SCHOOL OF CIVIL ENGINEERING

JOINT HIGHWAY RESEARCH PROJECT

FHWA/IN/JHRP-81/5

A LABORATORY INVESTIGATION ON
THE USE OF FOAMED ASPHALT FOR
RECYCLED BITUMINOUS PAVEMENTS

Michael Brennan

PURDUE UNIVERSITY
INDIANA STATE HIGHWAY COMMISSION

Interim Report

A LABORATORY INVESTIGATION ON THE USE OF FOAMED
ASPHALT FOR RECYCLED BITUMINOUS PAVEMENTS

TO: H. L. Michael, Director March 17, 1981
Joint Highway Research Project
File: 2-8-5

FROM: Leonard E. Wood, Research Engineer
Joint Highway Research Project Project: C-36-21E

Attached is an Interim Report entitled "A Laboratory Investigation on the Use of Foamed Asphalt for Recycled Bituminous Pavements" which is part of the HPR Research Project titled "The Use of Foamed Asphalt in Bituminous Stabilization of Base and Subbase Materials and Recycled Pavement types". Mr. Michael Brennan, Graduate Instructor in Research on our staff, has authored the report and conducted the study under the direction of Professors Leonard E. Wood and A. G. Altschaeffl.

This report presents the findings of a detailed laboratory investigation on the foaming characteristics of typical asphalt cements used in Indiana. In addition, selected foamed asphalts were evaluated relative to their use as binders in recycled bituminous pavements. The effects of curing time and moisture on the behavior of the recycled bituminous mixtures were also determined. Both Hveem and Marshall stability values were determined for the varying mixtures.

The report is offered as fulfillment of Task C of the Research Project and is also submitted to ISHC and FHWA for review and acceptance.

Respectfully submitted,

Leonard E. Wood
Research Engineer

LEW/mag

cc: A. F. Altschaeffl	D. E. Hancher	C. F. Scholer
W. L. Dolch	K. R. Hoover	K. C. Sinha
R. L. Eskew	J. F. McLaughlin	C. A. Venable
G. D. Gibson	R. D. Miles	H. P. Wehrenberg
W. H. Goetz	P. L. Owens	L. E. Wood
M. J. Gutzwiller	G. T. Satterly	E. J. Yoder
G. K. Hallock		S. R. Yoder

Digitized by the Internet Archive
in 2011 with funding from
LYRasis members and Sloan Foundation; Indiana Department of Transportation

Interim Report

A LABORATORY INVESTIGATION ON THE USE OF FOAMED
ASPHALT FOR RECYCLED BITUMINOUS PAVEMENTS

by

Michael Brennan
Graduate Instructor in Research

Joint Highway Research Project

Project No.: C-36-21E

File: 2-8-5

Prepared as Part of an Investigation

Conducted by

Joint Highway Research Project
Engineering Experiment Station
Purdue University

in cooperation with the

Indiana State Highway Commission

and the

U. S. Department of Transportation
Federal Highway Administration

The contents of this report reflects the views of the author who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification or regulation.

Purdue University
West Lafayette, Indiana
March 17, 1981

1. Report No. FHWA/IN/JHRP-81/5		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle A LABORATORY INVESTIGATION ON THE USE OF FOAMED ASPHALT FOR RECYCLED BITUMINOUS PAVEMENTS		5. Report Date March 17, 1981		6. Performing Organization Code	
		8. Performing Organization Report No. JHRP-81-5		10. Work Unit No.	
7. Author(s) Michael Brennan		11. Contract or Grant No. HPR-1(18) Part II		13. Type of Report and Period Covered Interim Report Laboratory Phase	
9. Performing Organization Name and Address Joint Highway Research Project Civil Engineering Building Purdue University West Lafayette, Indiana 47907		12. Sponsoring Agency Name and Address Indiana State Highway Commission State Office Building 100 North Senate Building Indianapolis, Indiana 46204		14. Sponsoring Agency Code	
		15. Supplementary Notes Prepared in cooperation with the U.S. Department of Transportation, Federal Highway Administration, Part of the Study titled, "The Use of Foamed Asphalt in Bituminous Stabilization of Base and Subbase Material and Recycled Bituminous Pavements".			
16. Abstract <p>This study had three objectives. The first to determine the foaming characteristics of a selection of asphalts which are commonly used in construction in Indiana. Foaming characteristics in terms of expansion ratio and half life were recorded. The second objective was to evaluate the performance of three of these asphalts as binders for a recycled bituminous paving mixture using (1) the Gyrotory and the Marshall Compactive methods, and (2) the Marshall Stability testing procedure, and (3) the Hveem Stability testing procedure. The third objective was to evaluate the effect of curing time and moisture on the stability of a recycled mix.</p> <p>Three asphalts were chosen for the study based upon their foaming characteristics. A foaming temperature of 160° C (325° F) and an added water content of 2% were selected as the best conditions for optimum foam volume and half life. Excellent Marshall stability values were obtained with 0.5% and 1.0% foamed asphalt added to the recycled mixtures. Curing time had a marked effect on the lower additions of foamed asphalt. The effect of water decreases with increased amounts of foamed asphalt. A comparison of the Marshall Stability values and the Hveem Stability values indicated that the same optimum percent of foamed asphalt was obtained.</p>					
17. Key Words Cold Recycling, Foamed Asphalt Bituminous Mixtures, Marshall Method, Curing, Water Resistance, Hveem Method			18. Distribution Statement No restrictions, This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161		
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages 48	
				22. Price	

