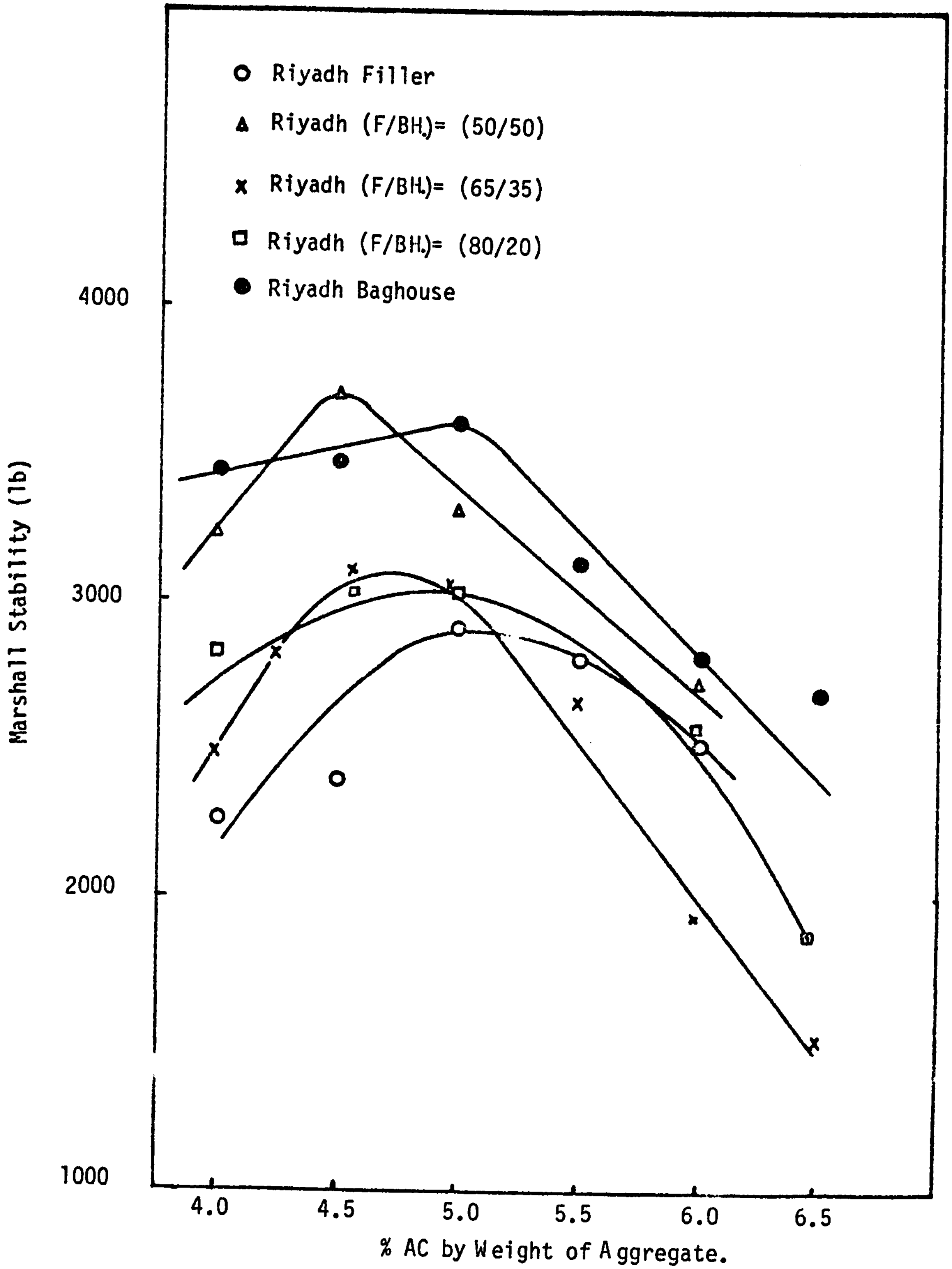


Figure-27: 30-minute Marshall Stability vs. (F/BH) Ratio for Riyadh Mixes

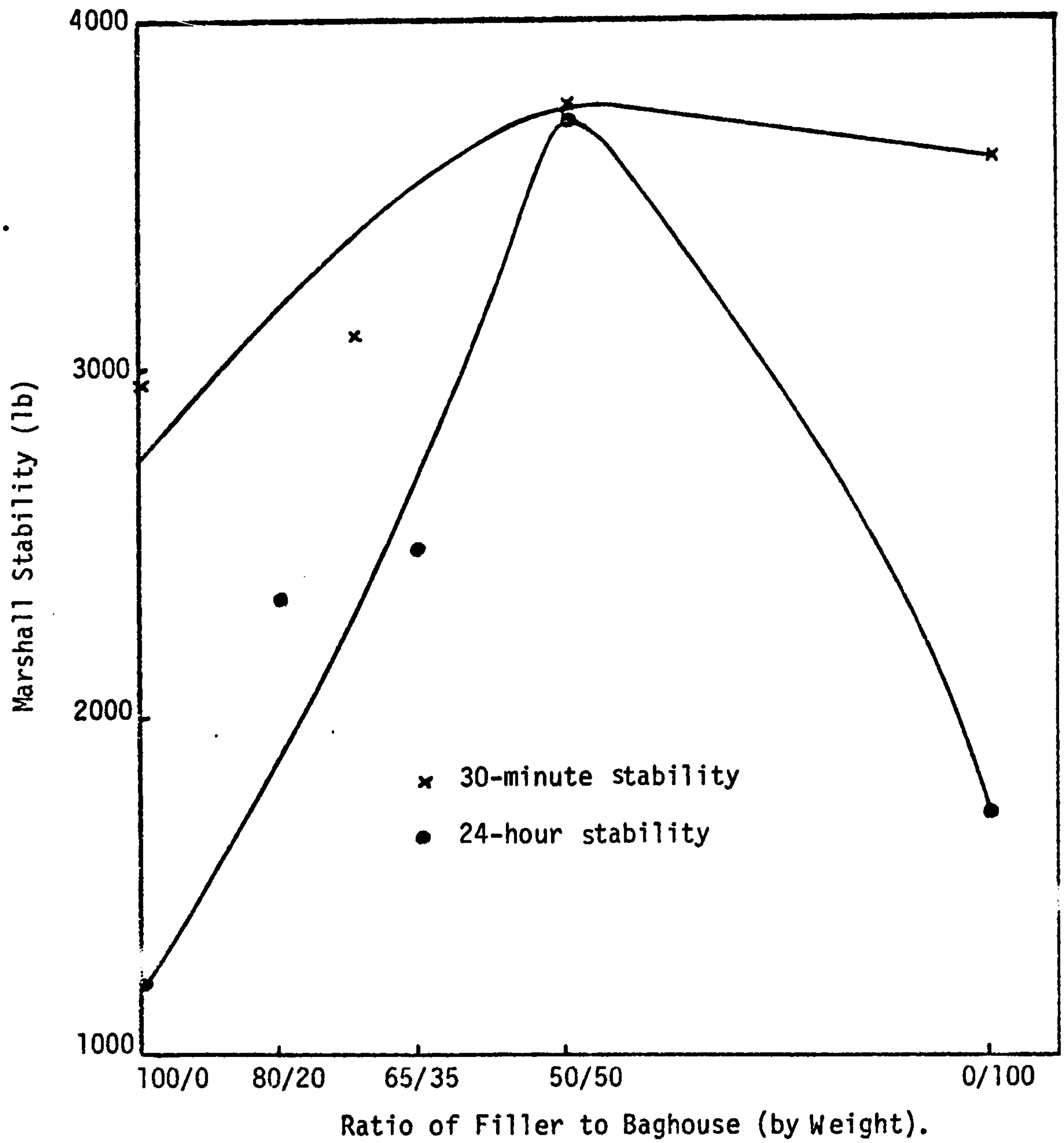


Figure 28: Stability vs. F/BH Ratio for Riyadh Mixes.

was also determined for each F/BH. ratio using the optimum asphalt content determined above. These results are again given in Figure 28. The stability loss for each ratio was determined and the results are given in Figure 29. It is clear that the stability loss decreases by an increase of F/BH. up to a value of 50/50, then stability loss starts to increase again. There was virtually no stability loss at the ratio of 50/50 as shown in Figure 28.

The effect of varying F/BH. ratio on specific gravity, air voids, and percentage voids is indicated in Figures 30, 31, 32, respectively. It is clear from these figures that the effect is very small.

5.4.3 Effect of Abohadryyah Baghouse Fines - Type I

The effect of including AB. BH. 1 in the mix was investigated by replacing portion of the 10 percent filler by AB.BH.1. Ratios of F/BH. used were identical to Riyadh baghouse fines.

Marshall stability tests were performed. The variation of specific gravity with asphalt content for different ratio of F/BH. is given in Figure 33. It shows that replacing part of the filler with AB.BH.1 decreased the specific gravity of the mix. However, the effect of increasing the percentage of AB.BH.1 did not decrease the

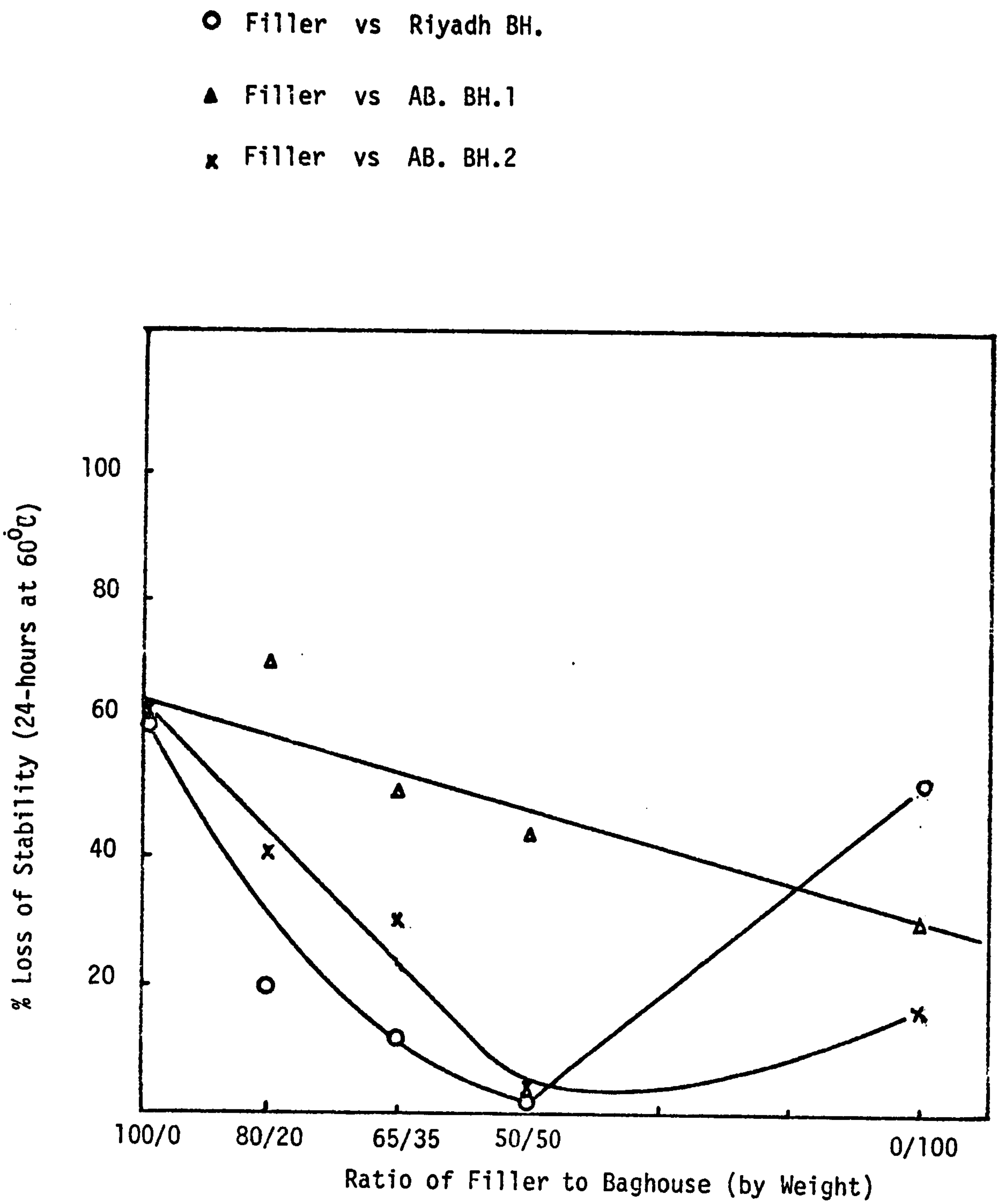


Figure 29: Stability Loss vs. F/BH Ratio.

