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BITUMINOUS MIXES PREPARED WITH FOAMED ASPHALT

by
L. H. Csanyi

IOWA ENGINEERING EXPERIMENT STATION

Iowa State University
Ames, Iowa

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BITUMINOUS MIXES
PREPARED WITH FOAMED ASPHALT

A contract for Project HR-20 "Treating Loess, Fine Sands and Soft Limestones with Liquid Binders" of the Iowa Highway Research Board was awarded in December, 1951, to the Iowa Engineering Experiment Station of Iowa State University as its Project 295-S. By 1954 the studies of the fine materials and asphalts had progressed quite well, and a method of treating the fine materials, called the atomization process, had been applied.

A study was begun in 1954 to see if some of the problems of the **atomization process** could be solved with the use of **foamed asphalt.**

Foamed asphalt has several advantages. The foaming of asphalt increases its volume, reduces its viscosity, and alters its surface tension so that it will adhere tenaciously to solids. Foamed asphalt displaces moisture from the surface of a solid and coats it with a thin film. Foamed asphalt can permeate deeply into damp soils. In the past these unusual characteristics were considered nuisances to be avoided if possible.

FOAMS

Until recently foams in general were curiosities. As knowledge was gained of their mechanics, special properties, and how to control them they have found many practical applications. Now foams are used in foods, candies, beverages, tooth pastes, shaving creams, bubble baths, cosmetics, cushions, mattresses, weather proofing, sound proofing, insulation, paints, and fire extinguishers, to name only a few. Foams of many kinds are used also in industry in many special processes.

Foams can be produced in many forms ranging from dense congealed foams, in which the minute bubbles are in contact with one another, to discrete foams, in which each bubble is separate and independent of another. In these various types of foams the bubbles may all be of one size, large or small, or they may vary in size. Foams may be set in plastic masses or they may be allowed to "break," permitting the foamed material to recover its original properties.

The foaming of a liquid, viscous liquid, plastic or semi-solid increases the volume of the material. Foaming also temporarily alters the surface tension of a material so that its adhesive properties are improved and it can spread over and coat a surface. Viscous liquids and semi-solids can be made thinner and less viscous by foaming. A material altered by foaming and the degree of alteration depends on the foam generated and the foaming agent used. By careful control the characteristics of a material may be temporarily modified to produce the desired results. When the foam is destroyed or "breaks", the material recovers its original properties.

Foamed Asphalt

Asphalt cements can be foamed in a number of ways. Water can be added to the asphalt cement as it is being heated. Steam or air can be injected into hot asphalt cement, or chemicals may be added to create the foam. Each of these methods was investigated, and steam injection appeared to have the greatest possibilities of success.

Asphalt cements when foamed became less viscous at atmospheric temperatures. Asphalt cements of 85-100 penetration when foamed showed penetrations of 300 and more, and this penetration was retained for several weeks. Asphalt cements of a penetration as low as 4 when foamed showed similar increase in penetration.

Foamed asphalt cements are sticky and rubbery adhering tenaciously to solid objects coated with them. They can be drawn into very fine threads, indicating a high ductility.

In all the tests the foams were made in open vessels. When asphalt cements were foamed in containers, the foam was neither uniform nor consistent, nor was it reproducible.

Foamed asphalt cements have desirable properties, but the asphalt must foam instantaneously if the desired character of the foam is to be produced consistently. An asphalt cement foam could not be pumped readily without

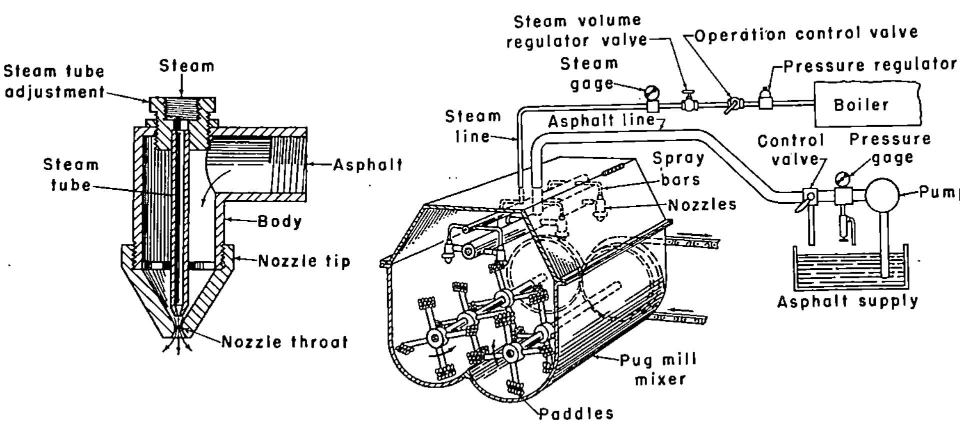


Fig. 1. At left. Foamed asphalt nozzle.
Fig. 2. At right. Foamed asphalt system.

breakdown of the foam. A nozzle was therefore developed by which the quantity of the asphalt cement could be controlled and which would give a uniform and consistent foam once the nozzle was properly set (figures 1, 2)

Foamed Asphalt Nozzle

The asphalt cement enters the nozzle and passes on to the nozzle tip where it is foamed instantaneously by the saturated steam. The continual flow of the asphalt and the steam discharged the foamed asphalt from the nozzle.

The type of foam produced is controlled by the dimensions of the nozzle tip, clearance between the foaming agent tube and the tip, and the quantity and pressure of the asphalt and steam.

If a foam in which each bubble of foam is separate and independent of another is desired, a discrete foam tip is used. A nozzle equipped with such a nozzle tip and properly adjusted will create a discrete foam composed of minute bubbles under a steam pressure of 60 to 90 psi and an asphalt pressure of 50 to 80 psi. Bubbles of various sizes may be produced by varying the pressures within the ranges indicated and other nozzle adjustments.

If a foam in which the bubbles are in contact with one another is desired, a concentrated foam nozzle tip is used. A variety of concentrated foam characteristics and hollow cone nozzle spread may be secured by varying pressures and nozzle adjustments. Asphalt pressures as low as 5 psi and steam pressures as low as 15 psi may be used. Best results under proper adjustment for nozzle spread are secured with asphalt pressure at 25 psi, asphalt at 300°F, and 40 psi steam pressure. A nozzle properly adjusted at these pressures has a capacity of about 3 gallons per minute. Slightly higher pressures will increase nozzle capacity.

Saturated steam has several advantages. The nozzle can be heated and kept warm prior to operation, and the steam clears the nozzle orifice of congealed asphalt. This is important in plant operation, particularly in batch plants where operation of the nozzles is intermittent.

Foamed Asphalt System

A spray bar assembly was developed to introduce the asphalt foam into a mixer in the quantity, time, and manner needed.

The assembly has a spray bar fitted with the prescribed number of nozzles, a system for measuring and supplying asphalt cement, and a supply and control system for the saturated steam. The spray bar has two manifolds, one an asphalt manifold to which the nozzles are attached and which feeds asphalt to the nozzles, and the other a steam manifold which feeds steam to the nozzles. The number of nozzles attached to the spray bar depends on the quantity of asphalt foam needed, and that depends upon the capacity of the mixer and the type of mixture required. The asphalt foam nozzles are spaced on the spray bar and the spray bar is set over the mixer so that the foamed asphalt is distributed uniformly over the aggregates in the mixer during mixing.

In the supply tank the asphalt cement is heated between 280 and 320°F. Attached to the tank are an asphalt pump fitted with a relief valve, an asphalt pressure gage, and a control valve which may direct asphalt cement to the spray bar or recirculate it to its source. Since pressures in this system are seldom over 80 psi, low pressure pipe may be used. This piping and asphalt manifold of the spray bar should be heat jacketed. The asphalt may be measured in different ways. In batch plants the asphalt cement may be measured by weigh tanks from which it is pumped to the spray bar or by asphalt meters. In continuous plants the asphalt cement may be measured by pre-set pumps interlocked with aggregated feeds.

The boiler for the steam supply may be a usual high pressure boiler of 125 pounds, or a steam jenny that can furnish saturated steam at 80 pounds or over. The pressure regulator adjusts the steam pressure to the asphalt pressure. Where steam is used to heat asphalt lines, the steam for the nozzles may be taken from the nearest jumper and conducted through the pressure regulator, steam gage, volume control and valve to the spray bar steam manifold.

When the nozzles and pressures have been adjusted, operation of the Foamed Asphalt System is simple. The steam is first turned on to clear the nozzle orifices and heat up the nozzles, then the asphalt may be turned on. In continuous plants, where the nozzles operate continuously, no further attention is necessary. In batch plants, where the system operates intermittently, a different procedure must be followed. For each batch, after the right quantity of asphalt has been introduced the asphalt valve is shut off and the steam is continued to clear the asphalt from the nozzle tip. When drainage has stopped, the steam is shut off. For the next batch the steam is again turned on slightly ahead of the asphalt and shut off after the asphalt.

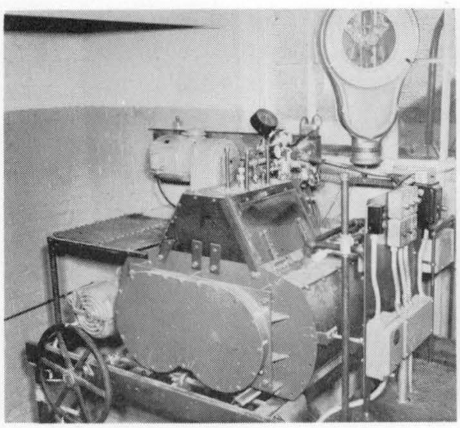
The Foamed Asphalt System may be adapted to any standard twin shaft pug mill mixer and to other typical applications with a minimum of mixer and operation modification.

TESTS OF FOAMED ASPHALT MIXES

After the Foamed Asphalt System had been developed, the action of foamed asphalt during mixing and of the effects of the foamed asphalt upon the properties of the mixes was indicated.

Laboratory and Pilot Plant Mixes

A 50 pound laboratory pug mill mixer (figure 5) and a 300 pound pilot plant pug mill mixer (figure 3) were adapted for the Foamed Asphalt Process. Steam was generated by a 60 gallon, automatic, oil fired steam jenny operating at 90 pounds (figure 4). Steam pressures were controlled between 10 and 90 pounds. The asphalt cement was measured volumetrically for the batch type laboratory mixer, and it was measured gravimetrically for the pilot plant batch type mixer. Both mixers were equipped with variable speed pumps for asphalt pressure and volume control and were fitted with water spray bars for moisture control.



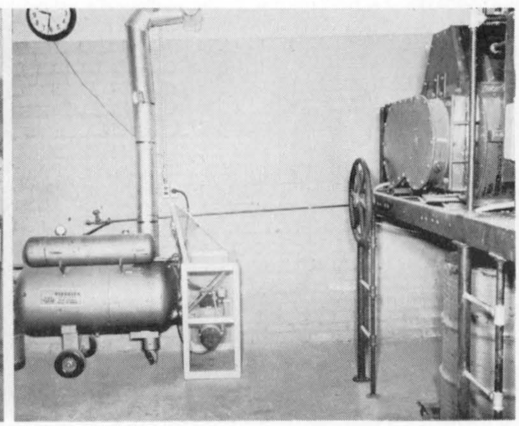
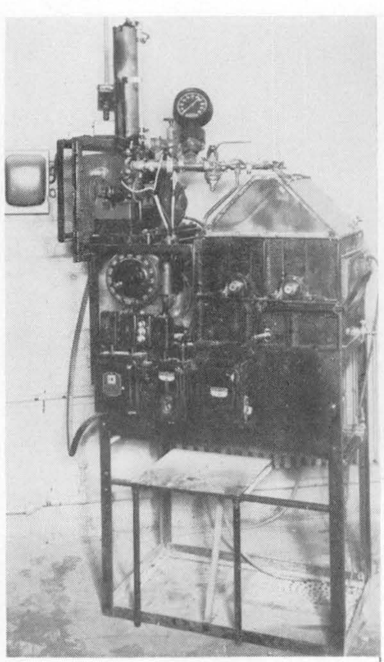


Fig. 3. At left. Pilot mixer equipped for foamed asphalt mix operation.

Fig. 4. At right. Small boiler unit for generating steam.



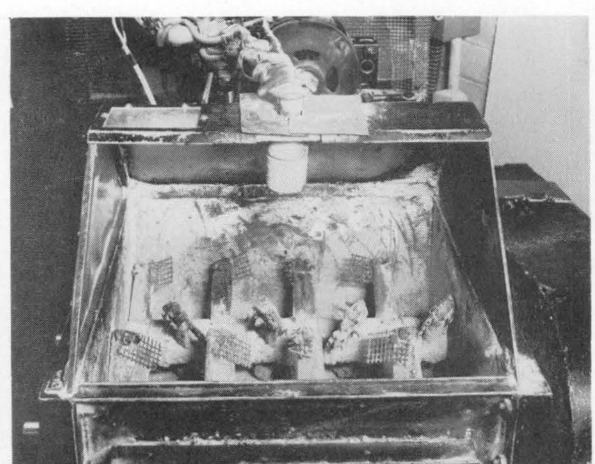


Fig. 5. Laboratory mixer adapted to atomization method. At right, inside the laboratory mixer showing atomizing nozzle, mixer cover, and grid paddle tips.

Types of Mixes Tested

The use of foamed asphalt in mixing procedure and its effect upon the physical properties of mixes were tested. Many kinds of mixes were tested, standard specification mixes, ungraded aggregate mixes, plant-mix soil stabilization mixes, in-place soil stabilization mixes, asphalt cement slurry mixes, liquid asphalt mastic mixes, and stock pile mixes. Both hot and cold types of the foregoing mixes were also investigated.

Standard Specification Mixes. The use of foamed asphalt in standard specification hot plant mixes was tested. The mix selected for this purpose was the Iowa State Highway Type A Asphaltic Concrete. So that direct comparisons might be made, mixes prepared on an actual construction job were used as a control. The same aggregates and asphalt cement used for the actual construction were used in preparing laboratory mixes in conjunction with foamed asphalt.