TABLE OF CONTENTS

	<u>Page</u>
HIGHLIGHT SUMMARY	iv
INTRODUCTION	1
OBJECTIVES	1
FOAMING CHARACTERISTICS OF THE ASPHALTS	2
Asphalts	2
Analysis Procedure	3
Results	4
EVALUATION OF FOAMED ASPHALT AS A BINDER FOR A RECYCLED MIX	11
Recycled Pavement Material	11
Asphalts	13
Analysis Procedure	13
Compaction Methods	14
Testing Procedure	14
Design of Experiment	15
Specimen Preparation	15
Results	18
EFFECT OF CURING TIME AND WATER	24
Design of Experiment	24
Experimental Procedure	24
Response Variables	26
Results	26
EVALUATION OF RECYCLED MIXES USING THE HVEEM RESISTANCE TEST	30
Experimental Design	30
Experimental Procedure	30
Hveem Resistance Value R-Value	32
Results	32
DISCUSSION AND CONCLUSIONS	38
REFERENCES CITED	42
APPENDIX	43

HIGHLIGHT SUMMARY

This study had three objectives. The first was to determine the foaming characteristics of a selection of asphalts which are commonly used in construction in Indiana. Foaming characteristics in terms of expansion ratio and half life were recorded. The second objective was to evaluate the performance of three of these asphalts as binders for a recycled bituminous paving mixture using (1) the Gyratory and the Marshall Compactive methods, (2) the Marshall Stability testing procedure, and (3) the Hveem Stability testing procedure. The third objective was to evaluate the effect of curing time and moisture on the stability of a recycled mix.

Three asphalts were chosen for the study based upon their foaming characteristics. A foaming temperature of 160°C (325°F) and an added water content of 2% were selected as the best conditions for optimum foam volume and half life. Excellent Marshall stability values were obtained with 0.5% and 1.0% foamed asphalt added to the recycled mixtures. Curing time had a marked effect on the lower additions of foamed asphalt. The effect of water decreases with increased amounts of foamed asphalt. A comparison of the Marshall Stability values and the Hveem Stability values indicated that the same optimum percent of foamed asphalt was obtained.

INTRODUCTION

The ability of foamed asphalt to coat and adhere to wet aggregate has been known for over 20 years. Bituminous road construction using foamed asphalt has been successfully tried and tested in projects in Australia, Canada, South Africa and the United States of America. (1,2,3,4,5).

Recent advances in foamed asphalt technology have created a new interest in the subject. In Indiana, relatively little experience is available on the production and use of foamed asphalt using locally available materials. For this reason, it was decided to conduct a series of studies on foamed asphalt production. This report describes the results of one of these studies.

OBJECTIVES

This study had three objectives. The first was to determine the foaming characteristics of a selection of asphalts which are commonly used in construction in Indiana. Foaming characteristics in terms of expansion ratio and half life were recorded. The second objective was to evaluate the performance of three of these asphalts as binders for a recycled bituminous paving mixture using (1) the Gyratory and the Marshall compactive methods, (2) the Marshall Stability testing procedure and (3) the Hveem Stability testing procedure. The three asphalts selected for this part of the study were those deemed to be most suitable on the basis of their foaming characteristics. The third objective was to evaluate the effect of curing time and moisture on the stability of a recycled mix.

FOAMING CHARACTERISTICS OF THE ASPHALTS

Asphalts

Eight asphalts were selected for the study. They consisted of four AC-20 grades from different sources, two AC-2.5 grades from different sources, one AP-4 grade, and one RC-SC base. The sources and viscosities of the asphalts are listed in Table 1.

Grade	Source	Penetration (0.1 mm)	Kinematic Viscosity at 135°C (275°F) cSt.
AC-20	A	42	443
AC-20	C	55	390
AC-20	B	68	437
AC-20	D	74	425
AC-2.5	A	185	160
AC-2.5	B	>200	195
AP-4	C	69 *	261
RC-SC base	A	78	285

*Material was purchased as a designated AP-4. The penetration measured in the laboratory, however, was slightly below minimum (70) penetration requirements.

Analysis Procedure

Foamed asphalt was produced using a Laboratory Foamix Asphalt Dispenser. The foam was produced by injecting air and cold water into hot asphalt as it passed under pressure through the nozzle of the dispenser. The foam expanded rapidly and reached its maximum volume. The ratio of maximum volume of foamed asphalt to the volume of liquid asphalt used was termed the expansion ratio. After reaching its maximum volume, the foam gradually dissipated until the foamed asphalt returned to the liquid phase. The time that elapsed from the moment that the foam was at its maximum volume to the time that it reached half of this volume was termed the half life of the foam. Accordingly, expansion ratios and half lives were used to compare the foaming characteristics of the asphalts.