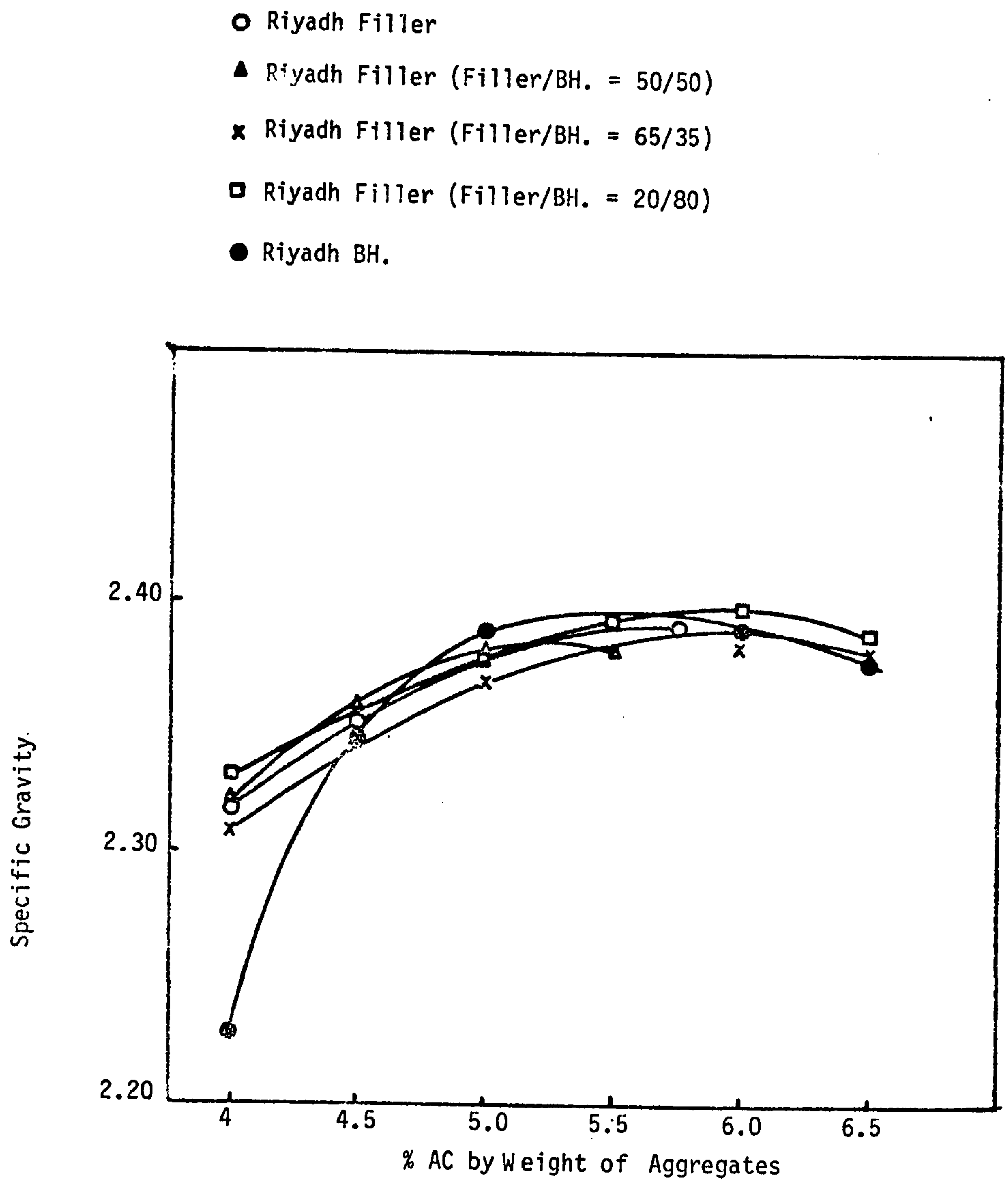


Figure 30: Specific Gravity vs. Percent Asphalt Content for Different F/BH. Ratios for Riyadh Mixes.

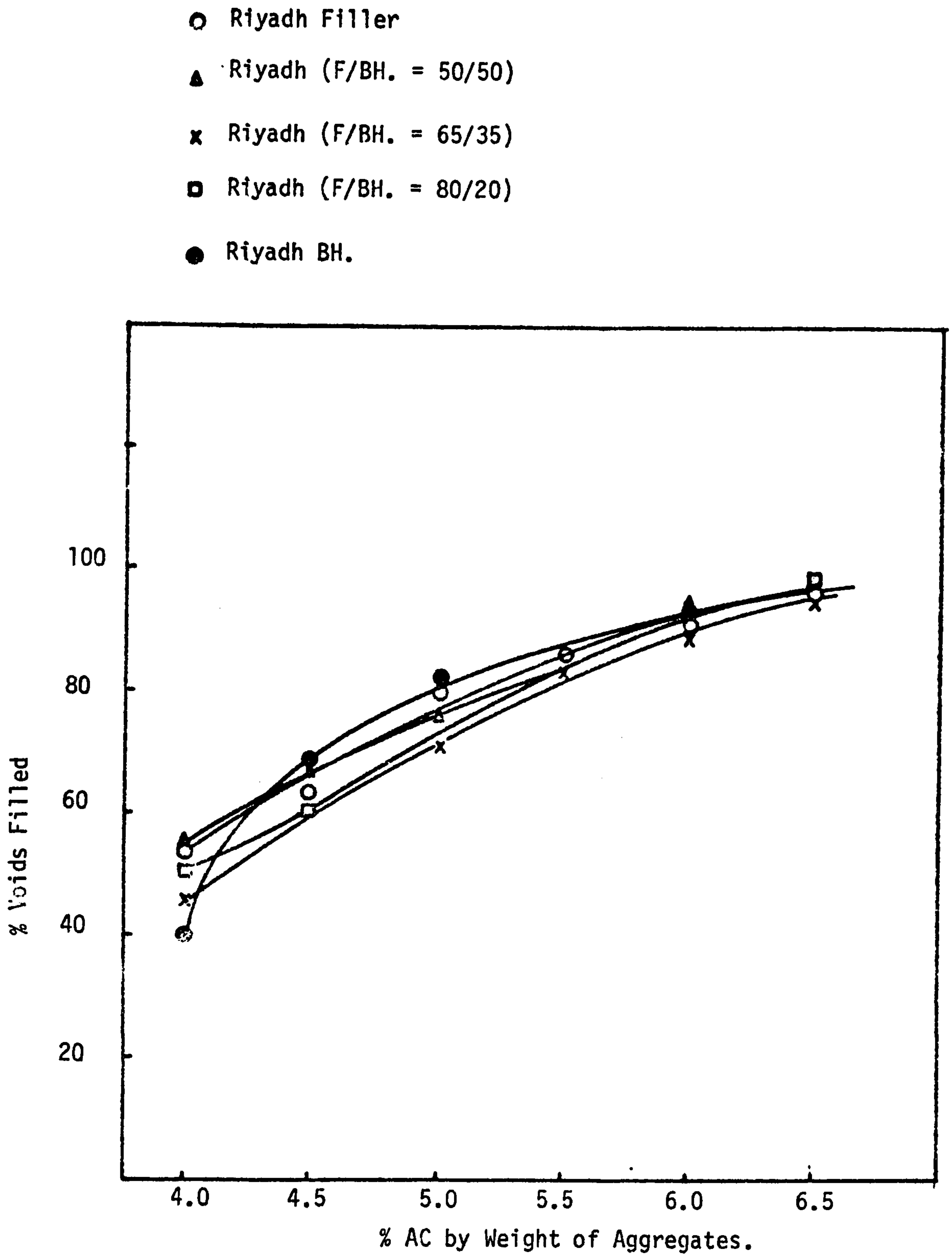


Figure 31: Percent Air Voids vs. Percent Asphalt Content for Different F/BH. Ratios for Riyadh Mixes.

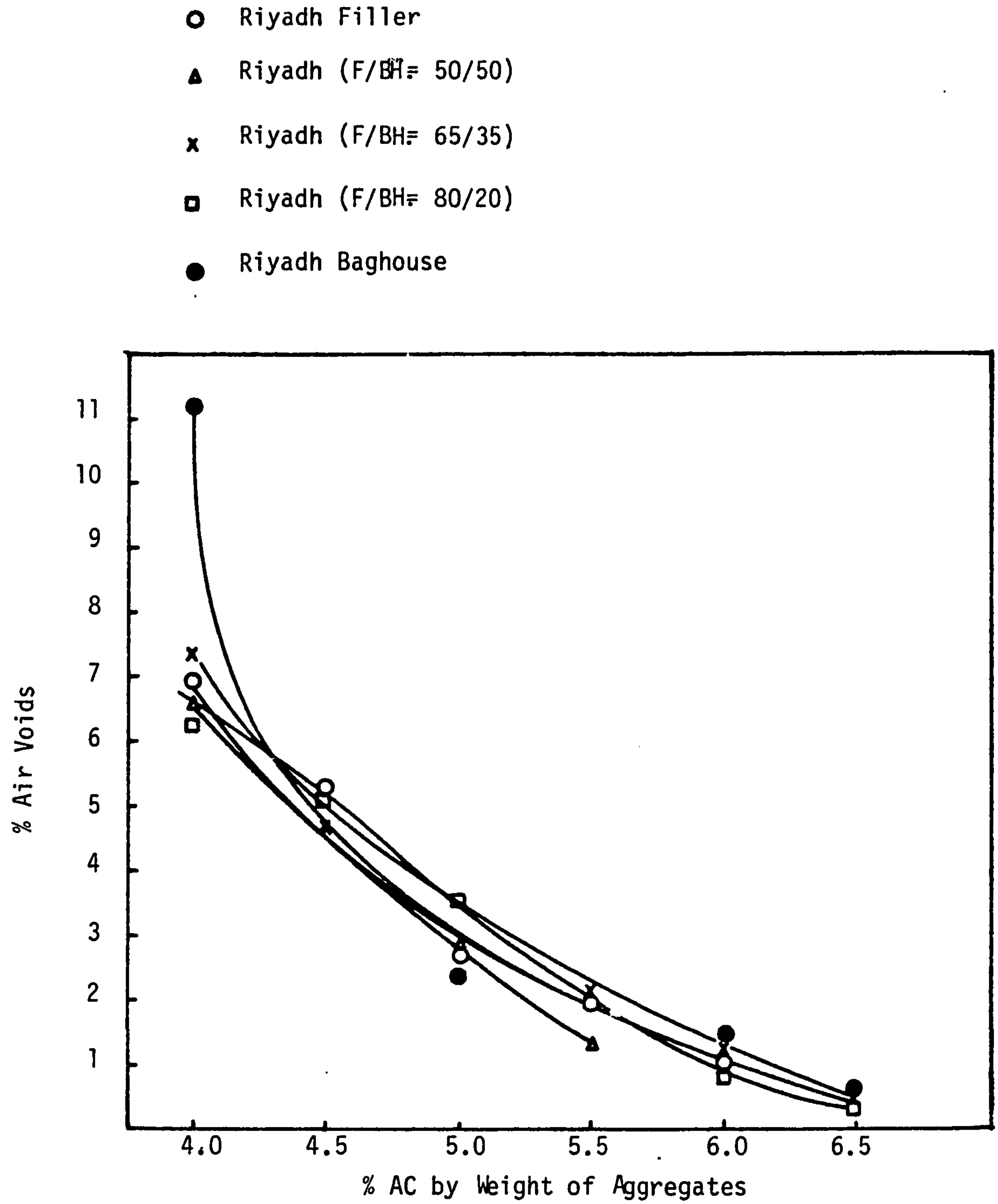


Figure 32: Percent of Voids Filled vs. Percent Asphalt Content for Different F/BH. Ratios for Riyadh Mixes