The aggregate blend used was a ¾ inch stone, 30%; pre-blended sand 35%; and chips 35% having the following gradation:

Sieve No.	Total Percent Passing	Iowa Specs[26] Type A
1 inch	100	98-100
¾ inch	99	98-100
½ inch	92	-100
⅜ inch	81	67-87
No. 4	60	47-68
No. 8	46	37-55
No. 30	25	19-34
No. 50	18	13-26
No. 100	10	6-
No. 200	6	3-10

Mixes containing 6.5% of 85-100 penetration asphalt cement prepared at the plant and in the laboratory were compacted and tested under usual Marshall Stability Test Procedure

In the first sequence of tests the laboratory mix was prepared in the 50 pound laboratory twin shaft pug mill mixer in accordance with all requirements for type A, asphaltic concrete of the Iowa highway specifications, except that the asphalt cement was added in the form of a foam. Six and one half percent of 85-100 penetration asphalt cement was used as in the plant mix. The Marshall test results of the laboratory mix were practically the same as those of the plant control mix. Visual examination of the foamed asphalt mix showed an excellent distribution of the asphalt throughout the mix and also that this mix appeared somewhat richer or fatter than the control mix, indicating a slight excess of asphalt.

A second sequence of tests was made to ascertain the effect of aggregate temperature on mixes using foamed asphalt. Mixes were prepared in which the temperature of the aggregate was varied between 160°F and 300°F. Excellent and uniform distribution of the asphalt was secured when the aggregate temperature was above 200°F. Below 200°F, although the fine aggregates were well coated, the coarse aggregate particles were only partially coated. Mixes prepared at 200°F showed a stability slightly less than those prepared at 300°F, but still well above minimum Marshall criteria of 500 pounds. These tests show that the temperature of aggregates is not nearly as critical for foamed asphalt mixes as for conventional mixes. Satisfactory mixes may be prepared with aggregates at 240°F. Mixes prepared at this temperature of aggregates would have a material effect on increasing both dryer and plant capacity, and reduce drying and plant operating costs.

A third sequence of tests was made to determine the possibility of using cold, damp or wet aggregates with foamed asphalt in mixes. The aggregates used in these tests were the same as those used before. Mixes were prepared with 6.5% foamed 85-100 penetration asphalt cement and the aggregates at 70°F containing about 3% moisture. Examination of these mixes disclosed that all of the fine aggregate particles were well coated, but coarse aggregate particles were only partially coated. Further test showed that mixes could be produced in which all particles of the aggregate were thoroughly coated when the aggregate contained 6 to 8% moisture and 7% of foamed asphalt was added. These tests showed that cold, wet, or damp aggregates may be used when the Foamed Asphalt Process is employed in preparing mixes.

The use of foamed asphalt in the preparation of standard specification mixes has the following advantages:

1. The asphalt cement is better and more uniformly distributed throughout the mix.

2. The operational procedure does not need to be changed, since the Foamed Asphalt Process utilizes the kneading action of the mixer and mixes are prepared under the usual mixing cycle time.

3. Aggregate temperatures as low as 240°F may be used without affecting the character and strength of the mix adversely. The lower aggregate temperature permits higher dryer and plant capacities and lower fuel costs.

4. Cold mixes may be prepared with cold, wet aggregates and hot asphalt cement.

Ungraded Aggregate Mixes

A mastic theory for the design and production of bituminous paving mixes using ungraded local aggregates with the atomization process is discussed in the following joint publication, Bulletin 19 of the Iowa Highway Commission and Bulletin 190 of the Iowa Engnieering Experiment Station. A number of tests were made to determine the efficacy of the Foamed Asphalt Process in producing such mixes under the mastic theory. For direct comparisons the mixes as prepared by the atomization method were prepared by the Foamed Asphalt Process. The materials used were essentially the same as those in the atomization method tests reported in the preceding joint publication. They were blow sand, fine sand, pulverized loess containing 38% clay, and limestone dust, as aggregates, and a 150 to 200 penetration asphalt cement as the binder. The gradation of the mineral aggregates was as follows:

Total Percent Passing	Fine Sand	Blow Sand	Pulverized Loess 38% Clay	Limestone Dust
No. 4 sieve	99	100	---	--
No. 10 sieve	94	99	---	--
No. 40 sieve	20	98	---	--
No. 60 sieve	--	---	---	98
No. 80 sieve	3	33	---	93
No. 100 sieve	--	---	---	90
No. 200 sieve	1	4	100	65

Since the properties of an ungraded local aggregate mix depend largely on the characteristics of the mastic, it was necessary to test the Foamed Asphalt Process in producing the mastic. The mixer was initially equipped with a discrete foam nozzle, one which emits foamed asphalt in separate, individual, small bubbles of binder. It also had the open grid type of fluffing mixer paddle tips. At that time it was believed that it was necessary to fluff and loosen or disperse the aggregate, with such paddle tips during mixing so that the individual bubbles of foamed asphalt might penetrate and contact all the particles of the aggregate. The fluffing tips were later proved unnecessary and better results were obtained with a concentrated foam nozzle which emits an asphalt foam in which the bubbles are interconnected. The kneading action of the mixer distributed the foamed asphalt throughout the aggregate. This meant that no changes in mixer design, paddle tip construction, or mixer operation were necessary, and the Foamed Asphalt Process could be adapted directly to a standard mixer. It also means that a mixer could be operated interchangeably either for foamed asphalt or for conventional processes.

The tests showed that satisfactory mastics could be produced when either pulverized loess or limestone dust were used as aggregate with foamed asphalt cement.

Work was initiated with ungraded aggregate mixes containing various combinations of aggregates and various binder contents. These mixes were prepared by placing the proper proportions of hot dry sand at about 350°F and dry dust at room temperature, about 70°F, into the mixer and mixing for about ten seconds to distribute the materials uniformly and to permit the dust to absorb some heat from the sand. Foamed asphalt was then added at a binder pressure of 25 psi and saturated steam pressure of 40 psi. The mixing of a 25 pound batch required about thirty seconds, making a total mixing time of about forty seconds. The temperature of the mixture discharged from the mixer was about 300°F. All mixes were homogeneous, and all particles were fully coated by thin films of binder.

Hubbard-Field Stability test specimens, 2 inches in diameter and about 1 inch in height, were prepared. After three days of curing at air temperature the specimens were tested for Hubbard-Field Stability at 140°F after 1 hour immersion in a hot water bath at 140°F. Void content determinations and freezing and thawing tests were also made on these specimens.

The results of the tests of specimens prepared by the Foamed Asphalt Process and of the same mixes prepared by the atomization method are shown in the following five tabulations. The mix proportions are given as percent of total aggregate for aggregates and percent of binder added based on total aggregate.

Blow Sand 70%, Pulverized Loess 30%

	Foamed Binder	Atomized Binder
8% Asphalt Cement		
Hubbard-Field Stability	1650	1250
Voids, percent	13.5	14
Resistance to Freezing-Thawing	Satisfactory	Satisfactory
9% Asphalt Cement		
Hubbard-Field Stability	1600	
Voids, percent	12.4	
Resistance to Freezing-Thawing	Satisfactory	
10% Asphalt Cement		
Hubbard-Field Stability	1650	1350
Voids, percent	9.6	10.3
Resistance to Freezing-Thawing	Satisfactory	Satisfactory
11% Asphalt Cement		
Hubbard-Field Stability	2050	1300
Voids, percent	6.0	7.1
Resistance to Freezing-Thawing	Satisfactory	Satisfactory

Blow Sand 75%, Pulverized Loess 25%

	Foamed Binder	Atomized Binder
7% Asphalt Cement		
Hubbard-Field Stability	1450	1050
Voids, percent	16.3	15.6
Resistance to Freezing-Thawing	Satisfactory	Poor

8% Asphalt Cement		
Hubbard-Field Stability	1900	1300
Voids, percent	14.2	13.6
Resistance to Freezing-Thawing	Satisfactory	Poor
9% Asphalt Cement		
Hubbard-Field Stability	1600	1250
Voids, percent	14.1	10.9
Resistance to Freezing-Thawing	Satisfactory	Satisfactory
10% Asphalt Cement		
Hubbard-Field Stability	1500	1350
Voids, percent	9.0	8.4
Resistance to Freezing-Thawing	Satisfactory	Satisfactory

Blow Sand 70%, Limestone Dust 30%

	Foamed Binder	Atomized Binder
6% Asphalt Cement		
Hubbard-Field Stability	1950	----
Voids, percent	14.5	----
Resistance to Freezing-Thawing	Satisfactory	----
7% Asphalt Cement		
Hubbard-Field Stability	2600	1800
Voids, percent	10.0	12.0
Resistance to Freezing-Thawing	Satisfactory	Satisfactory
8% Asphalt Cement		
Hubbard-Field Stability	2350	1800
Voids, percent	10.5	11.2
Resistance to Freezing-Thawing	Satisfactory	Satisfactory
9% Asphalt Cement		
Hubbard-Field Stability	3500	2350
Voids, percent	8.2	5.7
Resistance to Freezing-Thawing	Satisfactory	Satisfactory

Fine Sand 75%, Pulverized Loess 25%

	Foamed Binder	Atomized Binder
6% Asphalt Cement		
Hubbard-Field Stability	2400	1700
Voids, percent	9.2	8.9
Resistance to Freezing-Thawing	Satisfactory	Poor
7% Asphalt Cement		
Hubbard-Field Stability	2200	1200
Voids, percent	7.1	8.3
Resistance to Freezing-Thawing	Satisfactory	Satisfactory

8% Asphalt Cement		
Hubbard-Field Stability	1800	1000
Voids, percent	4.6	2.7
Resistance to Freezing-Thawing	Satisfactory	Satisfactory
9% Asphalt Cement		
Hubbard-Field Stability	2100	1400
Voids, percent	1.7	2.7
Resistance to Freezing-Thawing	Satisfactory	Satisfactory

Fine Sand 80%, Pulverized Loess 20%

	Foamed Binder	Atomized Binder
5% Asphalt Cement		
Hubbard-Field Stability	1400	1300
Voids, percent	11.7	11.6
Resistance to Freezing-Thawing	Fair	Poor
6% Asphalt Cement		
Hubbard-Field Stability	2000	1650
Voids, percent	9.7	9.0
Resistance to Freezing-Thawing	Fair	Poor
7% Asphalt Cement		
Hubbard-Field Stability	1650	1500
Voids, percent	5.9	6.6
Resistance to Freezing-Thawing	Satisfactory	Satisfactory
8% Asphalt Cement		
Hubbard-Field Stability	1700	1350
Voids, percent	3.7	4.7
Resistance to Freezing-Thawing	Satisfactory	Satisfactory

Tests were also made with agricultural limestone as a unit aggregate. The gradation of the material used in these tests is shown on page 33 herein. The ag lime was heated to 325°F and mixed with foamed asphalt. The test results are as follows:

Agricultural Limestone 100%

	Foamed Binder	Atomized Binder
7% Asphalt Cement		
Hubbard-Field Stability	2800	1050
Voids, percent	5	11
Freeze and Thaw	Satisfactory	Satisfactory

Using the Hubbard-Field Stability criteria all of the foamed asphalt mixes are suitable for medium or heavily travelled pavements. The foamed asphalt mixes are all better than those prepared by the atomization method.

Tests were also made of other aggregates such as run of bank fine gravels, run of crusher limestones, and others. All these tests showed that ungraded local aggregates can be used when the mixes are prepared by the Foamed Asphalt Process. The tests showed that the mixes are suitable for medium and heavy travelled pavements.

Although all of these mixes were prepared in batch type mixers, subsequent field tests showed that the Foamed Asphalt Process was also adaptable to continuous type mixers for the production of these local ungraded aggregate mixes.

Plant Soil Stabilization Mixes

The investigation using foamed asphalt in bituminous soil stabilization included the preparation and test of a number of mixes containing various soils, sands, and aggregates of varying moisture and different amounts of foamed asphalt. The mixes were all prepared at atmospheric temperature. Some of the mixes were prepared in the small laboratory mixers, and others in large quantities for trafficability tests were prepared in the pilot plant mixer.

The pilot plant mixer is a standard 300 pound capacity, batch type, twin shaft pug mill mixer equipped with conventional kneading type paddle tips operating at a shaft speed of about 90 rpm. The mixer was equipped with a foamed asphalt spray bar fitted with two concentrated foam nozzles. The asphalt was measured gravimetrically in a weigh tank from which it was pumped to the nozzles (figure 3). The nozzles were set for a concentrated asphalt cement foam when operating at 20 psi asphalt pressure and about 50 psi saturated steam pressure.

The first mixes were of 75% fine sand and 25% raw loess, and 5% and 6% of 150 to 200 penetration asphalt cement added as a concentrated foam. The fine sand used in these mixes was the same used in the ungraded aggregate sequence of tests. The loess was the same base material containing 38% clay used directly from stockpile with lumps as large as 3 inches in diameter. Both materials were mixed at air temperature.

Water was added in small quantities until the raw loess softened; after the sand and loess were in the mixer and mixing had been started. Agglomerations and lumps disintegrated and the loess was uniformly distributed throughout the mix. The quantity of water added was determined largely by the moisture in the aggregates. About 8% total moisture in the mix was sufficient to break down and distribute the loess. About thirty seconds of mixing time was required to attain a uniform mixture of aggregates and moisture. As soon as this condition was attained the foamed asphalt was added in about ten seconds. Mixing was continued after addition of the asphalt for about twenty to thirty seconds, making a total mixing time of about sixty to seventy seconds per batch. Excellent uniform mixes with evenly distributed mastic were produced.

The water added to the aggregates during mixing softens the clayey materials or heavy soil fractions so that the agglomerations are broken up and uniformly distributed throughout the mix. The water also separates the fine particles and suspends them in a liquid medium, making channels of moisture through which the foamed asphalt may penetrate to coat all the mineral particles. The quantity of water is not critical, but sufficient water must be in the mix to make a satisfactory mixture. Excess moisture is undesirable because it makes the mix too soupy and may reduce coating of the aggregates. The proper quantity of water for any mix may be readily determined by a few trial batches.