Expansion ratio and half life are affected by (1) the amount of foam produced, (2) the amount of water in the foam, and (3) the foaming temperature of the asphalt.⁽⁶⁾ The availability of one gallon cans was convenient for the production of foam in 200 gm batches. Expansion ratios up to 19 could be measured. The water content of the foam was expressed as a percentage by weight of the asphalt. The results of trial mixes⁽⁶⁾ indicated that it would be desirable to compare the foaming characteristics of foaming temperatures of 149°C(300°F), 163°C(325°F) and 177°C(350°F); and at water contents of 1½%, 2% and 2½%. Therefore, the expansion ratios and half lives were measured for each combination of these parameters.

The volume of foam corresponding to each integer expansion ratio was computed from the densities of the asphalts. Equal volumes of water were poured into an empty can so that a meter stick was graduated to show the height to which the foam should rise in the can for each expansion ratio. During the experiment, the meter stick was held vertically against the

outside of the can and the expansion ratio was estimated to the nearest half-division to which the foam expanded. A new can was used for each sample of foam produced.

The profile of the surface of the foam was irregular. It was generally humped in the center of the can during expansion and dipped during dissipation. Therefore, it was necessary to estimate the average level of the surface when measuring the expansion ratio and the half life.

Three samples of foam were produced at each of the 9 foaming temperature/water content combinations for each asphalt. The average expansion ratio and half life were used for making comparisons among the asphalts.

The kinematic viscosities of the asphalts were measured at 149°C(300°F) and 177°C(350°F) to compare expansion ratios half lifes and viscosities at these foaming temperatures.

Results

The expansion ratios and half lifes for the regular grades of asphalt are shown in Figures 1(a) and 1(b). As the RC-SC base is not commonly available, its performance is given separately in Table 2. Surprisingly, the RC-SC base had very good foaming characteristics with the highest expansion ratio 19, and the longest half life, 45 seconds.

FIGURE 1(a) EXPANSION RATIO AND HALF LIVES AT VARIOUS TEMPERATURES AND WATER CONTENTS

FIGURE 1(b) EXPANSION RATIO AND HALF LIVES AT VARIOUS TEMPERATURES AND WATER CONTENTS

Temperature (viscosity)

Water Content	149°C(161cSt.)		163°C		177°C(59cSt.)	
	Expansion Ratio	Half Life (seconds)	Expansion Ratio	Half Life (seconds)	Expansion Ratio	Half Life (seconds)
1½%	7.5	45.0	9.3	30.3	13.2	17.7
2%	9.8	44.3	12.7	26.3	14.3	19.3
2½%	12.3	37.3	15.0	19.3	19.0	17.7

Table 2. Expansion Ratios and Half Lives for the RC-SC Base

The effects of foaming temperature and water content on expansion ratio and half life are shown in Figures 1(a) and 1(b). In general, increasing the foaming temperature had the effect of increasing the expansion ratio, and decreasing the half life. Increasing the water content also had the effect of increasing the expansion ratio but of decreasing the half life. Therefore, a trade-off of half life for expansion ratio or vice versa was implicit in the selection of a particular set of values for foaming temperature and water content.

A foaming temperature of 163°C(325°F) and a water content of 2% was chosen for making comparisons between the asphalts. The AC-20 (42 pen) and AP-4 (69 pen) had the best characteristics with expansion ratios greater than 12 and half lives greater than 13 seconds. The selection of the third asphalt was not straightforward as the decision between the AC-2.5 (185 pen) and the

AC-20 (55 pen) involved a trade-off between expansion ratio and half life. The AC-2.5 (185 pen) was chosen so that a soft grade of asphalt would be included in the second stage of the study. The AC-2.5 had an expansion ratio of 12, and a half life of 7 seconds.

The relationship between the viscosities of the asphalts at the foaming temperature of $163^{\circ}\text{C}(325^{\circ}\text{F})$, the expansion ratios and the half lives for the three water contents are shown in Figures 2 and 3. The results indicate that viscosity alone is not a sufficient parameter to explain the variations in expansion ratio and half life.

FIGURE 2. EXPANSION RATIO versus VISCOSITY FOR A SELECTED ASPHALT

FIGURE 3. HALF LIFE versus VISCOSITY FOR A SELECTED ASPHALT

EVALUATION OF FOAMED ASPHALT AS A BINDER FOR A RECYCLED MIX

Recycled Pavement Material

The pavement material to be recycled was obtained from a State Road near Wabash, Indiana. Its asphalt content was 5.4% by weight of the total mix. The penetration of the recovered asphalt was approximately 20. The gradation of the recovered aggregate is shown in Figure 4. The material to be recycled was crushed before delivery to the laboratory. Its gradation was established using the 3/8 inch (9.5mm), No. 4 (4.75mm) and No. 16 (1.18mm) A.S.T.M. sieves; the gradation is also shown in Figure 4. The material was separated into four sizes and was recombined in the same proportions to ensure homogeneity in each recycled mix. The four sizes were:

- (1) > 3/8 inch (9.5mm)
- (2) 3/8" to No. 4 (9.5mm - 4.75mm)
- (3) No. 4 to No. 16 (4.75mm - 1.18mm)
- (4) < No. 16 (1.18mm)

FIGURE 4. GRADATIONS OF THE USED PAVEMENT MATERIAL AND THE RECOVERED AGGREGATE FOR THREE ASPHALT CEMENTS

Asphalts

New supplies of the three asphalts, AC-20, AP-4 and AC-2.5, selected in the first part of the study were obtained. Their sources and viscosities are given in Table 3.