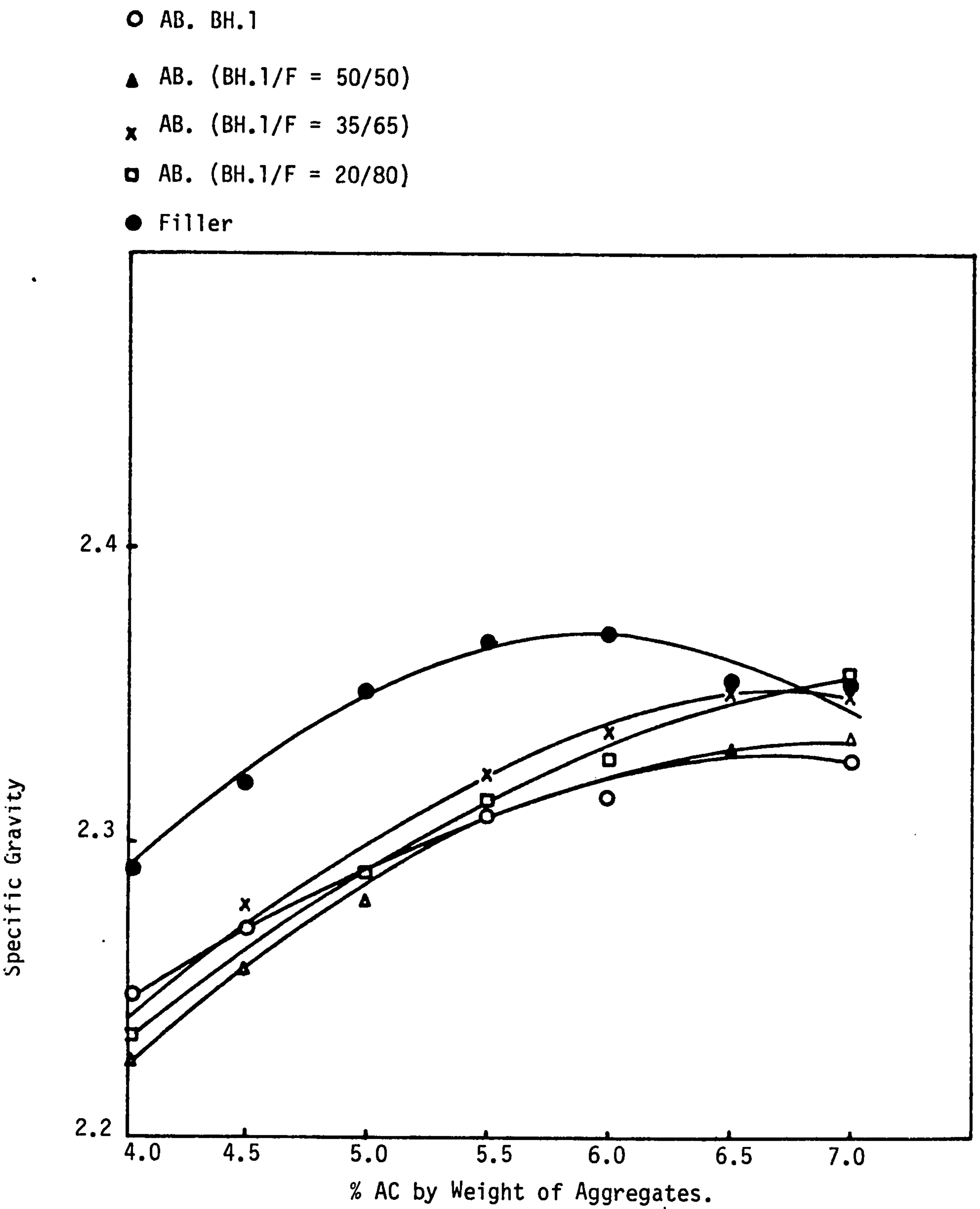


Figure-33: Specific Gravity vs. F/BH.1 Ratio for AB.BH.1.

specific gravity appreciably. The same conclusion applies to the variation of percent of voids filled, as shown in Figure 34.

Increasing the F/BH., however, led to a decrease in the percent in voids, as shown in Figure 35.

The stability of the mixes using varying F/BH. ratios is given in Figure 36. To investigate how the F/BH. affects the optimum asphalt content of the mix, the optimum asphalt content of each mix was determined, along with the stability corresponding to this optimum and its variation with F/BH., as given in Figure 37. It can be seen that the stability is not affected by increasing F/BH. up to 50/50. A slight drop in stability was observed beyond this ratio.

The 24-hour stability was determined for F/BH. ratios using the optimum asphalt content determined above. The results given in Figure 37 indicate that stability increases by an increase in the F/BH. ratio. The stability loss for each F/BH. was determined and the results are presented in Figure 29. It shows that as F/BH. increases, the loss of stability decreases. The stability loss dropped from 64 percent when no AB. BH.1 was used to about 30 percent when all the filler was replaced with AB. BH.1.

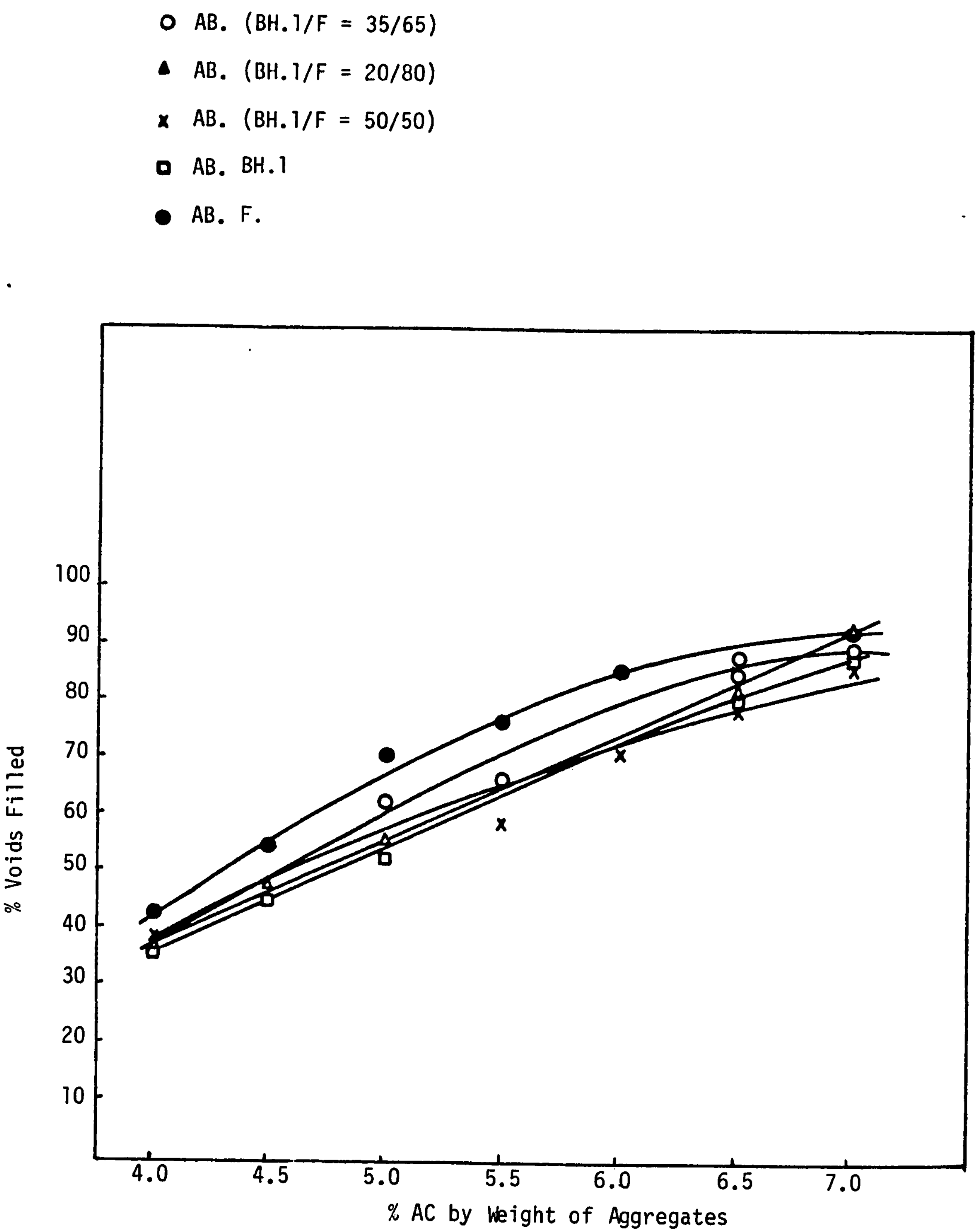


Figure 34 : Percent of Voids Filled vs. F/BH.1 Ratio for AB.BH.1.