Hubbard-Field Stability test specimens were prepared and then tested after three days of curing for comparisons with previous tests. The results of the 75% fine sand, 25% raw loess mixes were as follows:

Mix: 75% Fine Sand, 25% Raw Loess

		6% A.C.	5% A.C.
Moisture content during mixing 8%			
Hubbard-Field Stability	77 degrees F. Dry	3000	3100
	140 degrees F. Dry	1650	2200
	Standard 140 degrees F. Wet	600	650
% Voids in compacted mixture, not corrected for moisture		12%	14%
Unit Weight, pounds per cu. ft.		148	151
Resistance to Freezing and Thawing		Good	Good
Max. Volume Change		4%	3.6%

The specimens were still damp after three days of air curing, but relatively good stabilities of 600 to 650 pounds were secured. Specimens cured for eleven days prior to testing were much drier and showed a stability of 1100 pounds. It appears that as the water drains from the mix its stability increases and it attains the higher stability.

To test the trafficability of the 6% asphalt mix about three tons of the mixture was prepared in the pilot plant mixer and laid in a small field test area. A section of a roadway carrying about 400 cars per day was excavated over an area eight feet wide and twenty feet in length to a depth of five inches. The mixture was spread in this excavation in one six inch lift and compacted with a wobble wheel pneumatic roller to a compacted depth of five inches. The material spread smoothly and compacted readily. The test area was opened to traffic soon after laying and was observed for about a week. During this period the mixture performed excellently even after heavy rains. Because the surface scuffed slightly the surface was sealed with a single layer seal. This test area, laid in September, 1956, received a second single layer seal in 1957, and has served excellently during the past three and one half years. Weather conditions have varied during this period from 102°F to 20°F below zero, with heavy rains, snow, and ice on the surface.

The material from the excavation was subjected to stabilization in the pilot plant. The road had been surfaced with power house cinders laid about 1½ to 2 inches in thickness upon a heavy clayey soil. The materials were about 40% cinders and 60% soil having a gradation as follows:

Sieve	Total % Passing
⅜	93
4	82
10	68
40	46
80	34
200	26

In preparing the mix, after the cinder-clay material was in the mixer, water was added during mixing until the clayey soil was uniformly distributed. The total moisture content was about 8%. Then 6% of 150 to 200 penetration asphalt cement was added as a concentrated foam, and mixing was continued for about thirty seconds. Since this mixture had coarse aggregate particles, Marshall Stability specimens were prepared and tested. The results of these tests were as follows:

Moisture in Mixture	8%
Marshall Stability 140°F wet	480 pounds
Voids in compacted specimen	17%
Unit weight per cubic foot	142 pounds
Resistance to Freeze and Thaw	Fair

Other mixes were produced in a similar manner with 20% of raw loess added to the cinder-soil combination. These mixes were also tested for Marshall Stability. The results of these tests were as follows:

	5% A.C.	6% A.C.
Moisture in Mix	8%	8%
Marshall Stability 140°F wet pounds	500	460
Flow	16	21
Voids in compacted specimen, %	15	15
Unit weight pounds	148	142
Resistance to Freezing-Thawing	fair	fair

Analysis of the results of these tests indicate that some bituminous soil stabilized mixes within the Marshall Stability criteria for asphaltic concrete can be produced by the Foamed Asphalt Process.

Since the initial tests, river sands from Sioux City, Iowa, and from Minnesota; beach sand from South Carolina; and rock sands from Maine have been tested for adaptibility to stabilization by the Foamed Asphalt Process.

In these tests a series of mixes were prepared to determine the moisture content for the best distribution of the foamed asphalt throughout the mix. At optimum moisture excellent mixes are secured. At less than optimum moisture contents, the distribution tends to be spotty. All mixes were prepared and tested by the Standard Hubbard-Field Stability procedure at 77°F dry, 140°F wet. Tests were also conducted to determine resistance to freezing and thawing and moisture absorption after one hour immersion. The test results at optimum moisture are:

Sioux City Sands

Gradation Total % Passing	L. M. Sand #1 Dry	L. M. Sand #1 Washed	L. M. Sand #2 Dry	L. M. Sand #2 Washed
4	99	100	97	98
10	98	100	91	92
40	53	65	53	53
80	6	20.0	10	13
100	4	17	6	9
200	1.7	14.0	2	6
Sp. Gr. 2.58				
Mix Proportions				
% Sand	100	100	100	100
% A. C.	6	4	5	4
% Moisture	7	6	6	8
Hubbard-Field Stability				
77°F dry	3800	4300	2600	2500
140°F dry	1600	2000	510	550
140°F wet	1200	1200	320	230
Percent voids	5.1	9.0	8.6	7.8
Percent absorp.	0.6	2.2	2.4	4.1
Freeze & Thaw	ok	ok	ok	ok

Minnesota Sand

Passing Sieve	Total Percent
No. 4	100
No. 10	100
No. 40	98
No. 80	34
No. 200	7

Specific Gravity	2.63
Voids in Aggregate	43.1 percent
Moisture Content of Sand as Received	5.2 to 5.4 percent

Stabilized Mixtures	1	2	3	4
(Proportions based on dry Wt. of Sand)				
Percent Sand	100	100	100	100
Percent A.C.	6	6	5	4
Percent Moisture during mixing	5.4*	1.6	5.2*	7.6

Hubbard-Field Stability				
77°F dry	1900	1100	1800	1900
140°F dry	970	240	950	950
140°F wet	630	170	440	360
Percent Voids in compacted mixture	14.1	11.2	17.8	17.6
Percent Absorp., compacted mixture	0.8	0.9	0.9	3.6

All mixes resisted 12 cycles of freezing and thawing

* Normal moisture in samples

South Carolina Beach Sand

Sieve	Total % Passing
⅜	99
4	98
8	96
40	94
80	51
200	4

Sp. Gravity 2.67
Voids in sand 64.1%

Proportions				
Sand	100	100	100	100
% A. C.	6	6	5	4
% Moisture	8	10	8	8
Hubbard-Field Stability				
77°F dry	2200	2800	2200	2200
140°F dry	----	----	1030	850
140°F wet	660	930	600	450
Voids in mix %	16	14	20	22
Absorption %	2.0	1.2	5.0	11.0

Maine Sands

Gradation Sieve	Road Sand	Total Percent Passing Crusher Waste	Stone Dust
½″	---	100	---
⅜″	---	98	---
4	100	67	100
10	85	31	99
40	20	9	39
80	4	7	20
200	1	5.2	9
Sp. Gravity	2.69	2.69	2.71

Proportions			
Aggregate %	100	100	100
A.C. %	5	6	6
Moisture %	7	6	5.5
Hubbard-Field			
77°F dry	2900	4350	4860
140° dry	860	2500	2520
140°F wet	420	1460	840
Unit Wt. pound cu. ft.	134	146	139
Voids in mix %	13	4	9
Absorption %	4.2	1.6	2.7
Freeze-Thaw	excellent	excellent	excellent
Marshall Stability	--	--	--
140°F dry	--	1300	--
140°F wet	--	470	--
Flow	--	15	--

The Foamed Asphalt Process can stabilize sands for base course applications. The gradation of the sand is not critical. Sands of practically single size, between the 40 and 80 sieves, and between the 80 and 200 sieves can be stabilized by the method. More uniformly graded sand will naturally result in higher stabilities. High water content is desirable because it materially assists in distributing the foamed asphalt throughout the mix, but water content must be watched, because insufficient moisture means a spotty mixture and excessive moisture may wash some of the asphalt out of the mix.

In-Place Soil Stabilization

The Seaman-Andwall Company loaned to the Bituminous Research Laboratory for research purposes a Pulver-Mixer, stock Model D.S. 27 with an eight foot wide hood. This Pulver-Mixer was adapted to the Foamed Asphalt Process by adding a small, 60 gallon, steam jenny boiler to furnish the steam required for foaming the asphalt and heating the asphalt lines. A spray bar fitted with eight asphalt foam nozzles and other piping and controls was also added (figures 6 and 7). The spray bar was designed to be connected directly to the asphalt transport vehicle so that the pump on the vehicle could supply asphalt to the spray bar at the desired pressure. The foam nozzles operated at about 20 pound asphalt pressure and 40 pounds steam pressure. The foamed asphalt system could be controlled from the operator's seat on the machine.

Several preliminary tests were run during the summer of 1956. One of these was on the road, a section of which was stabilized by plant-mix foamed asphalt procedure. The material stabilized was about 40% cinders and 60% clayey soil, the gradation of which has been given previously. This test section was an area 24 feet wide and 250 feet in length. The asphalt transport used was a 180 gallon tar kettle equipped with a small 15 gpm asphalt pump

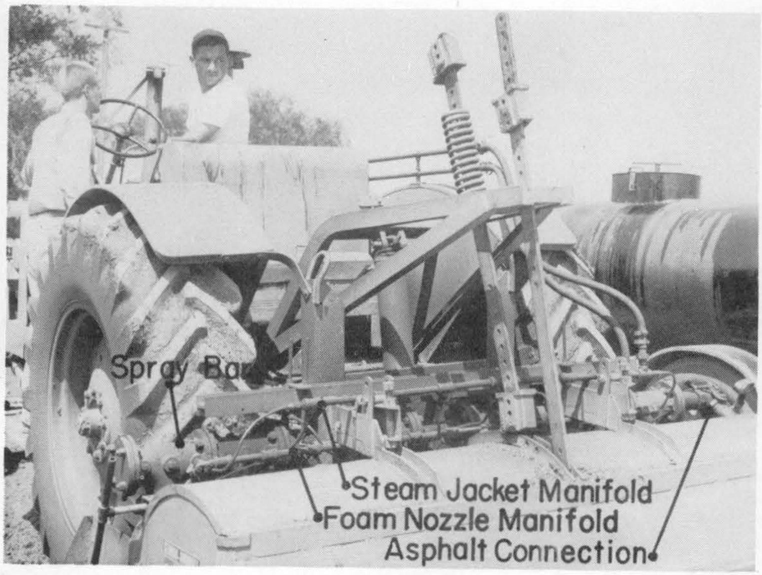
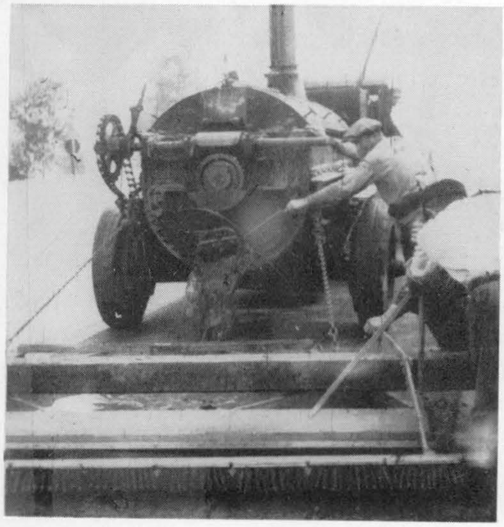


Fig. 6. Above, left. Steam boiler attachment on front.

Fig. 7. Above, right. Pulvic-Mixer with foamed asphalt spray bar and steam connections.

Fig. 8. At left. Hand spreading Schlämme.

Fig. 9. Below. Spreading Schlämme with broom drag.



and heaters to heat the asphalt cement to 330°F. The asphalt cement used was a 150 to 200 penetration grade.

Because the roadway had a layer of cinders about 1½ to 2 inches thick on clayey soil, a cutting and blending pass was made with the Pulver-Mixer. The cut, set at a 4 inch depth, made a loose mass of blended material about 6 inches deep. Water was added to the loose material to about 9% moisture content. Occasional heavy rains after the water was added made aeration of the blend necessary to reduce the moisture content. After the desired moisture was attained in the mix the asphalt stabilization passes were made. Because foam nozzles used on the spray bar were too few, the pump on the transport limited in capacity, and the speed of 40 feet per minute of the Pulver-Mixer too high, the desired quantity of 5% of asphalt could not be added to the mix in one pass. Therefore four passes were made and about 1 1/3% of foamed asphalt was added in each pass, about 5 1/3 in all.[26] The full depth of 6 inches was mixed with the asphalt in each pass.

Examination of the mixture showed that the particles of the fine clayey fractions were well coated with asphalt and that these fractions formed a mastic that bonded the coarser partially coated particles together into a dense mass. Some lumping was noted in the mixture due to the necessity of making four successive passes. The asphalt was, however, quite uniformly distributed throughout the mix. Physical property tests indicated that the mix had the strength and other characteristics needed as a base for the type and volume of traffic.

Immediately after the mixing was completed the mixture was rolled and compacted in two passes by a Seaman-Gunnison Duo Pactor roller with a combination of rubber and steel rolling, followed by a final finishing pass with steel alone. About a week after the completion of the stabilization of the area a single layer seal coat was applied. This seal coat was 0.2 gallon of 150-200 penetration asphalt cement and 20 pounds of coarse sand per square yard of surface. In 1957 a slurry seal coat was added to the surface.

This test area has given excellent service carrying 250 to 400 cars per day for the past 3½ years. The initial tests were so encouraging that in 1957 the remaining 500 feet of this street was similarly stabilized and sealed and another larger test section was laid on a nearby local gravel county road[7] (figures 21, 22).

These tests on in-place soil stabilization show that foamed asphalt cement has some advantages over the usual methods of bituminous soil stabilization.

1. Asphalt cement when foamed can be uniformly distributed throughout a wider range of wet soils including granular, sandy, and heavy clayey soils.

2. When foamed asphalt cement is used, the stabilized soil does not require aeration.

3. The stabilized soil may be rolled and sealed immediately after stabilization without extensive curing and can be opened to traffic sooner.

4. Any penetration grade of asphalt cement may be used because the nozzles can properly foam any asphalt cements between 5 and 300 plus penetration.