Grade	Source	Penetration (0.1 mm)	Kinematic Viscosity at 135°C (275°F) cSt.
AC-20	A	42	443
AP-4	C	69	261
AC-2.5	A	185	160

Table 3. Sources and viscosities of the asphalts used in the recycled mixes.

Analysis Procedure

At the outset, a cold mix analysis procedure was required to simulate the cold mix production of a recycled mix. The recycled mix was intended for use primarily as a base course.⁽⁷⁾ Csanyi⁽⁸⁾ had shown that cold mixes could be prepared with cold, wet aggregates and hot asphalt.

The recycled mixes were prepared by adding foamed asphalt to the cold, wet pavement material. The objective was to determine the optimum foamed asphalt content for the three grades of asphalt, and to compare the strengths of the mixes at different asphalt contents.

Compaction Methods

Trial mixes which were compacted by the Marshall hammer and the Gyratory machine indicated that gyratory compaction was more suitable for compacting the mixes at room temperature. It was decided to compare the mixes using a standard compactive effort which would simulate initial compaction after construction. A ram pressure of 1.38 MPa (200 psi) and 20 revolutions of the gyratory compactor were deemed to produce satisfactory compaction; densities of about 2.25 gm/cm^3 (140 lbs/ft^3) were achieved using this compactive effort.

Seventy five blows of the Marshall compaction hammer are equivalent to a ram pressure of 1.38 MPa (200 psi) and 30 revolutions of the gyratory compactor at a test temperature of 140°F (60°C).⁽⁹⁾ Comparisons of these compactive efforts on the recycled mix showed that this equivalence of the gyratory and Marshall compactive efforts was not true at room temperature; a maximum density of 2 gm/cm^3 (125 lbs/ft^3) was achieved by 75 blows of the Marshall hammer. However, it was decided to compare the strengths of the mixes using two compactive efforts:

- (1) Gyratory compaction at room temperature (72°F - 75°F) (22°C - 24°C) with a ram pressure of 1.38 MPa (200 psi) and 20 revolutions,
- (2) Marshall compaction at room temperature (72°F - 75°F) (22°C - 24°C) using 75 blows of the hammer.

Testing Procedure

The strengths of the mixes were compared by testing Marshall size specimens in the Marshall Stability Apparatus. The specimens were 10.26 cm (4 inches) in diameter and approximately 6.0 cm (2.5 inches) high when compacted in the Gyratory compactor. They were approximately 6.8 cm high

when compacted by the Marshall hammer. Three response variables were obtained for each specimen, namely:

- (1) Marshall stability (pounds)
- (2) Marshall flow (0.01 inch units)
- (3) Marshall stiffness (pounds/inch)

The stability correction factors published by the Asphalt Institute⁽¹⁰⁾ were applied to correct the stability values for variations in the heights of the specimens. The specimens were tested at room temperature which varied from 72°F to 75°F (22°C-24°C). Therefore, it was necessary to assume that any variations in strength due to fluctuations in room temperature were small so that comparisons between the specimens could be made. For this reason also, it was necessary to establish a strict experimental procedure for preparing the specimens.

Design of Experiment

Details of the numbers of Marshall size specimens produced are given in Table 4. The foamed asphalt content was expressed as a percentage by weight of the aggregate in the mix. Three specimens were produced at each foamed asphalt content for the three grades of asphalt and the two compactive efforts.

	Gyratory Compaction 1.38 MPa; 200 revs.					Marshall Compaction; 75 blows			
	0.5%	1%	2%	3%		0.5%	1%	2%	3%
AC-20	3	3	3	3	AC-20	3	3	3	3
AP-4	3	3	3	3	AP-4	3	3	3	3
AC-2.5	3	3	3	3	AC-2.5	3	3	3	3

Table 4. Design of Experiment for the Evaluation of Foamed Asphalt as a Binder for a Recycled Mix.

The average results of three specimens were used for making comparisons for the recycled mixes.

Specimen Preparation

Prior to preparation and mixing, 3300 gms of the recycled material was weighted out according to its gradation into 4 batches as follows:

- (1) 3 batches of coarse material; containing 616 gm retained on the No. 4 sieve,
- (2) 1 batch of fine material containing 1452 gm passing the No. 4 sieve.