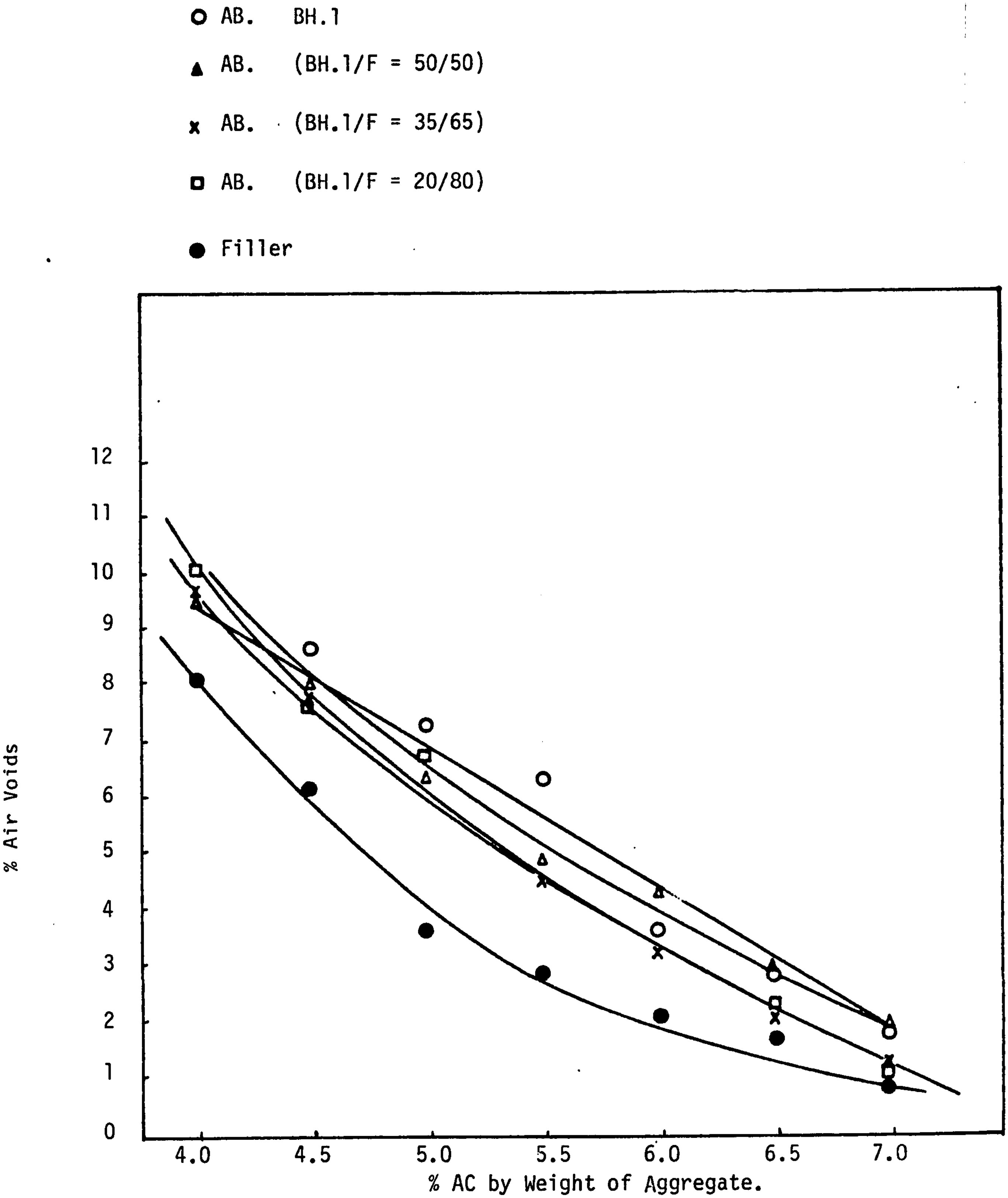


Figure 35 : Percent of Air Voids vs. F/BH.1 Ratio for AB.BH.1.

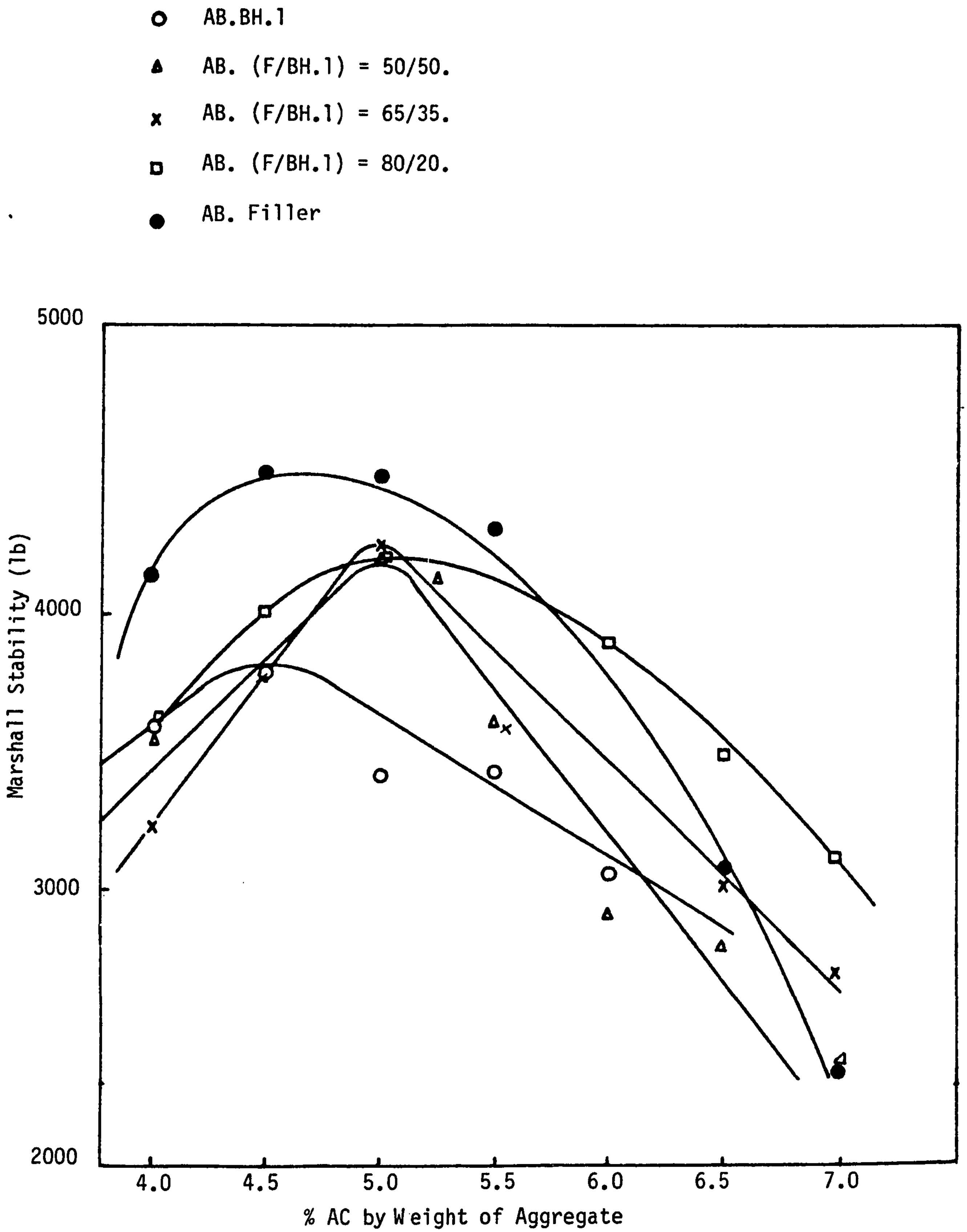


Figure 36: 30-minute Marshall Stability vs. F/BH Ratio for AB.BH.1.

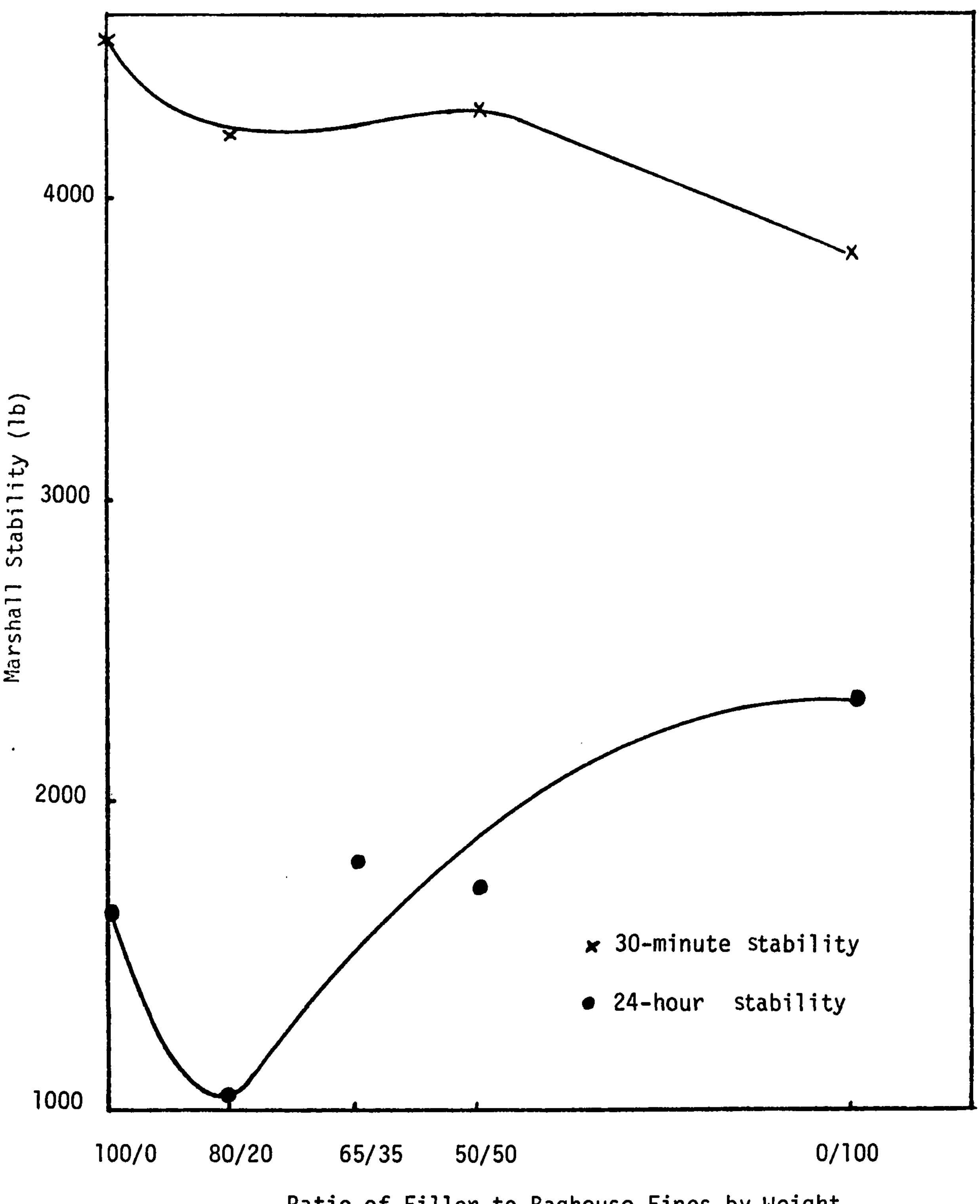


Figure 37: Marshall Stability vs. F/BH. Ratio for AB.BH.1.

The inclusion of AB.BH.1 in the mix has affected the optimum asphalt content. The optimum asphalt content increased from 5.21 percent when no AB.BH.1 was used up to a maximum value of 5.93 percent at a F/BH.1 ratio of 50/50. Beyond this ratio, the optimum asphalt content starts to drop slightly, as shown in Figure 26.

5.4.4 Effect of Abohadryyah Baghouse Fines - Type II

The effect of including AB. BH.2 in the mix was investigated by replacing portion of the 10 percent filler by AB. BH.2. Ratios of F/BH. used were identical to those for Riyadh baghouse fines.

Difficulties were encountered in mixing AB.BH.2 with an aggregate (at the ratio of F/BH = 0/100) at an asphalt content greater than 5.5 percent of the aggregate. This was caused by the quick hardening of asphalt/AB.BH.2, at 260°F. The mix temperature was raised up to 320°F, then the mix was compacted.