ASPHALT CEMENT SLURRY SEAL COATS

The difficulties in designing single layer seal coats to give consistent results and avoid such problems as bleeding, dusting, aggregate scatter, and ravelling has recently led to the development of slurry seal coats. Two basic types of slurry seal coats have been developed. One uses emulsified asphalt and another uses hot asphalt cement as the binder. The emulsified asphalt type was developed in California[27] and the asphalt cement type was developed by Dr. J. Oberbach in Germany[21,30] where is was called *Schlämme.*

Schlämme, which means *slurry* in English, has some unusual characteristics: it uses cold wet aggregates with hot asphalt cement; its consistency can be adjusted to meet any type of laying operations from brooming, screeding, or trowelling, after placement; the water that controls consistency drains away rapidly, reducing curing and setting time. An aggregate of special gradation between the No. 4 and 200 sieves with from 10 to 20 percent passing the No. 200 sieve is used in Schlämme. Asphalt cement having a penetration between 50 and 200, as required by the application, is the binder. Schlämme is mixed in a twin shaft pug mill mixer with a water-tight discharge gate and with mixing shafts that rotate at slightly higher than normal speed.

After the aggregate is in the mixer, water is added to produce a smooth paste. At this stage of the mixing, the mix is an aggregate paste. As soon as the paste is at the desired consistency hot asphalt cement, usually 11 to 15%, is added at 300°F. Mixing is continued until the asphalt has been thoroughly kneaded into the mixture and most of the aggregate particles have been coated, forming a mastic or asphalt paste. Additional water is added to form a slurry which is then dumped into an agitator truck for transport to the field where the slurry is to be spread. The asphalt paste may be dumped into the agitator truck where additional water is added and the slurry is mixed during transport. The agitator truck is a large single shaft pug mill mounted upon a carriage. Its purpose is to keep the asphalt coated aggregate particles suspended in the water and thus prevent their settling out and coalescing during transportation. An agitator truck must be used because the slurry tends to segregate and the asphalt wash out in a drum type concrete mixer transport truck.

Schlämme may be spread in different ways depending on the thickness desired and the surface upon which it is to be laid. When a surface is relatively porous or contains numerous small fine cracks, the slurry is made quite liquid so that it can fill the pores and cracks and densify the surface. The slurry may be spread by hand using soft brooms or by screed and broom drag (figures 8, 9). Less water is used in preparing the slurry for larger cracks or when a thicker layer of slurry is desired. The slurry may be spread by trowelling or by broom dragging.

When the slurry is spread, the asphalt coated aggregate particles settle out rapidly and coalesce, and the particles bond into a thin mat. On relatively warm, sunny days the mat will set sufficiently to carry traffic in about two hours. The finished slurry surface when set and dry is hard and tough and adheres firmly to the pavement. On damp, humid days it will take somewhat longer to set. If the slurry is placed on a heavily travelled road, light pneumatic rolling just after setting will make the mat more uniform in density. On lightly travelled roads rolling is not essential.

The preliminary tests in preparing the slurry were based on Dr. J. Oberbach's experiences with German materials and equipment. As the tests progressed extensive modifications were necessary in making a satisfactory slurry of Iowa aggregates with American equipment. The moisture in the aggregate paste and in the slurry had to be controlled if uniformly consistent slurries were to be produced.

Water in Aggregate Paste

The aggregate selected for study first was an agricultural limestone with a gradation conforming to the gradation contained in the German patents[29]. The gradation of this agricultural limestone was as follows:

Sieve	Total % Passing
4	100-95
10	80-90
40	40-45
80	25-35
200	15-25

The moisture content of this material when received varied from 5 to 22% depending on the part of the stockpile from which it was drawn. About 16% ± 1% moisture in the aggregate gave the consistency of the aggregate paste needed. A quick test was needed to determine if an aggregate required drying or if water should be added to secure the proper moisture.

A number of tests were tried. A slump cone with a base diameter of 4 inches, top diameter of 2 inches, and a height of 6⅛ inches operated on a standard flow table fitted with a ½ inch drop was developed[2] (figure 10). With the slump cone centered on the flow table it is slightly overfilled with aggregate paste and then the flow table is dropped ten times in five seconds. The cone is again filled and compacted. This is repeated until no further compaction is secured. Then the paste is struck off level, the slump cone is removed and the table is dropped five times in three seconds. The slump is then measured.

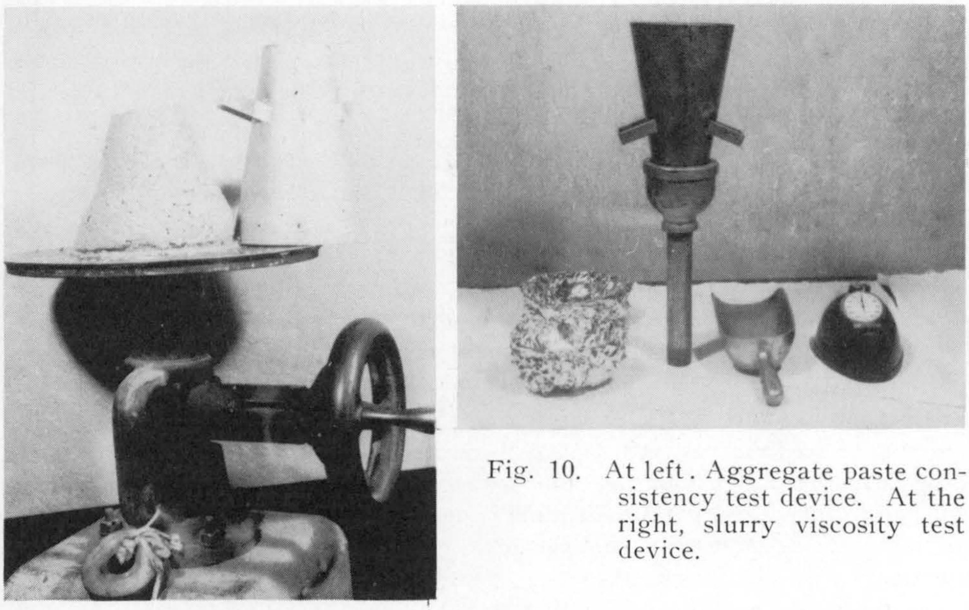


Fig. 10. At left. Aggregate paste consistency test device. At the right, slurry viscosity test device.

Since slump-moisture content of the paste will vary for different aggregates or combinations of aggregates, a slump-moisture cure (figure 11), must be prepared for each aggregate. A series of tests made with a variety of aggregates indicates that the moisture content of a paste may be determined within ½ percent plus or minus by this test. Since moisture in the aggregate is not very critical this error is not serious, and the test may be used as a rapid means of controlling moisture in the aggregate paste. A plant operator may by periodic checks control and adjust the moisture added to form the aggregate paste when the moisture in the aggregate varies widely.

Consistency of the Slurry. Since the consistency of the slurry depends on the amount of water added to the asphalt paste and since the laying and spreading of the slurry depends on its consistency, the quantity of water used must be under control to maintain the desired consistency.

To determine the slurry consistency a device, essentially an orifice type viscometer, was developed[2]. It is a slump cone, the same as that used to determine the consistency of the aggregate paste, fitted into a standard 2 inch to ¾ inch reducing coupling with 6 inches of ¾ inch pipe as a stem. The device is operated by closing the lower end of the stem with a cork or finger, then filling the cone with slurry. The time required to empty the device, in seconds, is the measure of the consistency of the slurry. Consistency curves for various aggregates must be prepared (figure 12).

Design of Slurry Mixes

Since no specific information as to the design of asphalt cement slurry mixes was available, several questions needed to be answered. How can the strength of these mixes be measured? What effect has moisture in the aggregate paste, type, and quantity of asphalt cement in the asphalt paste and quantity of moisture in the slurry upon such strength? How does moisture affect curing rate and shrinkage after placement? To find the answers new

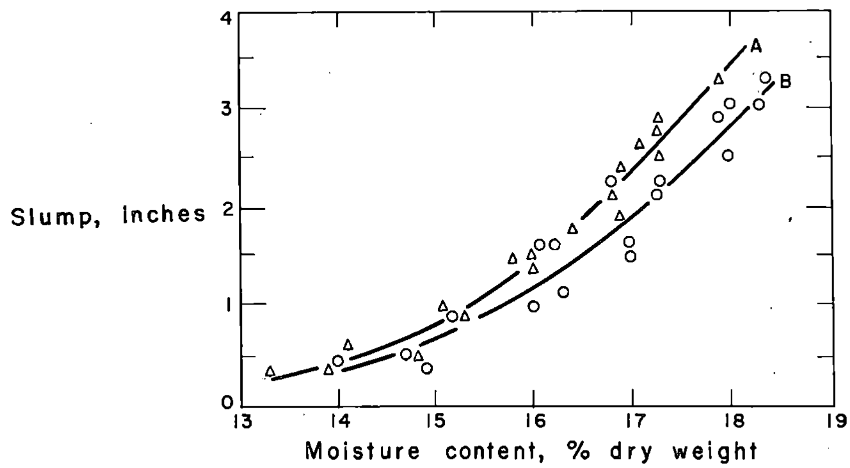


Fig. 11. Slump moisture curve for aggregate paste.

methods of test had to be developed because the slurry mixes differ so greatly from the usual bituminous mixes, both in method of preparation and in application, that usual design tests are not applicable.

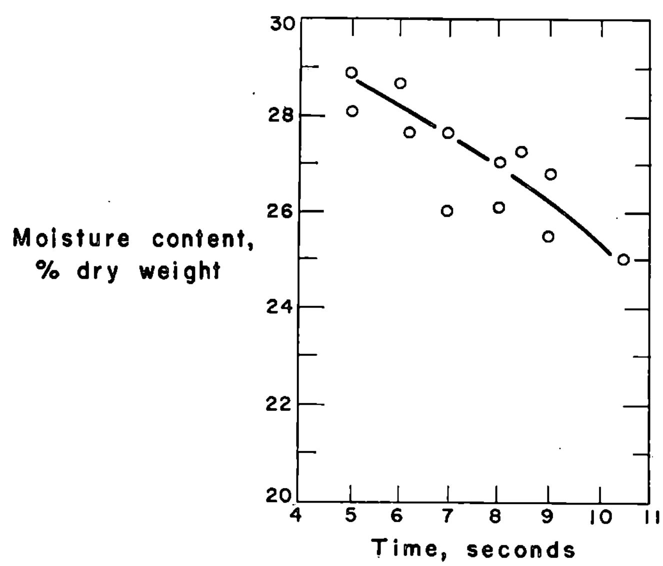


Fig. 12. Moisture time curve for asphalt cement slurry.

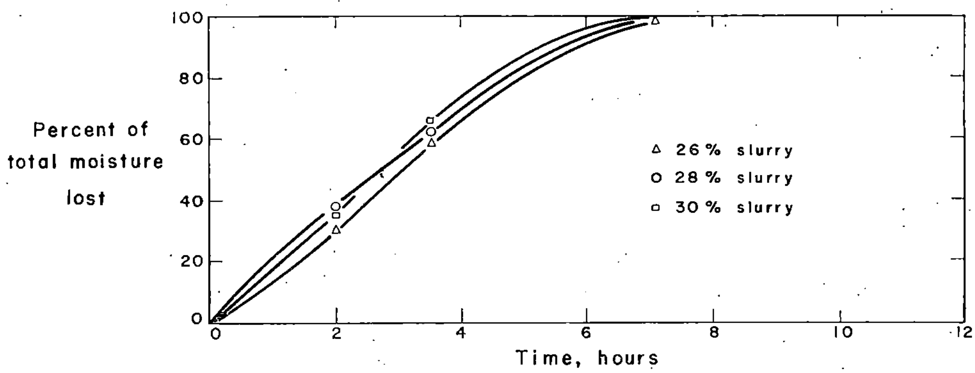


Fig. 13. Curing curve for ⅛ inch specimens.

The effect of moisture on the curing rate of the slurry when laid in the usual thicknesses of ⅛ inch and ¼ inch, and the physical characteristics of the curing slurry were studied first[24]. For this purpose a mix was prepared as follows: To aggregate paste of agricultural limestone with about 16% moisture, 13% of 150-200 penetration asphalt cement at 325°F was added to form the asphalt paste. Slurries containing 26, 28, and 30% total moisture were prepared from the asphalt paste. Test specimens were prepared of these slurries in ring molds 2 inches in diameter and ⅛ inch and ¼ inch in height setting on a steel base plate. The specimens were then cured in the molds at room temperature at 80°F and at a relative humidity of 10 to 20%. The loss of moisture was determined at certain time intervals (figures 13, 14). In observing the specimens during curing, it was noted that moisture was lost by drainage and evaporation immediately after molding. Drainage continued until the moisture content was about 20%. The color of the specimen becomes black at about 12% moisture. Shrinkage of the specimen begins at 12% moisture and the specimen becomes hard at about 10% moisture. About

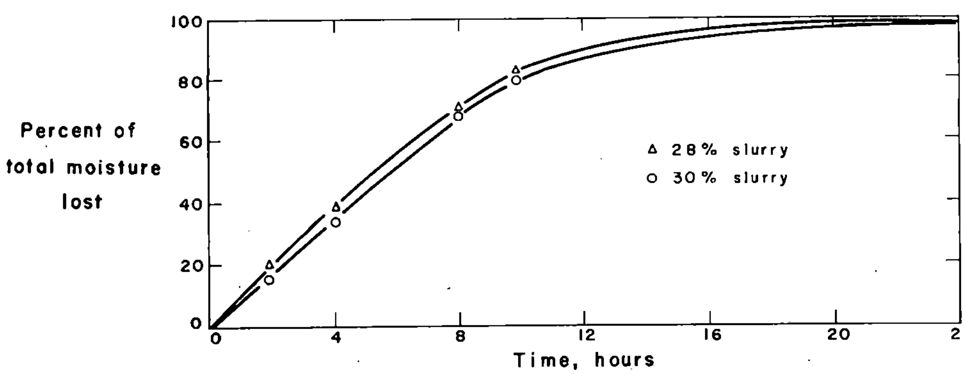


Fig. 14. Curing curve for ¼ inch specimens.

3% shrinkage was observed in ⅛ inch specimens. The ¼ inch specimens shrank about 5% and tended to curl upward at the edges. It was later observed that different aggregates cured similarly but had different shrinkage effects.