The fine material was mixed with a small quantity of water. The water acted as a vehicle for the foamed asphalt to thoroughly wet the mix.⁽¹¹⁾ The amount of water to be added was established by the fluff point of the fine material. The fluff point is the water content at which the material has its maximum loose volume. The procedure used for determining the fluff point is given in the Appendix. The fluff point was found to be 5% of water by weight of the fine material. Therefore 72.6 gm ($5\% \times 1452$ gm) of water were mixed with the fine material for one minute using a Hobart kitchen mixer.

The foamed asphalt was mixed with the recycled pavement material in two stages. First, the foamed asphalt and the cold, wet fine material was mixed for two minutes using a Hobart kitchen mixer, and then mixed by hand for an additional minute. Second, the mixed fine material was divided equally into 3 parts, and each part was thoroughly mixed by hand for one minute with a batch of coarse material.

Trial mixes and the results of cold mix designs using asphalt emulsion⁽¹²⁾ indicated that it was necessary to evaporate most of the water added to the mixes, in order to achieve the needed compacted densities. Therefore, the

recycled mixes were placed in transfer dishes in a forced draft oven at 60°C (140°F) for between 1 and 1½ hours before compaction began. Up to 75% of the water added to the mixes evaporated during this process.

The procedure transferring the recycled mixes from the oven to the Gyratory compactor is given below.

Procedure for transferring recycled mix from oven to the Gyratory Compactor.

The procedure for transferring the mixes to the Marshall compactor is given below.

Procedure for transferring recycled mix from oven to Marshall compactor.

The compacted specimens were left at room temperature (72°F-75°F) (22°C-24°C) for 24 hours. Their weights and volumes were then recorded. The specimens were tested at room temperature in the Marshall Stability testing

apparatus. Their weights were recorded again to account for small losses of material that occurred during testing. The failed specimens were next placed in an oven at 104°C (220°F) for 24 hours. After drying, the specimens were weighted to determine the loss in weight due to water content. Details of the calculations that were made are given below:

Let W_1 = weight of specimen just before testing

W_2 = " " " after testing

W_3 = " " " after drying

V = volume of specimen just before testing

Then, density = $\frac{W_1}{V}$, and

$$\text{water content during test} = \frac{(W_2 - W_3) \times 100}{W_3}$$

Results

The compacted densities of the mixes are presented in Figure 5. Densities obtained with 75 blows of the Marshall hammer were about 90% of the densities obtained using 1.38 MPa ram pressure and 20 revolutions of the Gyratory compactor. The variations in density obtained by varying the foamed asphalt content were small.

The stability values of the various mixes are plotted in Figure 6. The values obtained using gyratory compaction were two to three times greater than the values obtained by Marshall compaction. The maximum stability values obtained by the two compaction methods do not coincide. Variations in stability with foamed asphalt content were greater for gyratory compaction; consequently, its maximum stability value was more clearly defined. With gyratory compaction, the trend was for maximum stability to occur at low foamed asphalt contents from 0.5% to 1%. The highest stability value recorded

FIGURE 5. DENSITY versus FOAMED ASPHALT CONTENT FOR THREE ASPHALT CEMENTS

FIGURE 6. STABILITY versus FOAMED ASPHALT CONTENT FOR THREE ASPHALT CEMENTS

was 6000 pounds (2720 kg) with 0.5% of the AP-4 grade of asphalt.

Figure 7 shows the Marshall flow values. The range in flow values (0.01 inch units) varied from 10 to 17 for gyratory compaction. The range for Marshall compaction was from 16 to 34. The flow values for gyratory compaction were consistent with the stability results in so far as maximum stability occurred at lowest flow for the three grades of asphalt. The flow values for Marshall compaction were not consistent in this respect.

The Marshall stiffness values which represent the slope of the stability versus flow curve obtained from the autographic trace recorded during the stability test are shown in Figure 8. The values are $1 \frac{1}{3}$ to $2 \frac{1}{3}$ times greater for gyratory compaction. Maximum stiffness corresponded with maximum stability except for the AP-4 Marshall compacted mix. The maximum stiffness obtained was 102×10^3 pounds/inch (18.1×10^3 kg/cm) with $\frac{1}{2}\%$ of the AP-4 foamed asphalt in the recycled mix.

The average water content of the recycled mixes at the time of testing was 0.55%; the standard deviation was 0.15%.

FIGURE 7. FLOW versus FOAMED ASPHALT CONTENT FOR THREE ASPHALT CEMENTS

FIGURE 8. STIFFNESS versus FOAMED ASPHALT CONTENT FOR THREE ASPHALT CEMENTS

EFFECT OF CURING TIME AND WATER

Design of Experiment

In this set of experiments, the effects of curing time and water on the properties of mixes that were recycled with foamed asphalt were studied. An AP-4 was used as the foamed asphalt to be added to the recycled mix. Table 5 shows the experimental design for this study. A water sensitivity test was used to evaluate the resistance of the recycled mix to water. Two curing times (1 day and 7 days) were studied. Water sensitivity tests were run after the 7 days curing period.