Marshall stability tests were performed. The variation of specific gravity is given in Figure 38. It shows that replacing part of the filler with AB. BH.2 decreased the specific gravity of the mix. It is clear that as the F/BH. ratio decreases, specific gravity decreases except for the 50/50 ratio. The same conclusion applies

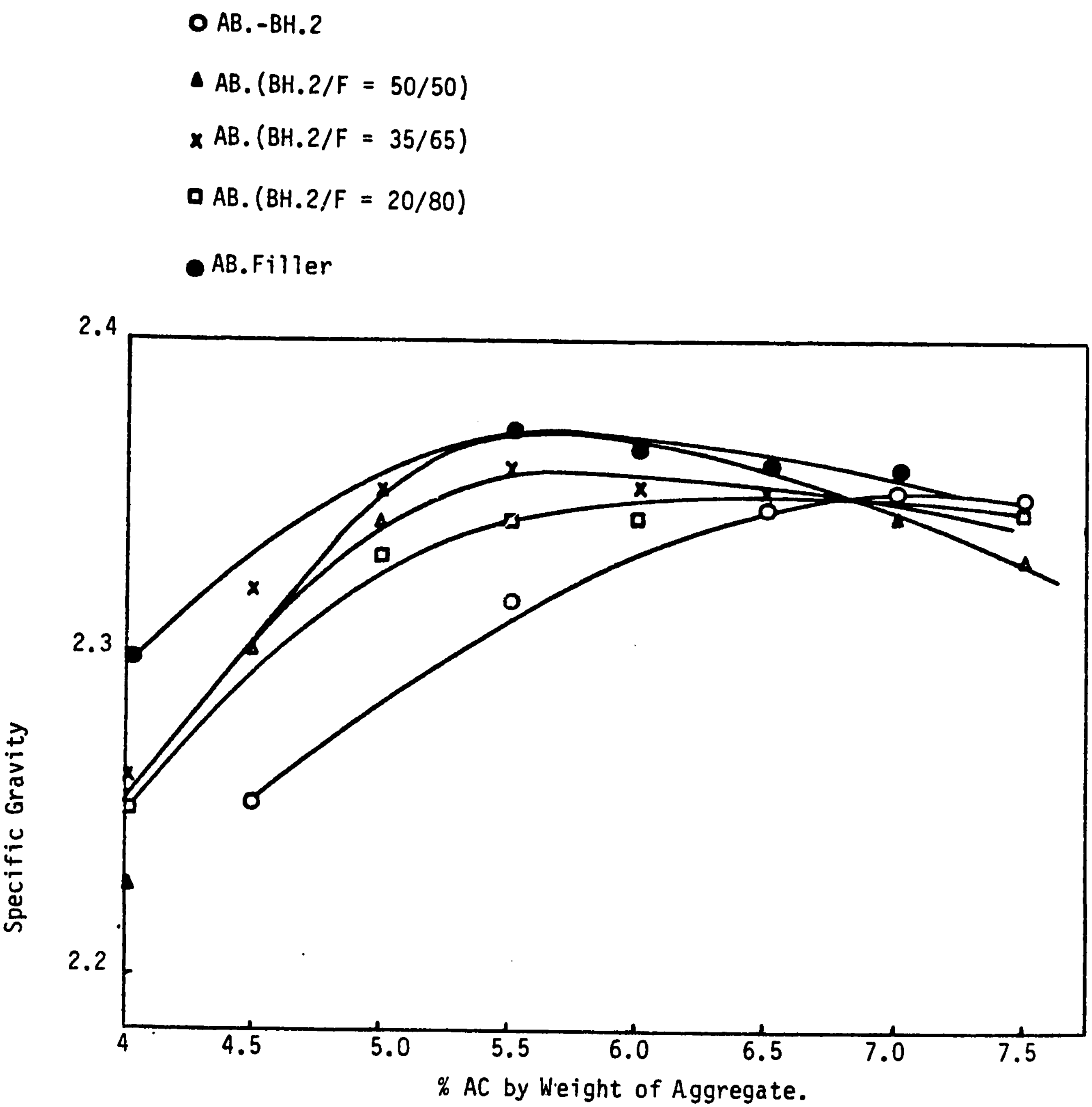


Figure 38: Specific Gravity vs. Percent AC for Different Ratio of F/BH.2 for AB.BH.2.

for the variation of percent voids filled, as shown in Figure 39. Increasing F/BH. will lead to a decrease in the percent of air voids, which is shown in Figure 40.

The stability of the mixes using varying F/BH. ratios was found, as shown in Figure 41. To investigate the effect of baghouse fines on the optimum asphalt content of the mix, the optimum asphalt content of each mix was determined. Stability corresponding to the optimum was determined, and variation with F/BH. is given in Figure 42. It indicates that the stability decreases by decreasing the F/BH. ratio.

The 24-hour stability was determined for F/BH. ratios using the optimum asphalt content determined above. The result given in Figure 42 indicates that stability increases by an increase in the F/BH. ratio. The stability loss for each F/BH. was determined and the results are shown in Figure 29. It shows that as F/BH. increases, the loss of stability decreases to a minimum at an F/BH. ratio of 50/50. Beyond that, stability loss increases slightly. Stability loss dropped from 62 percent when no AB. BH.2 was used to about 2 percent at an F/BH. ratio of 50/50, and then increased to 16 percent when all the filler was replaced with AB. BH.2.

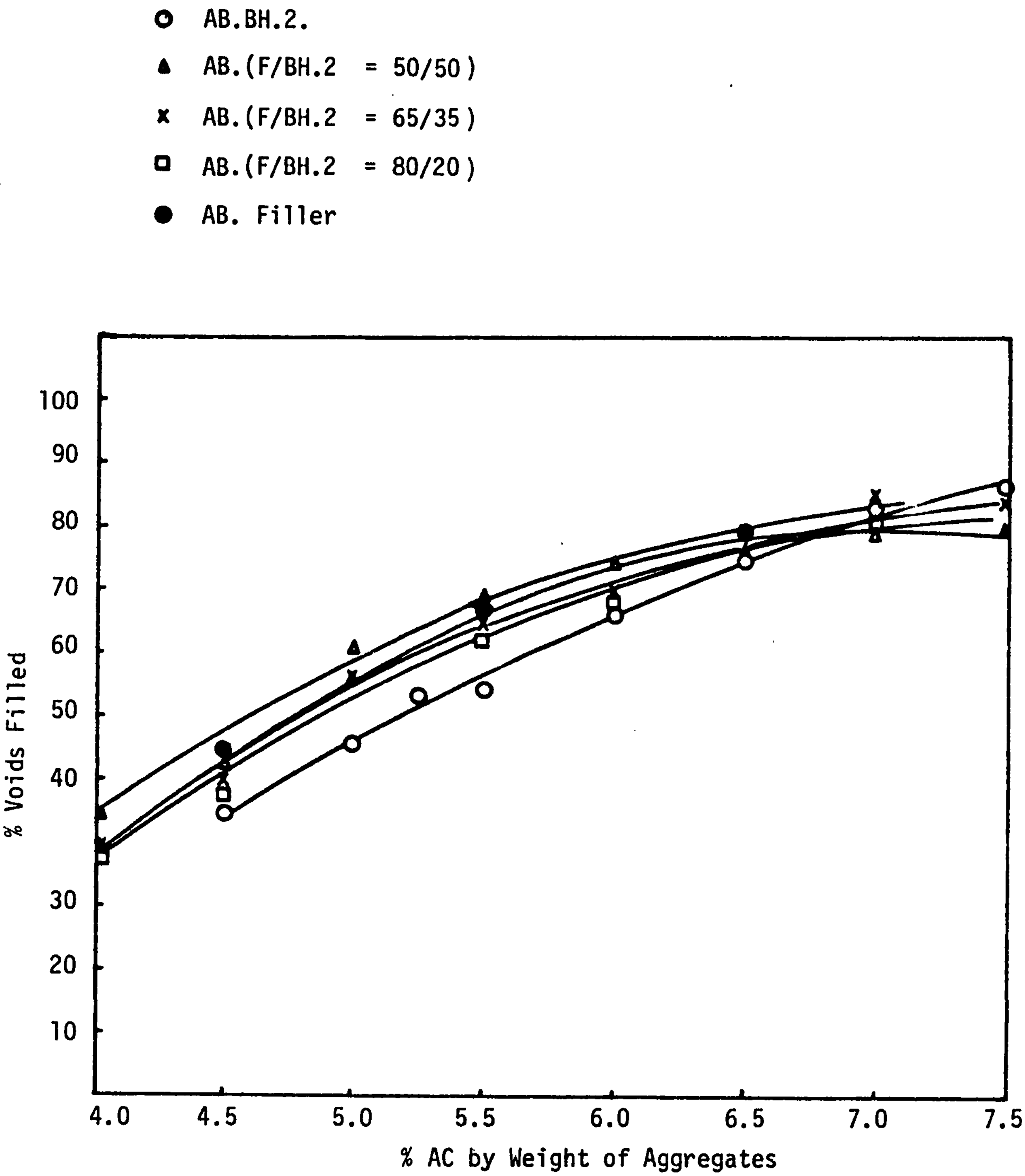


Figure 39: Percent Air Void Filled vs. Percent AC for Different Ratios of F/BH.2 for AB.BH.2.

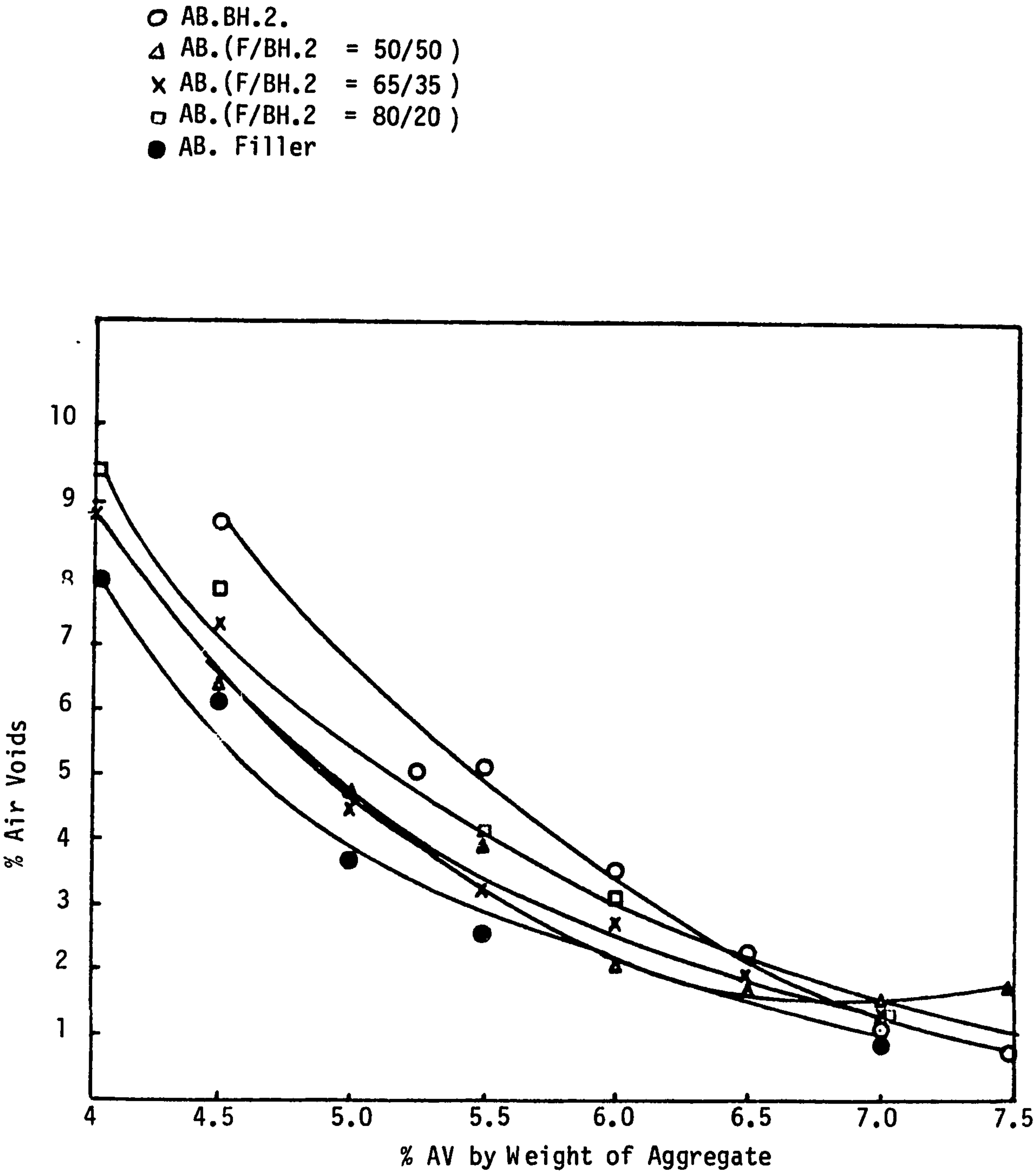


Figure 40: Percent Air Void vs. Percent AC for Different Ratios of F/BH.2 for AB.BH.2.