A penetrometer type test instrument was devised to determine the strength of the thin disc slurry specimens. This instrument had a vertical plunger fitted with a penetration head at the bottom and a weight loading platform on the top and mounted in a guide. The penetration head was a small cylinder with a penetration area of 1/3 square inch. A unit load of 180 psi imposed on the surface of the specimen could be attained with a plunger weight of 60 pounds. Depth and rate of penetration was used as an index of strength. Uniform test results could not be secured with this instrument, particularly in the ⅛ inch thick specimens, due to particle size of the aggregate.

As this type of slurry sets and the moisture leaves, the mix gradually reverts to the asphalt paste form which with further loss of moisture hardens to form the surfacing. It may be assumed that the physical properties of the asphalt paste have a bearing on the properties and characteristics of the surfacing. The properties of the asphalt paste may be used for design purposes.

The Hubbard-Field Stability test was tried to ascertain its adaptability to testing of the asphalt paste[23]. Specimens of the asphalt paste, taken directly

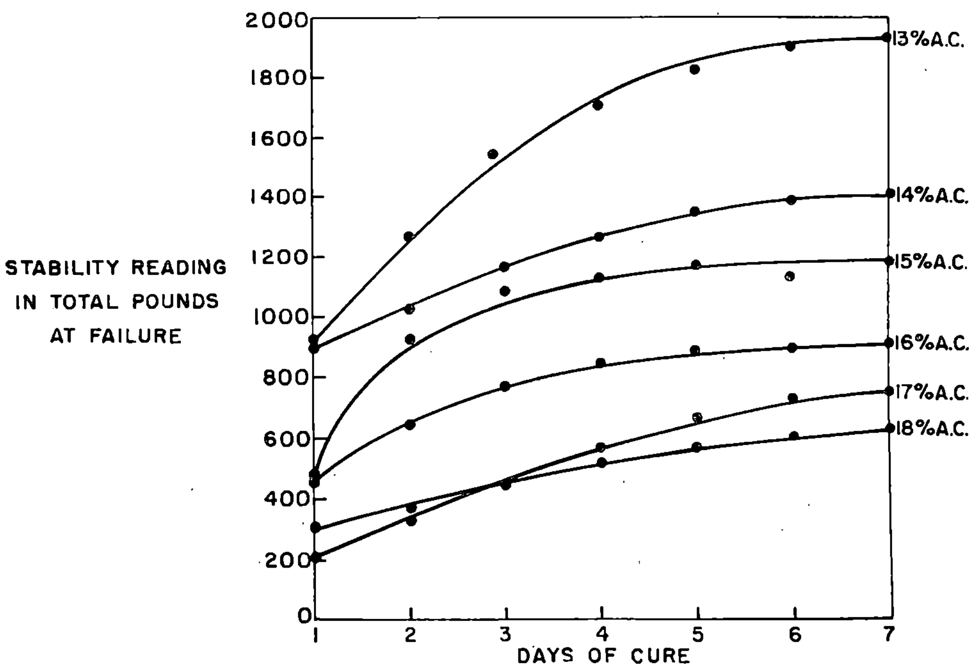


Fig. 15. Curing stability curves.

from the mixer, were compacted into specimens 2 inches in diameter and about 1 inch high. During compaction of the specimen under a static load of 3000 pounds per square inch a large amount of water in the asphalt paste was squeezed out of the specimen. After a one day cure at room temperature in air, the specimens had less than 2% moisture and after seven days' cure they had less than a half percent of moisture. A check of the effect of curing on stability showed that stability generally increased with curing time up to the seventh day, after which the curves levelled off (figure 15). All Hubbard-Field Stability tests were therefore made on specimens cured for seven days. at which time the specimens had a relatively consistent stability.

A large number of test mixes were prepared with agricultural limestone as the aggregate, and 150-200 penetration and 85-100 penetration asphalt cements as the binder. In these mixes the quantity of moisture in the aggregate paste was varied between 11% and 18% at 1% intervals, and the quantity of asphalt cement in the asphalt paste was varied between 13% and 18% at 1% intervals. The stability results at 77°F dry of these test specimens indicate that under similar conditions lower penetration asphalts will yield higher stabilities than higher penetration asphalts (figure 16). Rather unusual results were obtained when 16% moisture was used in the aggregate paste and 150-200 penetration asphalt cement was used as the binder. When less than 17% of asphalt cement was used, a sharp decrease in stability was noted at 16% moisture. The reason for this break is not known. The behavior of 85-100 penetration asphalt cement did not indicate this break, and later tests indicate that the break is caused by the moisture absorption character of the aggregate. It should be emphasized that these stability tests were made at 77°F dry, rather than at 140°F wet as prescribed for several reasons: some specimens disintegrated in the hot water bath; test results were low and showed insufficient differences from which effect of variables could be determined; results were not consistent.

The results of these tests indicate that the Hubbard-Field Stability test made at 77°F dry on the asphalt paste can be used to find the effects of several variables in the mix, and may be used to determine the better mix.

FOAMED ASPHALT SLURRY MIXES

Schlämme mixes following the Oberbach procedure require batch type mixers to produce the asphalt paste, and paddle type agitators are needed to produce the slurry. It could not be produced in a rotary drum type mixer because the aggregates tended to segregate. Since most of the plants in the United States are of the continuous type and no manufacturer produces a large enough paddle type mixer, direct adaption of Schlämme to American equipment was almost impossible.

Schlämme is fundamentally a mastic mix, since it requires in excess of 10% of fines passing the 200 mesh sieve. Since it had been proved that

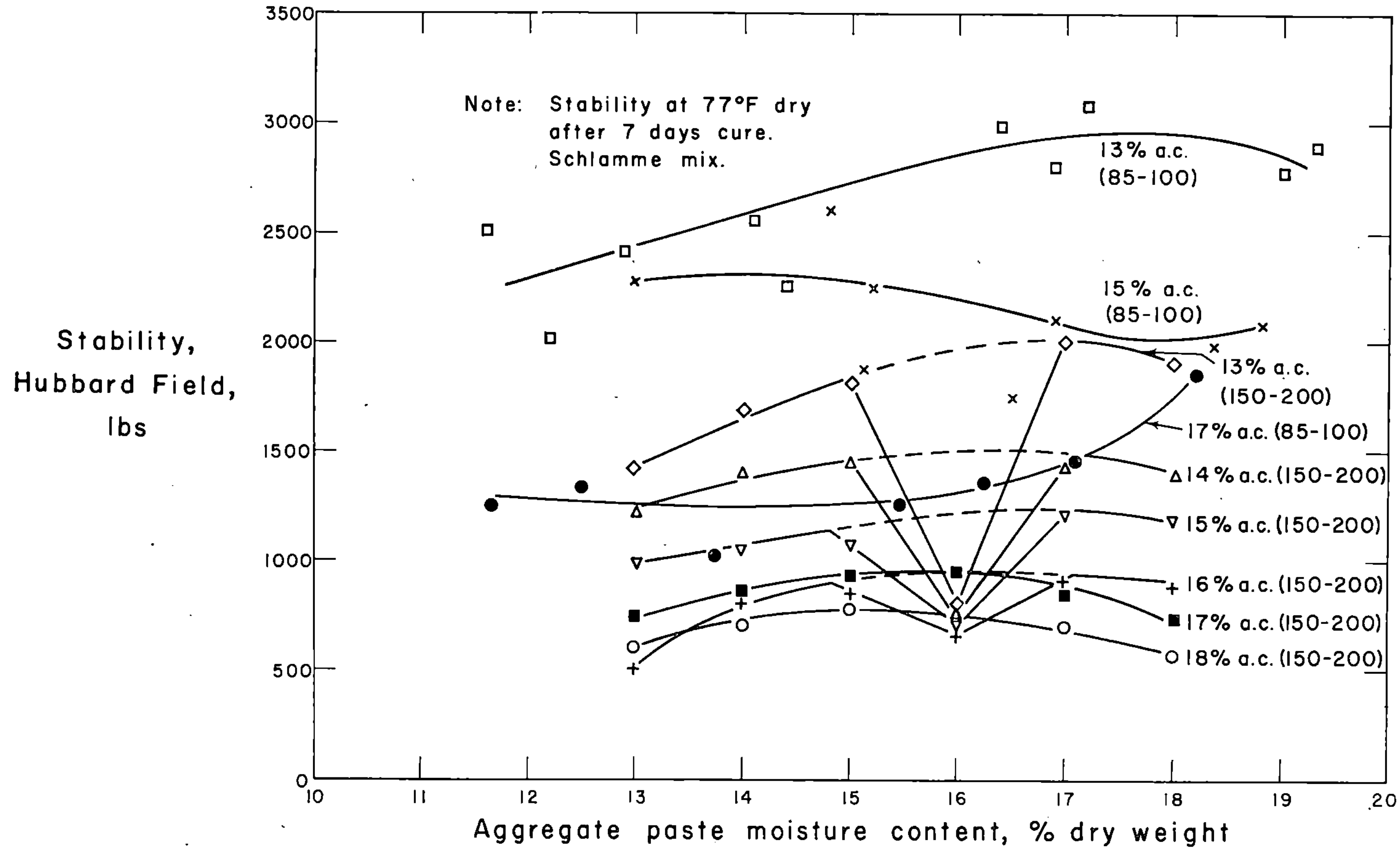


Fig. 16. Stability moisture curves Schlämme.

mastic mixes containing wet aggregates could be prepared in either batch or continuous mixers when the Foamed Asphalt Process was used, this process was tried in the production of a modified Schlämme slurry using American equipment and practices. Preliminary tests showed that a Modified Schlämme slurry could be produced by the Foamed Asphalt Process and that the asphalt paste could be produced in a continuous mixer and the slurry in a rotary drum mixer.

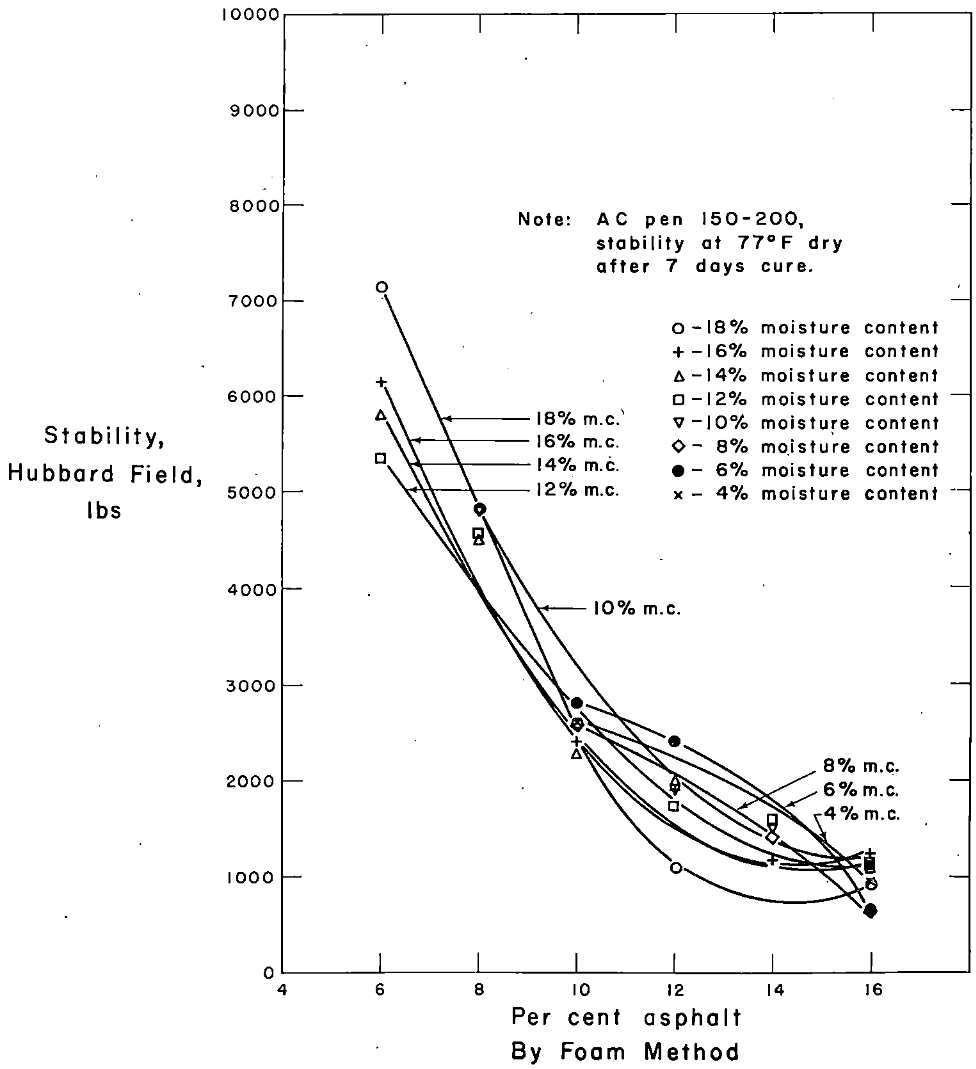


Fig. 17. Stability tests 77°F dry foamed asphalt slurry.