Experimental Procedures

Mixes were prepared using the same procedure as described in the earlier part of this report. Specimens were compacted with the gyratory compactor for 20 revolutions at 200 psi (1.38 MPa). Curing took place at room temperature. Cured samples were tested in the Marshall Testing apparatus as described earlier.

The water sensitivity test as recommended by the Asphalt Institute was modified and used. The procedures are briefly described below:

1. Specimens are to be subjected to one hour of vacuum of 30 mm Hg.
2. After a one hour period, water at room temperature of 22°C(72°F) is drawn into the vacuum chamber submerging the specimens and vacuum saturating them.
3. The vacuum is released and the specimens are then left in the water for 24 hours.
4. Prior to testing in the Marshall apparatus, the saturated surface dry weight of the specimen is determined to calculate the percentage of water absorption.

Table 5. Experimental Design for the Study of the Effect of Curing Time and Water on the Recycled Mixtures

Curing time % Foamed asphalt added	one day	seven days
1/2	×	⊗
1	×	⊗
2	×	⊗
3	×	⊗

Note: × 3 samples per cell tested dry
 ○ Water sensitivity test, 2 samples
 per cell

Response Variables

The response variables measured and analyzed in this study are as follows:

1. Marshall Stability
2. Marshall Stiffness
3. Marshall flow
4. Bulk Specific gravity
5. Percent Water Absorbed (in Water Sensitivity Test)

The first four variables have been described previously. The Percent Water Absorbed is the percent of water by weight of the dry specimen absorbed during the 24 hour soaking period.

Results

Figure 9 presents the Marshall stabilities vs the percent asphalt added for the recycled mix at 1 day curing, 7 days curing and water sensitivity test. It is noted that for the "as is" tests (1 day and 7 days), the optimum stability occurs when 0.5% asphalt was added. For the water sensitivity test, optimum stability occurs when 1% asphalt was added.

It is noted that the effect of curing is appreciable for 0.5% and 1% asphalt added. At 2% and 3% asphalt added, it is not. The effect of water decreases with increasing percent of asphalt added. At 3% asphalt added, the water sensitivity test does not have any effect on the stability of the recycled mix.

Figure 10 depicts the Marshall stiffness vs the % asphalt added. Similar trends as those of the Marshall stabilities are noted. The effect of curing time and water decreases with increasing percent asphalt added. Average Marshall flow values vary from 12 to 15 with no general pattern.

Figure 11 depicts the percent water absorbed in the water sensitivity test. The percent water absorbed decreases with increasing % asphalt added. Thus, it can be concluded that the more porous the specimens are the more they will be affected by the action of water.

FIGURE 9. MARSHALL STABILITIES OF RECYCLED MIXTURES WITH AP-4 ADDED FOR DIFFERENT EXPOSURE CONDITIONS

FIGURE 10 MARSHALL STIFFNESS FOR RECYCLED MIXTURES WITH AP-4 ADDED FOR DIFFERENT EXPOSURE CONDITIONS

FIGURE II. PERCENT WATER ABSORBED
IN THE WATER SENSITIVITY
TEST

EVALUATION OF RECYCLED MIXES USING THE HVEEM RESISTANCE TEST

In the previous experiments, Marshall tests were conducted in order to evaluate the behavior of various recycled mixes. In this set of experiments, Hveem Resistance tests were performed in combination with the Marshall tests. The results from the two tests were then analyzed and compared with one another.

Experimental Design

The same salvaged pavement material was used in this set of tests. A new factor - the oxidized condition of the old pavement material - was used. Three oxidized conditions of the pavement material were used. The original pavement material established one condition. The other two conditions were obtained by heating the salvaged material at 120⁰ C (248⁰ F) for one and three days. The foamed asphalt to be added to the recycled mixes was an AC 2.5. Table 6 shows the design of experiment for this study.

Experimental Procedure

Specimens were prepared by the same procedures as described earlier. Compacted samples were cured to the ultimate condition by placing them in a forced-draft oven at 140⁰ F for 24 hrs. The curing is "ultimate" in that most of the moisture in the specimen has evaporated by the end of the curing period. After the specimens had been cured in the oven, they were allowed to cool to room temperature. They were then tested at room temperature ($\approx 72^{\circ}$ F) in the Hveem Stabilometer for their R - Values. (A description of the R-Value is given in the next section). After the Hveem Resistance test, the same specimens were then tested in Marshall Apparatus for their Marshall Stability, Stiffness and Flow values.