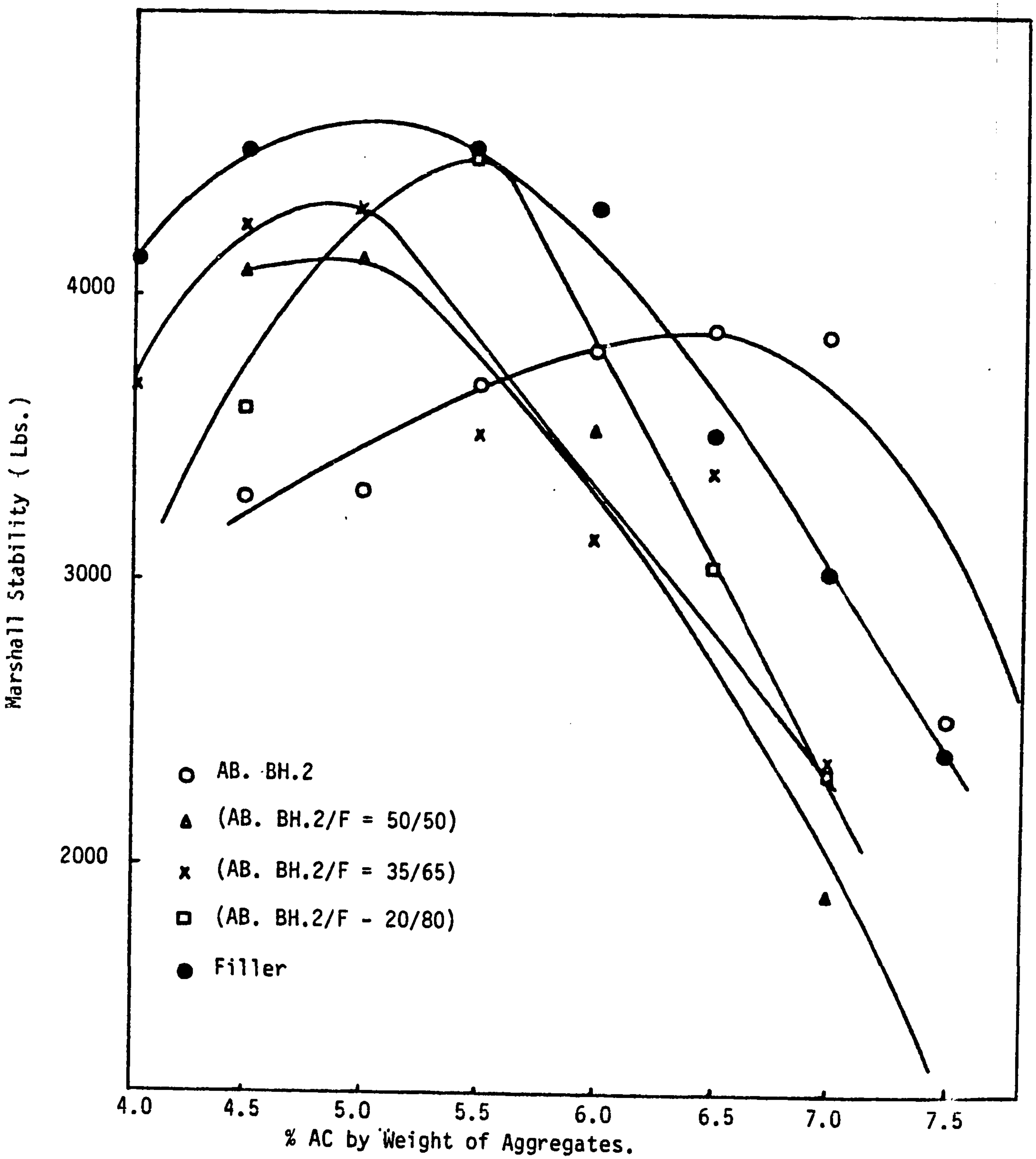


Figure-41: 30-minute Stability vs. Percent AC for Different Ratios of F/BH.2. for AB.BH.2.

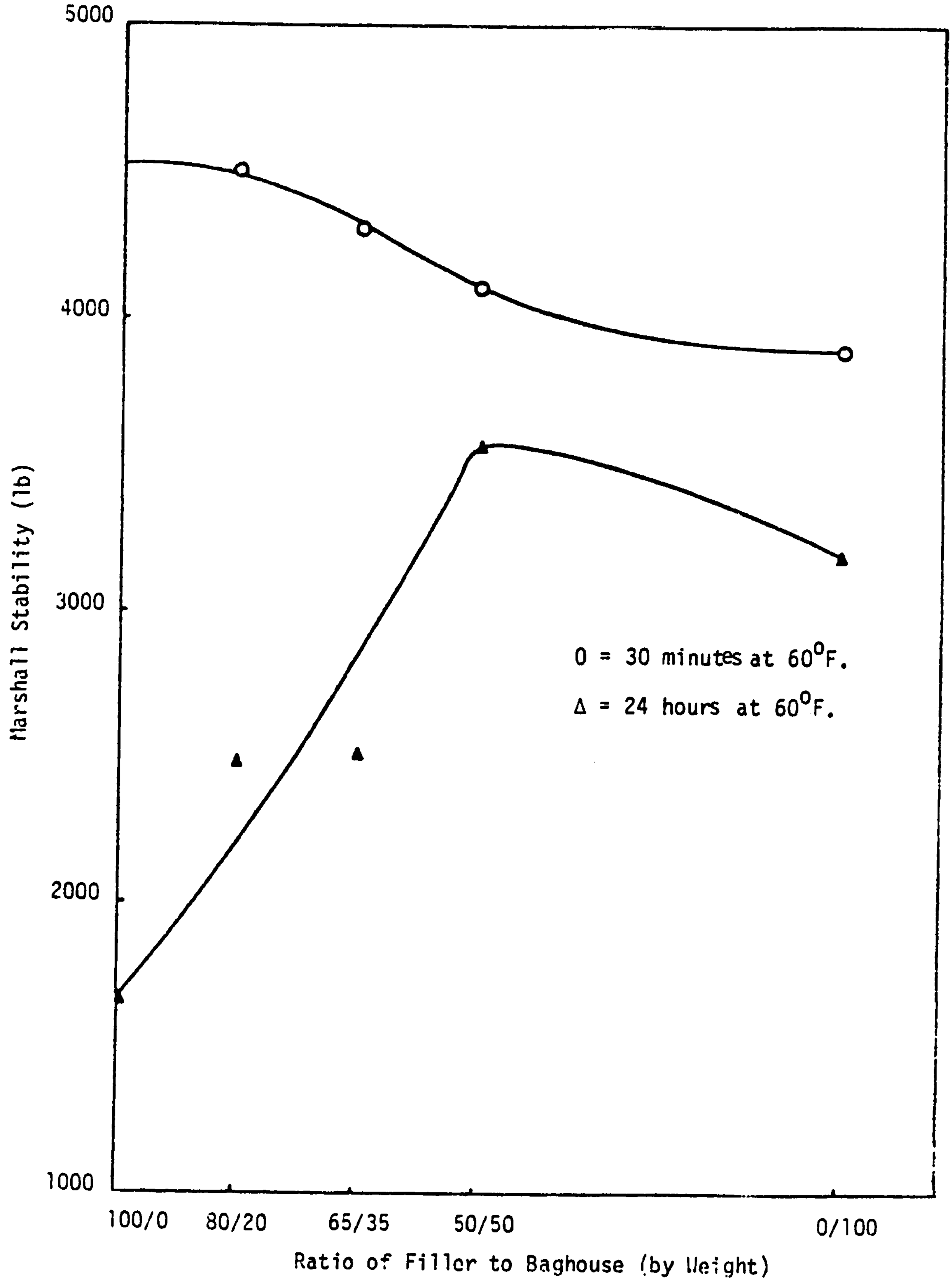


Figure 42: Stability vs. F/BH.2 Ratio for AB.BH.2

The inclusion of AB.BH.2 to the mix thus affected the optimum asphalt content. The optimum asphalt content increased from 5.21 percent when no AB.BH.2 was used up to a maximum value of 6.17 percent when filler was replaced by AB.BH.2, as shown in Figure 26.

Chapter 6

DISCUSSIONS AND CONCLUSIONS

6.1 DISCUSSION OF RESULTS

This section will discuss the results presented in Chapter 5. A comparison of the effects of the different sources of baghouse fines on the mix design will be given. A discussion for the different tests performed is given below.

6.1.1 Penetration

Penetration tests conducted on the asphalt filler mortars gave a good indication of the decrease in consistency due to the addition of filler. Similarly, when baghouse fines were added, penetration decreased linearly, as was shown in Figures 11 and 12. Greater decrease in penetration was observed when AB. BH.1 and AB. BH.2 were used. This decrease was mainly caused by the black carbons in these baghouse fines.

6.1.2 Softening Point

Softening points were different when different baghouse fines were used. The softening points when Riyadh baghouse fines and filler were used gave very close values. It was found that the addition of carbon to asphalt increases the softening point tremendously. It makes asphalt less susceptible to temperature. Due to this phenomenon, Abohadryyah baghouse fines gave higher softening points, as they contain some percentage of carbons. AB. BH.1 contains about 0.4 percent carbon while AH. BH.2 contains about 7.0 percent carbons.

AB. BH.2, when used in mixes where the ratio of AB. BH.2 to asphalt content was 2.0, caused quick hardening at 260°F. This difficulty, which was caused by carbons, was eliminated by raising the temperature of mix up to 320°F.

6.1.3 Viscosity

The viscosity analysis indicated a similar trend for the softening point, except for Riyadh BH. Viscosity was increased by increasing carbon content, as shown in Figure 16. Baghouses fines gave higher viscosity than filler, which gave lowest viscosity. Riyadh baghouse fines gave higher viscosity than AB. BH.1, but lower than

AH. BH.2.

Carbons cause an increase in the viscosity of asphalt, so that carbons which have a tremendous surface area cause a rapid increase in asphalt viscosity. It is quite difficult 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.

6.1.4 Mix Design

Filler has a significant effect on mix properties. Marshall stability increase by increasing the amount of filler. Adding filler increased the specific gravity of the mix and void filled, and decreased the percentage of air void. Optimum asphalt content varied significantly by adding filler, as was illustrated in Figure 24.