To compare the properties of asphalt pastes produced by the two methods, mixes similar to those of the Oberbach method were prepared by the Foamed Asphalt process. The moisture for the aggregate paste was added to the aggregate before putting it into the mixer, and mixing was started. The asphalt cement as a foam was added by the Foamed Asphalt Process and mixing was continued for about thirty seconds. The mix turned brown as the foamed asphalt was added, then after twenty seconds of mixing it turned black and became a smooth homogeneous asphalt paste in which the mastic was well

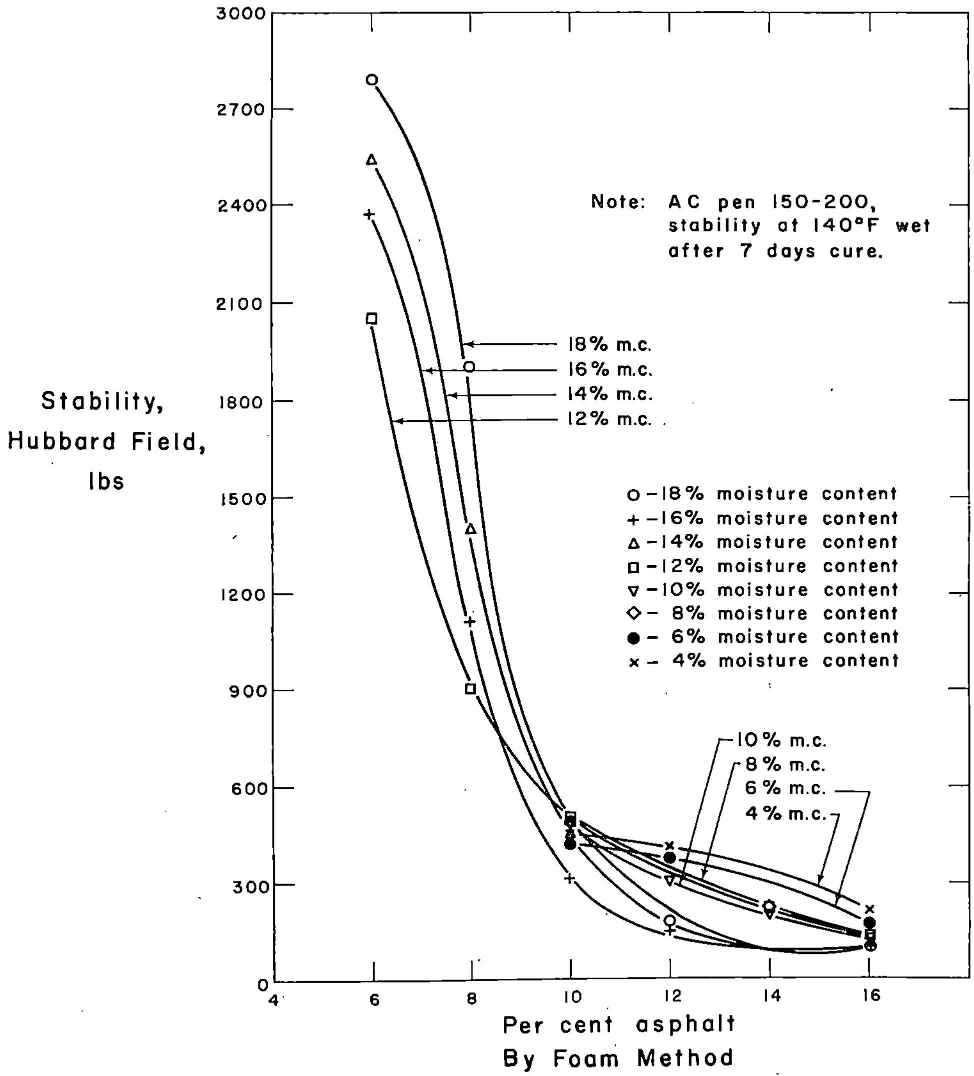


Fig. 18. Stability tests 140°F wet foamed asphalt slurry.

developed. When the asphalt paste was put into a small rotary drum type mixer and water was added it became a smooth, black slurry in which all particles were coated. There was no segregation of particles as in similar paste produced by the Oberbach method.

The asphalt pastes produced by the Foamed Asphalt Method were tested for Hubbard-Field Stability at both 77°F dry and 140°F wet after 7 days' cure (figures 17, 18, 19). Asphalt pastes with as little as 4% moisture and 6% asphalt can be produced by this process. Low asphalt contents require higher quantities of moisture, and higher quantities of asphalt require lesser quantities of moisture to produce a good asphalt paste. When 10% or more of asphalt is used the moisture content is not critical. Asphalt pastes produced by the Foamed Asphalt Process can resist disintegration when immersed in a hot water bath at 140°F for 1 hour (figure 18).

Comparison of test results between Schlämme mixes, made by the Oberbach method, and Modified Slurry mixes made by the Foamed Asphalt Process show that stabilities equal to or slightly higher can be secured in the modified slurries. They do not show the peculiar break noted at 16% moisture in the Schlämme mixes, and the curing rate of Schlämme and Modified Slurry mixes is in general the same.

Special Characteristics of Slurries

Both types of slurries are subject to aggregate properties. It was found that some limestones make excellent asphalt pastes but not smooth slurries. In one test the limestones secured from different levels of the same quarry behaved differently. The top layers, which had been leached severely, would not slurrify, but lower layers produced slurries. Further tests proved that alumina in the aggregate has some effect on the slurry and that addition of a little clay to limestone might make it slurrify well. This study is being carried forward in a new project.

Both types of slurries may be colored with inorganic dyes. Rich red, green, or yellow dyes can be added to the asphalt paste during mixing of the slurry. The colors have retained their brightness for over two years in service.

Both types of slurries have a higher resistance to the softening action of fuels and certain solvents than other asphaltic mixes. When these slurries are heat treated their resistance is greatly increased so that solvents such as gasoline, kerosene, and benzene hardly affect them.

Small Field Tests

A number of small field test pavements were laid on streets around the Bituminous Research Laboratory to determine the trafficability of the Modified Slurry and to compare it with a standard single layer seal coat. The mix used had 15-16% moisture in the aggregate paste, and 13-16% asphalt

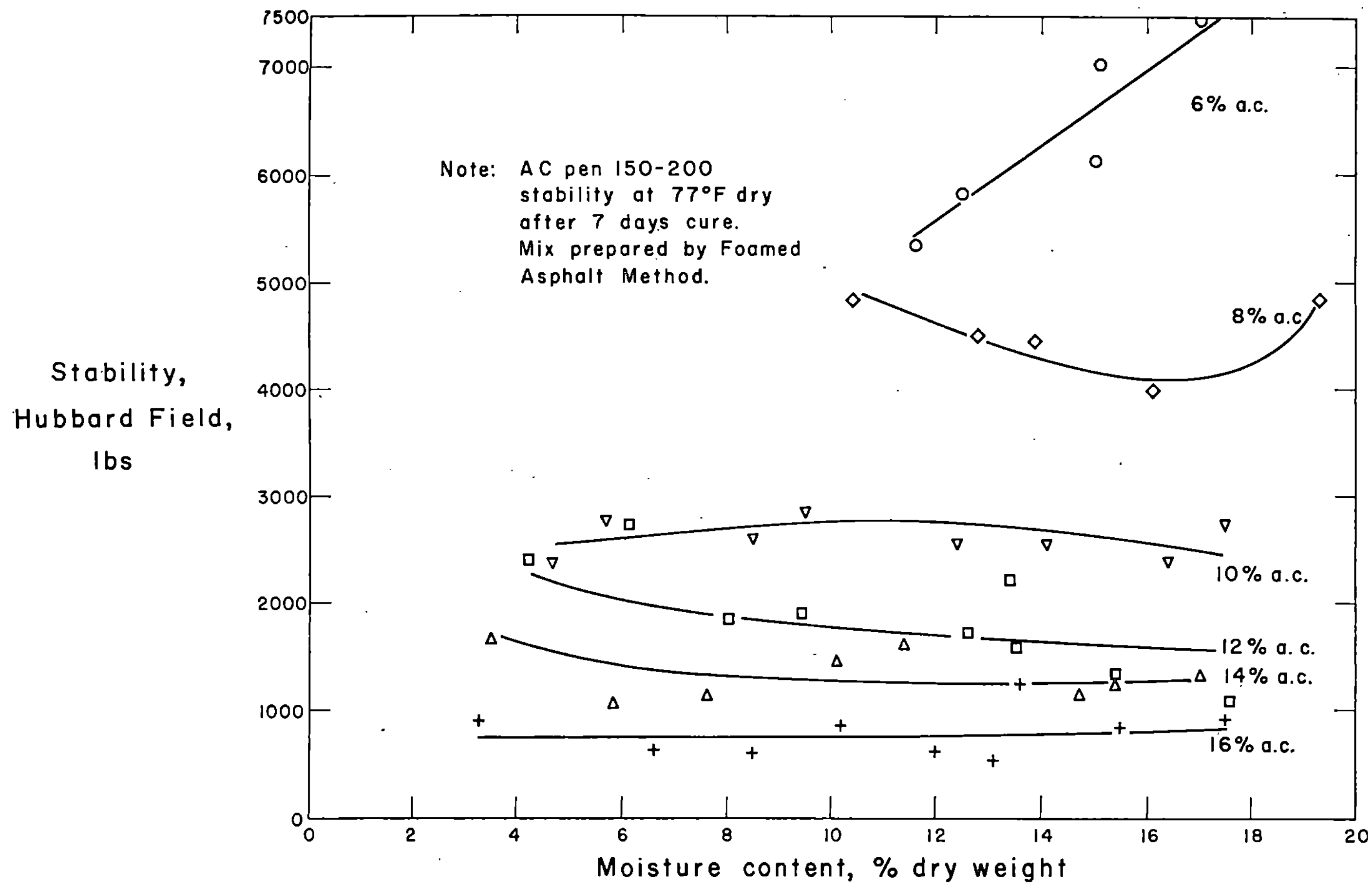


Fig. 19. Stability moisture curves, foamed asphalt slurry.

cement of 150-200 penetration was used in asphalt paste. The asphalt paste was made in the 300 pound laboratory batch mixer, and the slurry with about 28% moisture content was mixed in both a 4 cubic foot paddle type mortar mixer and a 3 cubic foot rotary drum type concrete mixer.

The slurries were laid by hand brooming with a soft bristle push broom. About 9 to 12 pounds of slurry per square yard was spread over the surface to secure a seal about 1/8 inch in thickness. On warm sunny days the surfacing could be rolled by a pneumatic roller 1½ hours after laying and then opened immediately to traffic. On humid days the curing periods had to be longer. When cars ran over the freshly laid slurry, as some did, the tires did not pick up the slurry, they only tracked it leaving their tire imprints. Some of these test sections have been in service for over four years showing little or no distress. The slurries make excellent seal coats for macadam, asphalt stabilized bases, and asphalt surfaces. They adhere tenaciously on Portland cement concrete in some places and in other areas they peel off rapidly.

Small areas of single layer seals were laid next to the slurry seals for comparison. The single layer seals of 0.2 gallons of MC3 binder per square yard were covered with 20 pounds of coarse sand per square yard, making a seal about 1/8 inch thick. The slurries proved to be better seals for surface moisture and showed better traffic wear resistance than the single layer seals.

Conclusions

1. Moisture content of the aggregate paste may be easily controlled by the test developed.

2. Moisture content of the slurry may be controlled by the consistency test.

3. The Hubbard-Field Stability Test may be used to evaluate the variables in the asphalt paste.

4. The Modified Slurry can be commercially produced with American equipment.

5. Slurry surfacings plant mixed under exact controls will overcome such usual problems of seal coats as dusting, bleeding and ravelling.

6. The slurries may be colored, and they have good resistance to fuel and oil spillage.

7. They make good surfacing for asphaltic pavements or bases.

HOT LIQUID ASPHALT MASTIC

A hot liquid asphalt mastic mix, used for many years in Germany, is called "Gussasphalt". This material when heated to 390°F to 420°F has the consistency of molasses. It may be laid either by screeding or by troweling. When the material cools it becomes a dense mass that is quite resiliant under traffic. This type of paving mix has been used in the large cities in Germany for many years. It is now being used to resurface the Autobahns. Although this mix is excellent it has found no acceptance in the United States chiefly because of its low rate of production which is cumbersome and time consuming.

In Germany, Gussasphalt is made in a cooker, fundamentally a fully enclosed single shaft mixer externally heated so that the temperature of the mixture can be kept between 390 and 420°F during mixing. The asphalt at 350°F is placed in the mixer and mineral dust is added. These are mixed until the mastic is formed, then fine and coarse aggregates are added in proper proportion, and mixing is continued for several additional hours. Total mixing requires from 6 to 8 hours. The composition of the mixture is as follows[28]:

Bitumen	9-10%
Mineral Dust	20-30%
Sand	30%
Chips	32%

The percentage of mineral dust is usually on the high side around 28 to 30%. The bitumen used is an 85-100 penetration asphalt cement, or a combination of about 75% asphalt cement and 25% natural Trinidad asphalt. The chips are usually ½ to ⅜ crushed rock.

When mixing has been completed, the Gussasphalt at about 400°F is discharged into an agitator truck. The agitator is a single shaft mixer with external heating mounted on a truck chassis. The agitator keeps the mix hot, liquid, and uniform during transportation. The Gussasphalt is discharged from the agitator to the pavement by chutes or buckets, where it is dumped. Due to its consistency which is that of light molasses it may be screeded over the surface, and as it cools it may be trowelled to a desired finish. After it has cooled further it may be lightly rolled. Gussasphalt may be laid in thicknesses from ½ inch up to 3 inches in one operation. Gussasphalt has highly desirable characteristics. It may be used in thin layer seal coats for the rehabilitation of old worn concrete and brick pavements. But its cumbersome production is a handicap to its use.

Tests were made using several aggregates including a sand-limestone combination and agricultural limestone as a unit aggregate. The gradations of the materials were as follows:

Total % Passing	Sand	Limestone Dust	Agricultural Limestone
No. 4 sieve	100	100	100
No. 10 sieve	89	100	90
No. 40 sieve	18	100	43
No. 80 sieve	3	93	29
No. 200 sieve	00	65	23

Trial of various combinations of sand and limestone dust indicated that a mix containing 70% sand and 30% limestone dust with 7% of 150-200 penetration asphalt cement, and the agricultural limestone straight with 7% of asphalt were best.

The aggregates were heated to 425°F to 450°F and then put into the laboratory twin shaft batch type mixer. As soon as mixing was started asphalt was added by the Foamed Asphalt Process. Only 30 seconds of mixing was required after the asphalt was added to produce a hot liquid asphalt mastic mix similar to Gussasphalt. The mix had a consistency of light molasses at 400°F and could easily be screeded or trowelled upon a surface in layers as thin as 1/8 inch and as thick as 1 to 2 inches. When this mix was spread upon a steel plate it adhered tenaciously and formed a tough, hard mat when cold.