Table 6. Experimental Design for the Evaluation of Recycled Mixtures Using R Test

Oxydized condition Asphalt added (%)	As is	1 Day heating	3 Days heating
1/2	×		
1	×	×	×
2	×	×	×
3	×	×	×

Note: × 3 samples per cell, tested at room temperature

Hveem Resistance Value R - Value

The Hveem Resistance Value (R - Value) is generally used in evaluating stabilized base mixtures. The testing procedure was similar to that of the Hveem Stabilometer Test with the exception that the vertical pressure is applied only up to 1.10 MPa (160 psi). (See ASTM D 2844). The equation for calculating the R - Value is as follows:

$$R = 100 - \frac{100}{\frac{2.5}{D_2} \times \frac{P_v}{P_n} - 1 + 1}$$

Where R = Hveem Resistance Value

P_v = Applied Vertical pressure, 1.10 MPa (160 psi)

P_n = Horizontal pressure at $P_v=1.10$ MPa (160 psi)

D_2 = Displacement of stabilometer fluid necessary to
increase horizontal pressure from 34.5 to 689 kPa
(5 to 100 psi)

Results

Figure (12) depicts the R - Values vs the percent of foamed asphalt added. It may be observed that for the pavement material as is, the optimum R - Value is obtained at between .5% and 1% asphalt added. For the material after 1 day heating, the optimum R - Value occurs at between 1% and 2% asphalt added. For the material after 3 days heating, the optimum is at 2% added. This trend would be expected, since the more oxidized pavement material requires more virgin binder to be restored to its optimum state.

Figure (13) shows the Marshall Stabilities of the same specimens. Similar trends can be observed. The optimum percents of asphalt added are the same as those in the Hveem Resistance test. The Marshall Stiffness values obtained are depicted in Figure (14). It is observed that the optimum percents of asphalt added are slightly higher than those in the previous two cases. For the material of 3 days heating, the optimum Marshall Stiffness is at 3% asphalt

FIG. 12 R-VALUE vs PERCENT ASPHALT
ADDED FOR RECYCLED MIXTURES OF
DIFFERENT OXYDIZED CONDITIONS

FIG. 13 MARSHALL STABILITIES vs PERCENT ASPHALT ADDED FOR RECYCLED MIXTURES OF DIFFERENT OXYDIZED CONDITIONS

FIG. 14 MARSHALL STIFFNESS vs PERCENT ASPHALT ADDED FOR RECYCLED MIXTURES OF DIFFERENT OXYDIZED CONDITIONS

added rather 2%, as shown by the previous two cases. Figure (15) depicts the Marshall Flow values for these mixes. It can be observed that minimum Marshall Flow values occurs at the points of optimum Marshall Stabilities.

FIG. 15 MARSHALL FLOW vs PERCENT ASPHALT
ADDED FOR RECYCLED MIXTURES OF
DIFFERENT OXYDIZED CONDITIONS

DISCUSSION AND CONCLUSIONS

Discussion

Satisfactory laboratory procedures for comparing the foaming characteristics of the asphalts and their uses in a recycled mix were established. Researchers had shown that it would be necessary to add a small amount of water to the payment material so that the foamed asphalt would thoroughly coat and adhere to it. The water content which gave the material its maximum loose volume, i.e. its fluff point, proved to be an ideal water content for mixing purposes. The mixing process was a relatively clean operation as the foamed asphalt did not adhere to the blade nor mixing bowl of the mixer. The moisture in the mix prevented this from happening. In order to achieve useful compacted densities, it was necessary to evaporate most of the water which facilitated mixing. Gyratory compaction with a Ram pressure of 1.38 MPa (200 psi) and 20 revolutions provided a degree of compaction which simulated initial compacted densities obtainable using construction equipment. The highest Marshall stability was obtained using $\frac{1}{2}\%$ of an AP-4 grade. At foamed asphalt contents of 1%, 2% and 3%, the differences in the stabilities of mixes using AP-4, AC-2.5 and AC-20 were not great.

It was observed that the Hveem Resistance values give the same optimum percent of asphalt added as the Marshall Stability values do. The Marshall Stiffness values, however, will tend to give a higher percent of asphalt to be added to the recycled mixture.

Conclusions

The conclusions of the first part of the study on the foaming characteristics of the asphalts were as follows:

1. Increasing the foaming temperature from $149^{\circ}\text{C}(300^{\circ}\text{F})$ to $177^{\circ}\text{C}(350^{\circ}\text{F})$ had the effect of increasing the expansion ratios but of decreasing the half-lives of the foams.

2. Increasing the water content of the foam from $1\frac{1}{2}\%$ to $2\frac{1}{2}\%$ also increased the expansion ratios but decreased the half lives.

3. A trade-off of expansion ratio for half life or vice versa was implicit in the selection of a particular foaming temperature and water content.

4. A foaming temperature of 163°C (325°F) and a water content of 2% were deemed to provide an acceptable trade off of foaming temperature for half life for making comparisons among the asphalts.

5. The RC-SC base had the highest expansion ratio, 19; and the longest half life 45 seconds.

6. The lowest expansion ratio was 6; and the shortest half life was 3 seconds.

7. The AC-20 (42 pen) had the best foaming characteristics; the AP-4 (69 pen) was rated second; and the AC-20 (55 pen) and AC-2.5 (185 pen) were rated third best.

8. The kinematic viscosity (cSt) of the asphalts at the foaming temperature was not a sufficient parameter alone to explain the variations in the foaming characteristics.

The AC-20 (42 pen), AP-4 (69 pen) and AC-2.5 (185 pen) were selected as the binders for the second part of the study. The conclusions regarding their uses as binders for a recycled mix were as follows:

(1) It was necessary to dry the recycled mixes in a forced draft oven at 60°C (140°F) for 1 to $1\frac{1}{4}$ hours after mixing so that reasonable compacted densities could be achieved.