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, then stability decreased, as illustrated in Figure 27. Optimum asphalt content increased slightly by adding BH., then decreased to a minimum value at F/BH. = 50/50, then increased. Percentage of air void varied in a short range.

Abohadryyah baghouse fines, when added to the mix, caused a slight reduction in stability. As the amount of baghouse was increased stability decreased till it reached the minimum at a ratio of F/BH = 0/100. Air voids and percent of air voids filled were varying in a wide range (wider than, Riyadh BH.).

Optimum asphalt content was increased in AB. BH.1 up to the maximum at a ratio of F/BH = 50/50, then decreased (opposite to Riyadh BH.). Optimum asphalt content was increased linearly by adding AH. BH.2. This increase in optimum was due to the existence of carbons.

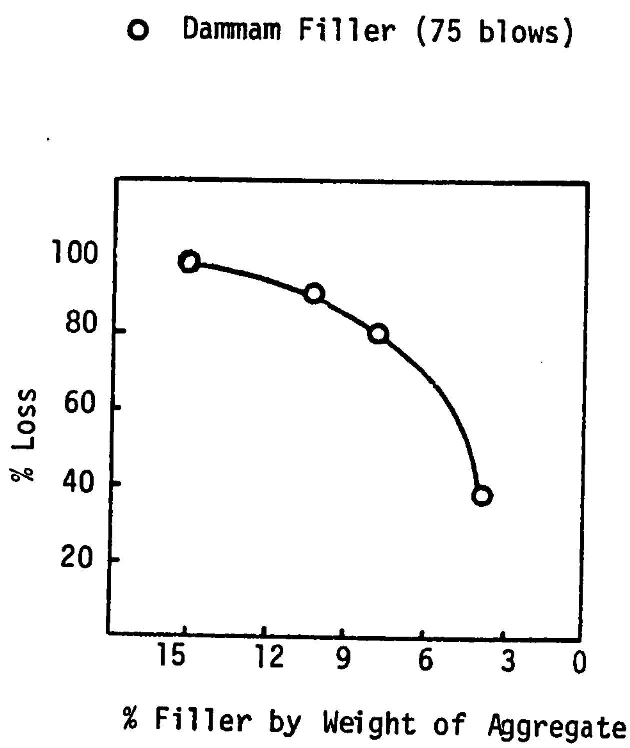
6.1.5 Loss of Stability

The major problem with Dammam and Abohadryyah mixes was the loss of stability. Dammam mix was found to be affected greatly when immersed for 24 hours at 60°C. Samples compacted by 50 blows on each side collapsed regardless of the filler used. By increasing the compaction effort to 75 blows on each side, stability loss decreased tremendously.

The amount of filler was found to be one of the main contributors to stability loss and possibly the major reason. By increasing the filler from 4 percent up to 15 percent, stability loss (at 75 blows) increased from

39 percent up to 100 percent, as shown in Figure 43. Stability loss was found to decrease by increasing asphalt content above the optimum for filler content larger than 8 percent, as given in Table 5. The effect of filler on stability loss was obvious when used in the Riyadh mix. Although Riydh gravels are sound and should not be influenced by water, Riyadh filler mix had a high stability loss, reaching 60 percent or higher. This loss was attributed mainly to the filler (limestone dust).

It was found that Riyadh baghouse fines can decrease the stability loss tremendously and can prevent it. By increasing the amount of baghouse fines in the filler, stability loss decreased gradually to approximately 2.0 percent at an F/BH. ratio of 50/50. In fact, some of the specimens showed higher stability after 24 hours than after 30 minutes. By adding more baghouse fines, stability loss increased. At a combined ratio of 50/50, an ideal filler is obtained requiring the minimum optimum asphalt content and giving 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 in AB. BH.2, where stability loss decreased from 62 to 4 percent at a Filler/BH. ratio



Figur 43: Stability Loss vs. Filler Content for Dammam Mix Using 75 Blows.

of 50/50, then increased to 15 percent at a F/BH. ratio of 0/100.

Stability loss at a F/BH ratio of 0/100 for AB. BH.2 was lower than that for AB. BH.1, which in turn was lower than Riyadh BH., as shown in Figure 29. This effect was caused by carbon fines which exist in AB. BH.2 at 6 percent concentration, while it is only 0.5 percent in AB. BH.1, and zero percent for Riyadh baghouse fines. It is believed that carbon fines increase the resistance of asphalt to water effects and temperature variation.

6.2 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 AASHO should be used.
2) Decreasing the filler percentage 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 modulus , and softening point of the mortar.

5) Presence of large percentage of carbons in the baghouse fines will have a major effect on the performance of baghouse in the mix. This will decrease the stability loss of the mix and increase the optimum of asphalt content.

6) Mixes which utilize approximately a 50/50 ratio of filler to baghouse fines are the optimum mixes.

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APPENDIX

TABLE 7

PENETRATION TEST ON RIYADH AND ABOHADRYYAH BAGHOUSE

Cum = 100% Filler: Filler %	Cum = 100% Filler: Baghouse %	Riyadh (F/A) = 2.08	AB.BH. I (F/A) = 1.9	AB.BH. II (F/A) = 1.9
100	0	28.6	26.0	26.0
80	20	28.0	23.0	25.6
70	30	27.8	23.0	23.0
65	35	26.0	22.0	21.8
60	40	25.6	21.0	22.0
50	50	25.0	19.2	20.5
0	100	21.5	16.0	16.6

TABLE 8

SOFTENING POINT FOR (FILLER/ASPHALT) MIX

	(FILLER/ASPHALT) RATIO				
Filler Type	0	1.0	1.5	1.8	2.0
Filler	21 °C	49 °C	59 °C	96 °C	67 °C
Riyadh Baghouse	21 °C	48 °C	60 °C	---	68 °C
A.Baghouse I	21 °C	52 °C	66 °C	---	78 °C
A.Baghouse II	21 °C	60 °C	96 °C	---	>100 °C

TABLE 9

SOFTENING POINT FOR (CARBON/ASPHALT) MORTARS

F/A	0.5	1.0	1.5
Carbon from A.Baghouse II	62	130 °C	-*-

-*- Could not be determined.

TABLE 10

PENETRATION FOR ASPHALTIC MORTARS

DAMMAM & RIYADH MIX
(Variable Asphalt Content)

Filler/Asphalt by weight	Riyadh B.H.	Dammam Filler
0.5	63.0	67.0
1.0	47.5	51.0
1.5	33.5	35.5
2.0	23.0	26.0

DAMMAM MIX
(Variable Filler Content)

Filler/Asphalt*	Pen.
0.717	57.8
1.433	35.0
2.15	23.7
2.69	17.7

TABLE 11

SHEAR MODULUS BY REHOMETER

SHEAR MODULUS, (g/cm^2) (per 100 sec.)

#	FINES TYPE	(FINES/ASPHALT) RATIO BY WEIGHT		
		0.5	1	2
1	Carbon	402	704.0	---
2	AB.BH.2	---	189.0	11132
3	Riyadh BH.	---	222.0	2778
4	AB.(BH.2/F=50/50)	---	141.0	1566
5	Riyadh(BH./F=50/50)	---	167.0	1220
6	AB.BH.1	---	171.0	1219
7	Filler	---	122.5	750

TABLE 12

VISCOSITY ANALYSIS BY REHOMETER

	FINES TYPE	VISCOSITY, POISES		
		FINES/ASPHALT RATIO		
		0.5	1	2
1	Carbon	3939.6	68992.0	
2	AB.BH.2	---	1852.2	109094.0
3	Riyadh BH.	---	2176.0	27224.0
4	AB.(BH.2/F=50/50)	---	1382.0	15347.0
5	Riyadh(BH./F=50/50)	---	1637.0	11956.0
6	AB.BH.1	---	1675.8	11946.0
7	Filler	---	1200.5	7350

TABLE 13

HOT-MIX DESIGN BY MARSHALL STABILITY FOR DAMMAM MIX

TEST \ MIX	DAMMAM (50 BLOWS) 10% FILLER			DAMMAM (50 BLOWS) 15% FILLER				
Asphalt Content (% of Aggregate)	4.5	5.6	6.5	5.0	5.6	6.0	6.5	7.0
Bulk Specific Gravity	2.214	2.31	2.329	2.306	2.316	2.325	2.344	2.343
Air Voids (%)	8.72	3.51	1.25	4.25	1.96	2.08	1.6	-----
Voids Filled (%)	47.6	74.7	91.0	68.7	84.0	86.0	95.0	100.0
Marshall Stability (lb. at 60°C for 30 min.)	2318	2480	2060	3120	2650	2850	2420	2060
Flow (in 0.01 in.)	10.0	13.5	21.0	10.0	11.0	13.0	16.0	20.0
Optimum Asphalt Content		5.775				5.3		

TABLE 14

HOT-MIX DESIGN BY MARSHALL METHOD FOR DAMMAM MIX

TEST \ MIX	DAMMAM (50 BLOWS) 4% FILLER				DAMMAM FILLER (50 BLOWS) AT DIFFERENT PERCENTAGES			
					4%	8%	12%	15%
Asphalt Content (% of Aggregate)	4.5	5.0	5.6	6.0	5.6	5.6	5.6	5.6
Bulk Specific Gravity	2.235	2.244	2.31	2.283	2.31	2.353	2.35	2.35
Air Voids (%)	7.84	6.824	3.73	3.852	3.51	2.0	1.84	2.0
Voids Filled (%)	50.5	57.1	73.6	75.0	74.75	82.0	85.17	85.0
Marshall Stability (lb. at $60^{0}C$ for 30 min.)	1860	2000	1915	1900	1915	2178	2581	2600
Flow (in 0.01 in.)	10.0	11.0	10.5	12.0	10.3	11.7	12.8	17.0
Optimum Asphalt Content	5.4							

TABLE 15

HOT-MIX DESIGN BY MARSHALL METHOD FOR RIYADH MIX

TEST \ MIX	RIYADH BAGHOUSE					
Asphalt Content (% of Aggregate)	4.0	4.5	5.0	5.5	6.0	6.5
Bulk Specific Gravity	2.21	2.356	2.389	2.388	2.383	2.387
Air Void (%)	11.21	4.62	2.58	1.98	1.407	0.442
Voids Filled (%)	40.7	69.5	81.9	85.45	90.09	96.92
Marshall Stability (lb. at 60°C for 30 min.)	3450	3455	3606	3136	2727	2720
Flow (in 0.01 in.)	10.0	11.5	13.0	14.0	15.0	16.0
Optimum Asphalt Content			4.813			

TABLE 16

HOT-MIX DESIGN BY MARSHALL METHOD FOR RIYADH MIX

TEST \ MIX	RIYADH FILLER (FILLER/BAGHOUSE) = 100/0					RIYADH FILLER (FILLER/BAGHOUSE) = 50/50			
Asphalt Content (% of Aggregate)	4.0	4.5	5.0	5.5	6.0	4.0	4.5	5.0	5.5
Bulk Specific Gravity	2.317	2.339	2.386	2.389	2.390	2.32	2.356	2.381	2.38
Air Voids (%)	6.91	5.30	2.7	1.897	1.034	6.79	4.615	2.90	2.22
Voids Filled (%)	54.0	63.6	79.65	86.0	92.54	54.3	67.0	78.44	84.0
Marshall Stability (lb.at 60°C for 30 min.)	2265	2393	2930	2810	2516	3242	3716	3330	2813
Flow (in 0.01 in.)	9.5	12.0	14.0	14.5	15.5	10.0	11.0	13.7	15.0
Optimum Asphalt Content			5.0				4.75		