These mixes lost their liquid characteristics at about 375°F, but remained quite plastic, permitting screeding or trowelling, down to 290°F. Below this temperature they began to set and harden. This method of producing a hot liquid asphalt mastic similar to Gussasphalt will meet American production demands, and is suited to American production equipment.

These mixes seemed excellent in the laboratory, therefore in November, 1955, a small amount was laid on an old worn concrete pavement carrying about 4000 vehicles a day. The mix with agricultural limestone and 8% asphalt was laid 1/2 inch thick over a 20 square foot area. The laying temperature of the mix was 400°F, and the air temperature at the time of laying was 10°F. The mix was laid directly on the pavement surface by trowelling without any surface preparation except brooming. The mix set rapidly so that traffic was running over it within twenty minutes after laying. This test area has been in use the past four years with no distress whatever, though pavement temperatures have been as high as 140°F and as low as 25°F below zero.

FULL SCALE TESTS OF FOAMED ASPHALT MIXES

When each phase in the development of the Foamed Asphalt Process and its applications was completed and tested in the laboratory, and when pilot field tests were promising, arrangements were made to test the developments in commercial plant production with roads laid under contract. These full scale field tests included the use of the Foamed Asphalt Process with hot plant mix, and local ungraded aggregates as road surfaces and bases; with asphalt soil stabilization for pavement bases; with modified slurry seal coats; with hot liquid asphalt mastic mixes for road surfacing; with long time asphalt stock pile mixes; with modified slurry as a crack filler; with precoated aggregates for seal coats; and with cold travel plant mix and local ungraded aggregate mixes for road surfaces.

Hot Plant Mix With Local Ungraded Aggregates

The Foamed Asphalt Process was commercially tested for the production and serviceability of hot plant mix local ungraded aggregate mixes as a part of Research Project HR 44 of the Iowa Highway Research Board and Ringgold County, Iowa[31]. The work on this project was done during the early summer of 1957, by the Concrete Materials Company of Cedar Rapids, Iowa. A Cedar Rapids continuous mixer asphalt plant was converted to the foamed asphalt system, and several types of ungraded aggregate mixes were laid on the Sales Barn Road south of Mount Ayr, Iowa.

TABLE I. TEST ROADS BUILT BY IOWA HIGHWAY COMMISSION CONTRACTS

Project	Type of test	Length of road	Road type	Location	Year
HR-44 SN-1669	Foamed Asphalt (some sections of) Atomization Process	1 mile 6 miles	Farm to Market	Ringgold Co.	1957
HR-54	Soil Stabilization & Foamed Asphalt	½ mile	Farm to Market	Story Co.	1957
HR-63	Foamed Asphalt Slurry (seal coat)	1½ miles 1½ miles 3 mile	US 6 State 210 & 211	E. of D. M. Story Co.	1958
HR-66	Foamed Asphalt Slurry (seal coat)	3 mile	Farm to Market	Hancock Co.	1959

Adapting this plant for operation under the foamed asphalt system required that a spray bar carrying thirteen foamed asphalt nozzles be placed over the mixer and be connected by piping to the asphalt supply pump of the plant. The plant could be operated interchangeably between normal and foamed asphalt operations. A small Cleaver-Brooks 10 h.p. steam boiler furnished steam at 90 pounds pressure to the system. The foamed asphalt nozzles operated at 25 pounds asphalt pressure and 40 pounds steam pressure.

The aggregates used in preparing the mixes were as follows:

Agricultural Limestone, which was available at the quarry in large stockpiles, some seven years old, had the following gradation:

Sieve	Total % Passing
4	98
8	79
16	60
30	45
50	33
100	26
200	22

Rolled stone base aggregate, also available in large stock-piles, had the following gradation:

Sieve	Total % Passing
¾"	100
½"	94
⅜"	81
No. 4	58
No. 8	42
No. 30	24
No. 200	16

In producing both types of asphalt mixes, the aggregates were dried and heated in the usual manner to about 280°F. The asphalt cement used was of a 150-200 penetration grade also heated to about 280°F. The agricultural limestone mix for the Foamed Asphalt Process required 6½ to 7% asphalt and the rolled stone base mixes required 5½ to 6% asphalt. The plant operating capacity under the foam method was about 110 tons per hour for agricultural limestone mix and about 130 tons per hour for the rolled stone base aggregate mix. Excellent mixes in which all particles were coated were secured.

The mixes were laid in the road as part both of the base and wearing surface by a Barber-Green finisher. The mixes were readily workable and provided smooth surfaces, and they compacted well under both pneumatic and steel rolling.

Asphalt Soil Stabilization

Two large full scale asphalt soil stabilization field tests were undertaken, the stabilization of a half mile section of a county road and the stabilization of a five acre parking lot.

The County Road Project by the Bituminous Research Laboratory of Iowa State University was Project No. 347-S sponsored by the Iowa Highway Research Board[26]. The work under this project was done during the late summer of 1957. An asphalt stabilized base was laid for a typical county road using the materials present on the road as the aggregate. The site of the project was 24th Street on the north edge of Ames, Iowa, extending ½ mile west of U.S. 69 (figure 20).

This was a typical county gravel road with a 22 foot surface. The road carried about 160 vehicles per day. The road had been graded in 1951 by material from the ditches. In 1957, when this work was undertaken, only about ¾ inch of gravel remained on the surface. Soil samples taken from the road showed a variation from an A-2(4) to an A-6(9) classification (table II) in material to be processed and an A-4(3) to A-7-6(15) classification soil (table III) in the subgrade.

Table II. Properties Soil Materials, Loose, Blended, in Six Inch Base Before Adding Foamed Asphalt

Sample Station	Lane	Gradation, % Passing 4	10	40	80	200	5mu	1mu	Atterberg Limits LL	PL	PI	Proctor Test Maximum Density Dry	Optimun Moisture	Bureau of Public Roads Classification	Field Moisture	Specific Gravity
3+00	S*	83	75	66	56	48	25	21	33	17	16	112	13	A-6(5)	13	2.51
	C	82	77	69	58	49	--	--	35	19	16	114	15	A-6(5)	14	2.50
	N	83	77	66	52	41	--	--	27	17	10	125	11	A-4(1)	8	2.55
8+00	S	92	89	78	63	49	--	--	23	17	6	117	11	A-4(3)	10	2.55
	C	92	88	78	63	48	--	--	24	15	9	114	15	A-4(3)	12	2.55
	N	89	87	79	65	55	26	17	34	23	11	111	15	A-6(5)	13	2.53
13+00	S	93	91	86	77	69	38	25	39	24	15	97	21	A-6(9)	17	2.42
	C	--	--	--	--	--	--	--	--	--	--	---	--	----	--	--
	N	89	85	68	54	43	--	--	27	17	10	105	18	A-4(2)	8	2.53
18+00	S	91	88	77	61	48	--	--	30	17	13	114	12	A-6(4)	9	2.53
	C	74	68	58	46	37	17	12	28	21	7	119	12	A-4(1)	11	2.51
	N	98	95	85	68	56	--	--	31	18	13	105	17	A-6(5)	15	2.46
23+00	S	89	86	74	58	45	--	--	25	17	8	122	12	A-4(2)	12	2.58
	C	69	56	42	31	23	11	9	22	16	6	131	8	A-2-4(0)	8	2.65
	N	93	90	81	66	55	--	--	31	20	11	106	17	A-6(5)	12	2.50

*S=South Lane C=Center Lane N=North Lane

Table III. Properties Soil Materials, Subbase

Sample Station	Lane	Gradation, % Passing 4	10	40	80	200	5mu	1mu	Atterberg Limits LL	PL	PI	Proctor Test Maximum Density	Optimum Moisture	Bureau of Public Roads Classification
3+00	S	100	99	94	84	75	--	--	31	17	14	100	20	A-6(10)
	C	98	97	89	77	67	31	24	33	18	15	106	19	A-6(8)
	N	98	95	86	72	60	--	--	31	15	16	109	14	A-6(7)
8+00	S	97	93	81	64	49	26	15	24	15	9	117	13	A-4(3)
	C	100	99	91	76	65	--	--	36	24	12	99	19	A-6(7)
	N	100	99	92	79	70	--	--	35	23	12	98	22	A-6(8)
13+00	S	100	99	94	86	79	43	32	47	22	24	94	26	A-7-6(15)
	C	---	--	---	--	--	--	--	--	--	--	--	--	--
	N	100	100	95	84	74	--	--	40	24	16	88	23	A-6(10)
18+00	S	93	92	83	65	51	--	--	29	17	12	112	11	A-6(4)
	C	99	98	91	74	59	--	--	33	22	11	104	18	A-6(5)
	N	100	99	91	75	61	31	18	32	19	13	101	21	A-6(6)
23+00	S	96	91	80	64	51	--	--	25	18	7	119	12	A-4(3)
	C	93	91	82	67	56	--	--	28	19	9	112	15	A-4(4)
	N	100	99	90	72	61	--	--	24	16	8	101	21	A-4(5)

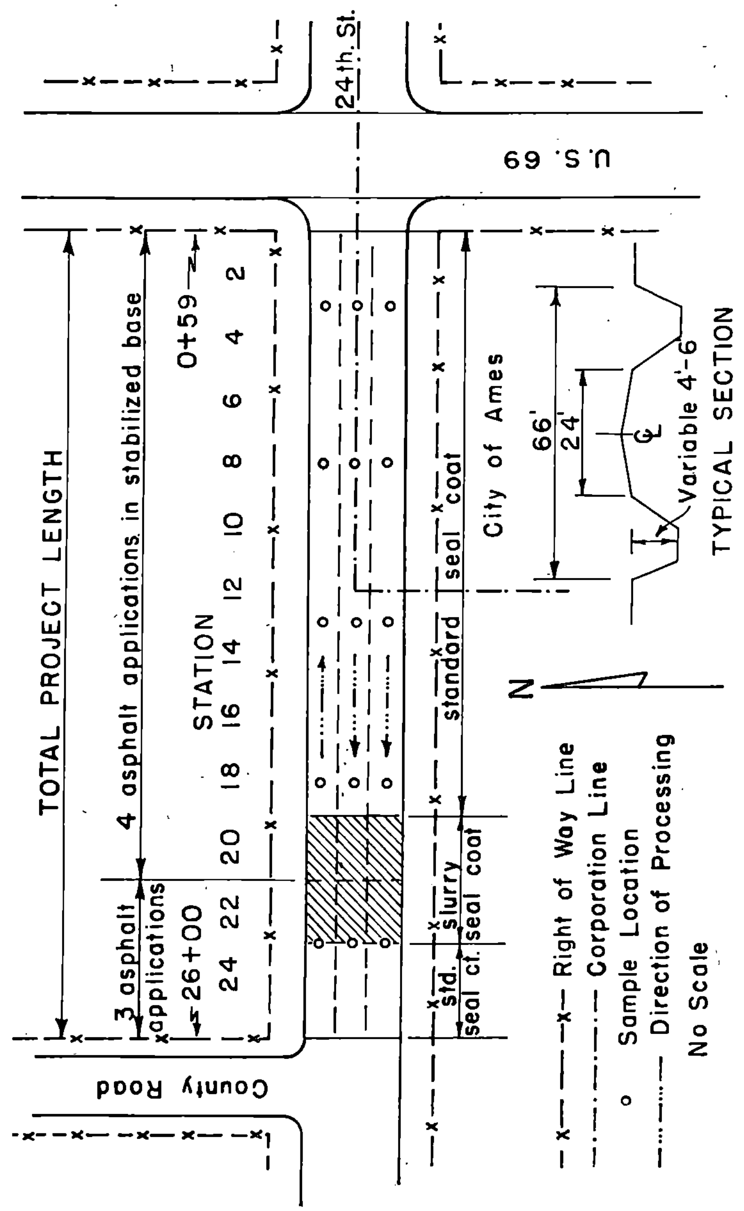
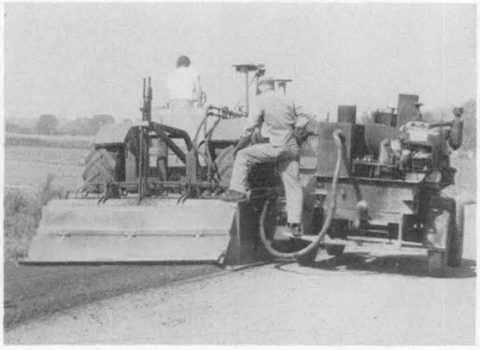


Fig. 20. Location of soil stabilization test road.

The foamed asphalt stabilization was with a Seaman-Andwall Model DS-WS7 Pulver-Mixer adapted to the Foamed Asphalt Process (figure 7). To adapt the machine to the foamed asphalt system required the installation of a small steam jenny to produce saturated steam at 90 pounds, a spray bar with 12 foamed asphalt nozzles and piping. The foamed asphalt nozzles were set 17 inches above ground surface for uniform coverage of the mix when the nozzles operated at 25 pounds asphalt pressure and 40 pounds steam pressure. An asphalt cement with a penetration of 113 was supplied by a small asphalt transport towed by the Pulver-Mixer (figure 21).



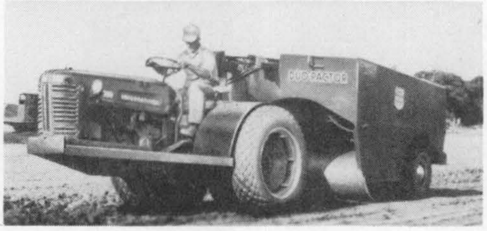


Fig. 21. Stabilizing soil with foamed asphalt. Front view, at left. Rear view, at right. Below, roller used for compaction.

A 700 foot strip of one lane was scarified by a blade grader. This was followed successively by a pulverizing and mixing pass with the Pulver-Mixer, a pass with a water sprinkler truck to bring moisture in the soil up to 9% if necessary, and then four passes with the Pulver-Mixer during which asphalt was added. The section was rolled immediately with a roller, using steel and rubber combination followed by a finishing roll with steel. Successive strips of 700 feet lengths were processed until a lane was completed. Each lane was similarly constructed. When all three lanes were completed, a blade grader brought the material to grade and the surface was rolled.