(2) Gyratory compaction with a ram pressure of 1.38 MPa (200 psi) and 20 revolutions produced densities of about 2.25 gm/cm^3 (140 lbs/ft^3); Marshall compaction with 75 blows of the hammer produced densities of about 2.0 gm/cm^3 (125 lbs/ft^3).

(3) The Marshall stability values obtained by Gyratory compaction were twice the values obtained by Marshall compaction.

(4) The highest stability obtained was 6000 pounds with 0.5% of the AP-4 foamed asphalt in the recycled mix.

(5) Maximum stability occurred at the least flow for the Gyratory compacted mixes. Maximum stability and least flow did not coincide for the Marshall compacted mixes.

(6) The range of flow values for the gyratory compacted mixes was from 10 to 17 (0.01 inch units); the range for Marshall compaction was from 16 to 34.

(7) Maximum Marshall stiffness coincided with maximum stability for the Gyratory compacted mixes. The highest stiffness recorded was 102×10^3 pounds/inch with 0.5% of the AP-4 foamed asphalt in the recycled mix.

(8) Seventy-five blows of the Marshall hammer did not provide sufficient compaction to simulate initial compaction after construction. The possibility of achieving better results using a greater number of blows could be investigated.

(9) The effect of seven (7) day curing versus one (1) day curing was quite pronounced for 0.5% and 1.0% of added foamed asphalt binder.

(10) Marshall stability values obtained following the water sensitivity test displayed a peak at 1% added binder. The effect of water decreased with an increase in the binder content.

(11) Marshall Stiffness values followed the same trends as those reported for Marshall Stabilities with regard to both curing and moisture sensitivity.

(12) The percent water absorbed during the water sensitivity test decreases with increasing percent binder added.

The conclusions determined from the portion of the study that compared the Marshall Stability test results to the Hveem Stability test results are as follows:

(1) The Marshall Stability test results give the same optimum percent of asphalt added as the Hveem Resistance values.

(2) The Marshall Stiffness values tend to give a higher percent of asphalt to be added to the recycled mixture.

REFERENCES CITED

1. Mobil Oil Australia Ltd. Technical Bulletin No. 6, "Foamed Bitumen - A New Development".
2. Bowering, R. H. and Currie, D. T., "Experiences with Some Bitumen Treated Materials in Australia", 7th World Meeting IRF, Munich (1973).
3. Mobil Oil Australia Ltd. Technical Report No. 714, "Laboratory Equipment and Test Procedures for the Evaluation of Soils Stabilized with Foamed Bitumen."
4. Mobil Oil Australia Ltd. Technical Report No. 731. "Foamed Asphalt Soil Stabilization - Mix Design and Associated Studies".
5. Bowering, R. H. and Martin, C. L., "Foamed Bitumen Production and Application of Mixtures Evaluation and Performance of Pavements". Proceedings of the Association of Asphalt Paving Technologists, Vol. 45, (1976) pp. 453-477.
6. Continental Oil Company, Refining Technical Services Laboratory, "FOAMIXtm Asphalt-Laboratory Dispenser Operating Variables", Ponca City, Oklahoma, May 1978.
7. Abel, F. "Foamed Asphalt Base Stabilization", Proc. 6th Annual Asphalt Paving Seminar, Colorado State University, Dec 7-8, 1978.
8. Csanyi, L. H. "Bituminous Mixes prepared with Foamed Asphalt", Bulletin No. 189, Iowa Engineering Experiment Station, Iowa State University, Ames, Iowa 1960.
9. 1976 Annual Book of ASTM Standards, Part 15.
10. The Asphalt Institute, "Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types", Manual Series No. 2 (MS-2), Asphalt Institute Building, College Park, Maryland, 1979.
11. Construction Canada, "Plant Setup for Foamed Asphalt", Construction Canada, p. 20-23, July 1964.
12. Gadallah, A. A. "A Study of the Design Parameters, For Asphalt Emulsion Treated Mixtures", Research Report No. 30, Joint Highway Research Project, Purdue University, West Lafayette, Indiana, 1976.

APPENDIX

The method used to determine the Fluff Point of the Used Pavement Material

The test was carried out on material passing the No. 4 sieve. The fluff point was defined as the water content at which this material had its maximum loose volume. It was determined as follows:

- (1) 200 gm of material were loosely poured into a graduated cylinder. The height of the material in the material was noted.
- (2) The material was put into a basin and thoroughly mixed with 1% (2 gm) of water.
- (3) Then, the wet material was loosely poured back into the graduated cylinder and the new increased height was noted.
- (4) This procedure was repeated for 2%, 3%, etc. of water; and the heights of the material in the cylinder were noted.
- (5) The water content at which the material reached its maximum height was recorded as the fluff point.

At water contents above the fluff point the volume of the used pavement material remained the same; the volumes decreased when the same procedure was used on virgin aggregates.

COVER DESIGN BY ALDO GIORGINI