TABLE 17

HOT-MIX DESIGN BY MARSHALL METHOD FOR RIYADH MIX

MIX / TEST	RIYADH (F/B) = 65/35						RIYADH (F/B) = 20/80					
Asphalt Content (% of Aggregate)	4.0	4.5	5.0	5.5	6.0	6.5	4.0	4.5	5.0	5.5	6.0	6.5
Bulk Specific Gravity	2.308	2.343	2.366	2.384	2.387	2.38	2.336	2.344	2.365	2.382	2.397	2.390
Air Voids (%)	7.27	5.14	3.52	2.09	1.24	0.442	6.147	5.1	3.56	2.18	0.83	0.442
Voids Filled (%)	46.5	59.5	71.32	82.5	89.92	96.5	50.95	59.7	71.1	82.0	93.0	96.5
Marshall Stability (lb. at 60°C for 30 min.)	2486	3075	3040	3030	1875	1500	2855	2820	3040	2665	2620	1575
Flow (in 0.01 in.)	10.5	10.5	11.5	12.5	15.0	18.0	9.5	11.5	12.0	13.5	17.0	21.0
Optimum Asphalt Content			5.17							5.23		

TABLE 18

STABILITY LOSS ANALYSIS FOR RIYADH MIX

TYPES OF FILLER	PURE FILLER		(20/80) (B/F)		(35/65) (B/F)		(50/50) (B/F)		BAGHOUSE	
Asphalt Content (% of Aggregate)	*5.0	5.04	*5.25	5.04	*5.167	5.04	*4.75	5.04	*4.83	5.04
Bulk Specific Gravity	2.39	2.38	2.377	2.361	2.377	2.377	2.375	2.372	2.373	2.349
Air Voids (%)	2.62	2.6	2.9	3.5	2.9	3.01	3.5	3.223	3.0	2.5
Void Filled (%)	80.0	79.0	84.0	75.0	79.0	77.0	74.0	76.5	78.0	72.0
Marshall Stability (lb.at 60°C for 30 min.)	2930	2806	2860	2300	3200	3140	3800	3265	3525	2930
Flow	14.0	14.5	13.0	11.0	12.0	11.0	12.0	13.25	14.0	14.0
Marshall Stability Lb. (lb.at 60°C for 24 hours)	1182	----	23182	1780	2452	2335	3750	3100	1702	-----
Flow	29.0	-----	16.5	23.0	19.5	17.5	14.0	17.0	29.0	-----
Loss (%)	60.0	-----	20.0	23.3	23.3	25.5	1.3	5.0	51.0	-----

* Optimum AC for ratio indicated

TABLE 19

HOT-MIX DESIGN BY THE MARSHALL METHOD FOR ABOHADRYYAH AGGREGATE

TEST \ MIX	ABOHADRYYAH (FILLER/BH) = 100/0						
Asphalt Content (% of aggregate)	4.0	4.5	5.25	5.5	6.0	6.5	7.0
Bulk Specific Gravity	2.29	2.32	2.353	2.365	2.3665	2.3596	2.3598
Air Voids(%)	8.12	6.11	3.72	2.87	2.13	1.7	0.89
Voids Filled (%)	43.9	54.9	71.0	77.4	83.7	87.7	93.7
Marshall Stability (lb. at 60°C for 30 min.)	4130	4524	4500	4300	3480	3060	2362
Flow (in 0.01 in.)	11.0	13.0	15.0	14.5	15.0	16.0	18.0
Optimum Asphalt Content				5.213			

TABLE 20

HOT-MIX DESIGN BY THE MARSHALL METHOD FOR ABOHADRYYAH AGGREGATE

TEST \ MIX	ABOHADRYYAH (BH.1/F) = 100/0							ABOHADRYYAH (BH.1/F) = 50/50						
Asphalt Content (% of Aggregate)	4.0	4.5	5.0	5.5	6.0	6.5	7.0	4.0	4.5	5.0	5.5	6.0	6.5	7.0
Bulk Specific Gravity	2.248	2.257	2.260	2.314	2.329	2.333	2.33	2.254	2.271	2.289	2.28	2.317	2.33	2.336
Air Voids (%)	9.7	8.66	7.329	4.97	3.68	2.92	1.85	9.442	8.09	6.342	6.37	4.18	2.92	1.89
Voids Filled (%)	38.6	45.5	53.5	65.94	74.5	80.3	88.0	39.5	47.4	58.0	60.0	71.93	80.3	87.4
Marshall Stability Lb. (lb.at 60°C for 30 min.)	3587	3806	3440	3411	3214	3170	2187	3558	3490	4287	3150	2909	2887	2362
Flow (in 0.01 in.)	9.0	13.0	14.0	15.0	15.5	15.0	22.0	12.0	12.5	13.0	14.0	15.0	16.0	16.0
Optimum Asphalt Content	5.713							5.925						

TABLE 21

HOT-MIX DESIGN BY THE MARSHALL METHOD FOR ABOHADRYYAH AGGREGATE

TEST \ MIX	ABOHADRYYAH (BH.1/F) = 65/35							ABOHADRYYAH (BH.1/F) = 80/20						
Asphalt Content (% of Aggregate)	4.0	4.5	5.0	5.5	6.0	6.5	7.0	4.0	4.5	5.0	5.5	6.0	6.5	7.0
Bulk Specific Gravity	2.25	2.274	2.32	2.318	2.337	2.35	2.348	2.237	2.279	2.28	2.316	2.327	2.347	2.357
Air Voids (%)	9.6	7.97	5.074	4.8	3.35	2.08	1.39	10.12	8.77	6.79	4.89	3.76	2.21	1.01
Voids Filled (%)	39.1	47.8	63.65	66.8	76.3	85.2	90.45	37.7	48.5	56.23	66.3	74.1	84.43	92.9
Marshall Stability (lb. at 60°C for 30 min.)	3237	3787	4243	3586	3630	3066	2712	3586	4002	4199	3600	3840	3438	3125
Flow (in 0.01 in.)	13.0	13.0	12.0	16.0	16.0	17.0	18.0	10.0	11.5	12.0	16.0	15.0	15.5	17.0
Optimum Asphalt Content	5.79							5.74						

TABLE 22

HOT-MIX DESIGN BY THE MARSHALL METHOD FOR ABOHADRYYAH AGGREGATE

TEST / MIX	ABOHADRYYAH (BH.2/F) = 100/0							ABOHADRYYAH (BH.2/F) = 50/50						
Asphalt Content (% of aggregate)	4.5	5.0	5.25	6.0	6.5	7.0	7.5	4.5	5.0	5.5	6.0	6.5	7.0	7.5
Bulk Specific Gravity	2.252	2.275	2.317	2.334	2.347	2.355	2.352	2.31	2.323	2.373	2.368	2.36	2.344	2.33
Air Voids (%)	8.63	6.91	5.196	3.474	2.21	1.104	0.72	6.52	4.8	2.55	2.07	1.7	1.55	1.65
Voids Filled (%)	44.9	55.8	64.0	75.64	84.4	92.3	95.0	53.2	65.4	79.5	84.3	87.8	89.4	89.4
Marshall Stability (lb. at 60°C for 30 min.)	3277	3295	3670	3795	3887	3864	2545	4091	4110	3665	3523	2273	1873	1380
Flow (in 0.01 in)	12.0	13.0	12.5	13.0	15.5	16.5	20.0	10.0	13.0	15.0	14.5	18.0	23.0	30.0
Optimum Asphalt Content	6.173							5.65						

TABLE 23

HOT-MIX DESIGN BY THE MARSHALL METHOD FOR ABOHADRYYAH AGGREGATE

TEST \ MIX	ABOHADRYYAH (BH.2/F) = 35/65							ABOHADRYYA (BH.2/F) = 20/80						
Asphalt Content (% of Aggregate)	4.0	4.5	5.0	5.5	6.0	6.5	7.0	4.0	4.5	5.0	5.5	6.0	6.5	7.0
Bulk Specific Gravity	2.26	2.29	2.337	2.356	2.353	2.353	2.355	2.249	2.279	2.33	2.341	2.342	2.348	2.346
Air Voids (%)	9.2	7.235	4.38	3.244	2.688	1.96	1.05	9.64	7.77	4.66	3.86	3.14	2.17	1.47
Voids Filled (%)	40.2	50.05	67.16	75.11	80.2	86.0	92.6	38.95	48.5	65.7	71.6	77.5	84.7	89.95
Marshall Stability Lb. (lb. at 60°C for 30 min.)	3718	4246	4287	3500	3155	3393	2366	3455	3601	3706	4512	300	3035	2322
Flow (in 0.01 in.)	11.0	13.5	15.0	16.0	16.5	17.5	19.0	9.0	11.5	13.0	14.0	16.5	17.0	18.0
Optimum Asphalt Content	5.4							5.3						

TABLE 24

STABILITY LOSS ANALYSIS FOR ABOHADRYYAH AT CONSTANT ASPHALT CONTENT

FILLER TYPE	ABOHADRYYAH BAGHOUSE I	(ABH.1/F) (50/50)	(ABH.1/F) (35/65)	(ABH.1/F) (20/80)	FILLER	(ABH.2/F) (20/80)	(ABH.2/F) (35/65)	(ABH.2/F) (50/50)	ABOHADRYYAH BAGHOUSE II
Asphalt Content (% of Aggregate)	5.25	5.25	5.25	5.25	5.25	5.25	5.25	5.25	5.25
Bulk Specific Gravity	3.3441	3.352	3.359	3.346	2.353	2.363	2.365	2.349	2.317
Air Void (%)	4.09	3.76	3.478	4.01	3.72	3.3	3.23	3.89	5.196
(%) Voids Filled	69.2	71.0	72.6	69.6	71.2	73.6	74.0	70.3	64.0
Marshall Stability (lb.at 60°C for 30 minutes)	3690	4300	4390	4420	4400	4050	3595	3500	3670
Flow	10.0	10.5	13.7	14.0	15.0	16.0	13.7	13.0	12.7

TABLE 25

STABILITY LOSS ANALYSIS FOR ABOHADRYYAH AT OPTIMUM ASPHALT CONTENT

TYPE OF FILLER	ABOHADRYYAH BAGHOUSE I	(ABH.1/F) (50/50)	(ABH.1/F) (35/65)	(ABH.1/F) (20/80)	PURE FILLER	(ABH.2/F) (20/80)	(ABH.2/F) (35/65)	(ABH.2/F) (50/50)	ABOHADRYYAH BAGHOUSE II
Asphalt Content (% of Aggregate)	5.7	5.92*	5.79*	5.74*	5.25*	5.3*	5.4*	5.65*	6.17*
Bulk Specific Gravity	2.32	2.336	2.321	2.331	2.35	2.349	2.357	2.354	2.351
Air Voids (%)	4.5	3.5	4.35	3.94	3.85	3.85	3.4	3.13	2.7
(%) Voids Filled	69.0	75.0	68.8	72.0	70.5	70.1	73.7	76.0	80.0
Marshall Stability (lb.at 60°C for 30 min.)	3360	3020	3600	3720	4500	4200	3650	3660	3810
Flow	15.0	15.0	17.0	16.0	15.0	13.5	15.5	15.0	14.0
Marshall Stability (lb. at 60°C for 24 hours)	2343	1679	1800	1035	1764	2490	2500	3591	3200
Flow	22.0	26.0	24.5	22.5	24.0	22.0	26.5	21.0	22.5
(%) Loss	30.0	44.0	50.0	72.0	61.0	41.0	31.0	2.0	16.0

* Optimum asphalt content