The stabilized base was opened to traffic for seven days in order to observe the effect of weather and traffic. During this period several heavy rains caused no damage. But high speed traffic tended to scuff the surface, and the base was sealed in two sections, one with a standard single layer seal coat and another with a slurry seal (figure 22).

Marshall Stability tests were made on both loose stabilized mixtures and cores taken from the finished base construction. The specimens immersed in water at 140°F for one hour showed stabilities between 350 and 420 pounds, which indicates a good sound mix. The asphalt cement had been well dis-

Fig. 22. Top, stabilized soil before rolling. Center, soil stabilized with 5 1/3% foamed asphalt after rolling. Bottom, finished surfaces with seal coat at left and slurry seal coat at right.

tributed throughout the fines, but the large particles of the coarse aggregate were not coated. The mix compacted tightly under rolling.

During the spring several chuck holes appeared along a longitudinal line where two lanes of construction joined. Apparently during construction an insufficient lap-over in lanes had been made causing an insufficiency of asphalt at the joint. These holes were repaired, and the road was satisfactory until late fall in 1959 when the surface seal began to show distress. The road was again sealed. In the spring of 1960, after a severe winter, the road was in excellent condition, indicating that the base is holding well. Since paving this road traffic has more than doubled. Though the 4 inch base here is doing very well, perhaps a 6 inch depth might have been better.

Sioux City Parking Lot

The Harnischfeger Co. of Milwaukee, Wisconsin, took a license of the Foamed Asphalt Process Patents and adapted one of their P & H Single Pass Stabilizers to the process. The spray bar had 18 foamed asphalt nozzles, and a small steam jenny provided the necessary steam.

The Brower Construction Company of Sioux City rented this machine to construct an asphalt stabilized base for a large parking lot at a shopping center in Sioux City. This shopping center on Iowa State Highway 7 is in the northwest section of the city. An area of about five acres was stabilized to a depth of six inches.

Laboratory tests indicated that the loess soil of the area would have to be blended with sand for stabilization with six percent foamed asphalt. The gradations of the loess and the blending river sand were as follows:

	Total % Passing	
Sieve No.	Loess	River Sand
4	100	100
10	99	100
40	99	82
80	98	16
200	97	0
Clay 5μ	15%	--
Colloidal Clay 1μ	8%	--

A blend of 33% of river sand with the loess at 11% moisture content processed with six percent of 100-120 penetration foamed asphalt cement gave the following results:

Hubbard-Field Stability	77°F dry	4150
	140°F dry	2500
	140°F wet	400
Resistance to Freeze & Thaw — satisfactory		
Moisture absorption	3.0%	

To control subgrade moisture several longitudinal French drains were installed and interconnected to drain into a creek near the area. Stabilization was done longitudinally in five foot strips, the width of the stabilizer. Since a depth of six inches of stabilization was required, a two inch layer of sand was placed on the soil. Water was then sprinkled over the sand ahead of the stabilizer in a quantity sufficient to raise the moisture content of the soil-sand blend to 11 percent. As the stabilizer moved forward, it cut the soil to a depth of four inches, mixed the sand and soil, added the required amount of asphalt, thoroughly mixed the materials into a homogeneous mixture and discharged the mix in a level layer about eight inches in loose depth (figure 23). The stabilizer moved forward at a speed of about 33 feet a minute in stabilizing the materials.

Fig. 23. Single pass stabilizer in operation.

Compaction of the stabilized soil began immediately after each strip about 500 feet in length was done. Compaction was secured with a sheep foot roller towing a spike drag. After four or five strips had been compacted in this manner the loose surface material was bladed to a finished surface and then was compacted by pneumatic rolling and finished with steel rolling.

When the stabilized soil base was finished a wearing course of single layer seal, using 0.5 gallon of rapid-set high viscosity emulsified asphalt and 20 pounds of 3/8″ gravel per square yard was laid on the surface[16, 17].

At one time after a very heavy rain the contractor proceeded with stabilization though the moisture content of the soil was 24 percent. An excellent mix was secured. However before the base could be compacted, aeration was required. Another time loaded seven yard concrete transit mixer trucks began to run over the base almost immediately after it was compacted, and no damage to the base could be found. After the parking lot had been in service for about five months compressed air pavement breakers had to be used to cut through the base to install additional light fixtures.

The parking lot was opened during the latter part of May, 1959. An inspection of the parking lot early in April, 1960, after one of the severest and wettest winters in the area, showed a few small alligator cracks, and in one small section the pavement appeared spongy indicating subgrade moisture difficulties. But one of the French under-drains in this area had been omitted and excess moisture had accumulated in the subgrade. The distress noted was not serious, and after subgrade moisture subsides all the areas can be restored to good condition by patching. The remainder of the parking area was in excellent condition.

ASPHALT CEMENT SLURRY SEAL COATS

The production of asphalt cement slurry in a commercial plant and with commercial equipment, and its use on full scale road surfacings were first tested during the summer of 1958. This test, sponsored by the Iowa Highway Research Board under Project HR 63, was executed by the Bituminous Research Laboratory under its Project No. 367-S.

A small standard Cedar Rapids continuous mixing asphalt plant, with a capacity of 25 tons per hour, was adapted to the foamed asphalt system. A

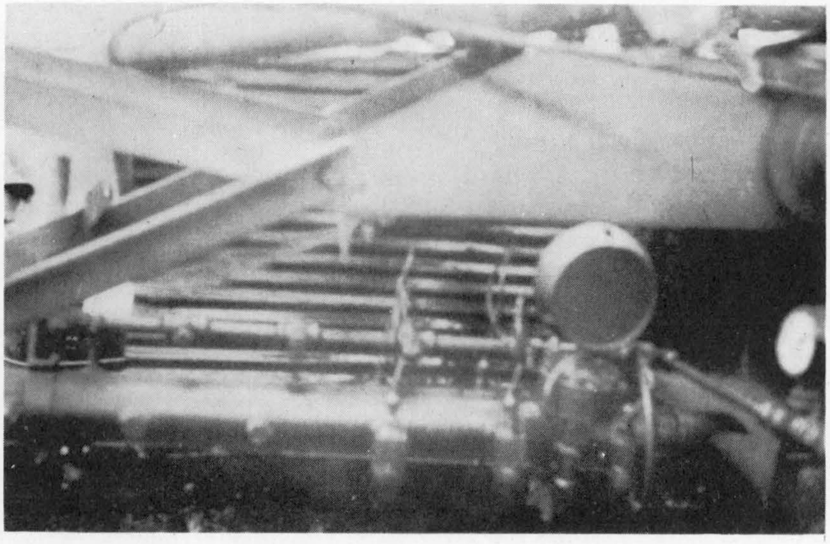


Fig. 24. Foamed asphalt spray bar in a continuous mix plant.

spreader was constructed for laying the asphalt cement slurry and laying asphalt cement slurry seal coats on selected sections on U. S. Highway 6 east of Des Moines, Iowa, and on Iowa Highways 210 and 211. The pavements sealed were all asphaltic concrete pavements that were exhibiting various degrees of surface wear. The sections sealed were selected by the Iowa Highway Commission engineers to determine the effectiveness of the asphalt cement slurry as a suitable seal for varied forms of pavement distress.

The Cedar Rapids plant was adapted to the foamed asphalt system by the addition of a spray bar fitted with six foamed asphalt nozzles, a small Cleaver Brooks 10 HP boiler to furnish the steam required, and water spray bar to bring the aggregate to required moisture content (figure 24). The plant was set up in Cook's Quarry, northeast of Ames, Iowa.

A skid type slurry spreader with an adjustable three segment screed and a soft broom drag was constructed for laying the slurry on the road (figure 25).

The aggregate used for the asphalt paste was an agricultural limestone crusher waste product available in many sections in Iowa with the following gradations:

Sieve size	Total % passing
4	100
10	70-90
40	35-50
80	20-30
200	12-20

This material, placed in the cold feed hopper of the plant, which was equipped with a cut-off gate and steel belt feeder to control volume of material, was discharged directly into the mixer. As the aggregate dropped into the mixer, water was sprayed into it to bring the moisture content to about 14 percent. As the moist aggregate entered the mixer a few paddles distributed the moisture uniformly and prepared the aggregate paste. Then the foamed asphalt cement, a 100-120 penetration grade, was added to give a 12 to 14 percent asphalt mix. Additional mixing made the asphalt paste.

The asphalt paste was discharged from the mixer onto a belt conveyor and into a five cubic yard concrete transit mix truck. When the truck was loaded, water was added to raise the moisture content of the material to about 25%. The mixer operated at mixing speed until a uniform slurry was secured.

During transport of the slurry to the laying site the mixer ran at agitator speed. The distance of transport from the plant to U. S. Highway 6 was about forty miles, and to Iowa 210 and 211 was about twenty miles.

When the truck arrived at the laying site additional water was added to make the consistency of the slurry compatible with the condition of the surface

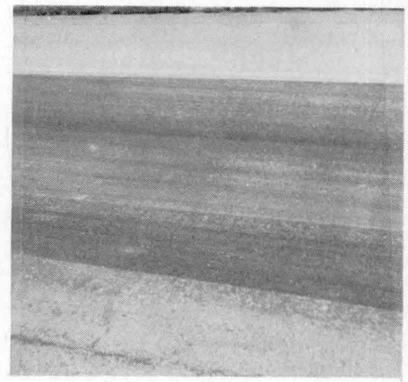


Fig. 25. At left. Laying foamed asphalt cement slurry seal coat. At right, close-up of asphalt cement slurry seal coat in place.

to be sealed. The moisture in the slurry was usually around 28 to 30 percent. As soon as the slurry was of the proper consistency the truck was moved into position on the road and the spreader was attached to its rear end by tow chains. The position of the spreader was then adjusted so that the slurry was discharged into its forward section. The spreader screed was then set to the road crown and a depth of ⅛ inch of slurry to be laid.

The truck towing the spreader moved forward at a speed of one to two miles per hour, and the slurry fed into the spreader where it was screeded and broomed over the surface forming the seal coat over a width of eight feet. The slurry cured for varying periods of time, depending upon weather conditions, before it was opened to traffic. On warm dry days about two hours was needed, on humid cloudy days as much as 6 hours was required. The seal coat formed was a smooth, tight, sturdy mat that adhered firmly to the surface.

On Highway U.S. 6 a 1200 foot section of asphalt cement slurry seal coat was laid on a warm, sunny, windy day with low humidity. This section was opened to traffic about 1½ hours after laying, traffic over this section averages about 6000 vehicles per day travelling at high speed. On the following day, which was partly cloudy and rather humid, an additional 2000 feet of asphalt cement slurry seal coat was laid and opened to traffic about 2½ hours after laying. About four hours after laying a heavy rain fell upon the seal coat. As the heavy traffic travelled over the seal coat it appeared to work the rain water into the seal and reslurrify it in the wheel tracks and splash the slurry to the side where the heavy rain washed it away. The following day 3200 feet of slurry was laid on a cloudy humid day. This section was allowed to cure for six hours before it was opened to traffic. Later in the evening rain again fell with the same results. After several weeks in service, the first section which had been well cured before the rain was in excellent condition. Those affected by the rain had wheel tracks, but though the slurry had been washed away in the wheel tracks, the pores and cracks in the surface were tightly sealed.

The seal coats laid on Highways 210 and 211, where traffic volumes averaged about 200 vehicles per day, showed no distress even in those places where 4 inch deep chuck holes had been filled after rain. In April, 1960, the first section laid on U.S. 6 and those on Iowa 210 and 211 were still in excellent condition after 1½ years in service.

Hancock County Project

Early in 1959 the Iowa Highway Research Board in co-operation with Hancock County sponsored a project designated as HR 66 for the seal coating of a county farm to market road extending from U.S. 69 in Goodell, Iowa, westward for a distance of nine miles. The work on this project was divided into three three-mile-long sections. Beginning at Goodell, Iowa, and extending westward the first three miles were of usual single layer seal coat construction, the next three miles were of asphalt cement slurry seal, and the last three miles were of emulsified asphalt slurry seal. The contract for this work was awarded to the Everds Bros. Construction Company of Algona, Iowa. In the asphalt cement slurry seal section a single lift seal ⅛ inch thick was laid the first mile, a double lift seal each ⅛ inch thick the second mile and a triple lift seal each ⅛inch thick the third mile.

The contractor rented the Cedar Rapids Plant used on the previous year's work and had it adapted under license to the Foamed Asphalt System. The aggregate on this job was an agricultural limestone having a gradation much the same as that used in the previous job. It differed in mineral composition somewhat and about 5% clay was added to produce a satisfactory slurry. The slurry therefore was 95% agricultural limestone with 5% clay and about 14% water to form the aggregate paste to which 13%, 100-120 penetration foamed asphalt cement was added to produce the asphalt paste. The preparation of the slurry required additional water to raise the moisture to about 28%.

The road surface was swept with a broom and sprinkled to remove dust and dirt. A single lift ⅛ inch thick was laid over the entire three miles. After a day or two another ⅛ inch lift was laid over the second two miles, and this was followed in a day or two with the third and last lift the third mile. An excellent seal coat was secured, and since traffic was not permitted on this road during construction, work progressed without difficulties.

An inspection made during March, 1960, about ten months after construction of this seal and after one of the severest winters ever in Iowa, showed that the asphalt cement slurry seal coat was in excellent condition.

Crack Filler

The use of the asphalt cement slurry as a crack filler was an unexpected discovery in this project.

It has been mentioned that on Highway U.S. 6 the slurry seal was destroyed by heavy traffic when rain fell before the seal had set sufficiently. Although the slurry was splashed aside by traffic it was noticed that all of the cracks in the pavement remained well sealed and were not affected by the rain and traffic. This led to a test of the asphalt cement slurry as a crack or joint filler for several types of pavements. Some of the slurry was placed in 50 gallon drums for this test.

Cracks are easily filled. The crack is first broomed clean. The slurry, stirred in the drum to secure a homogeneous mix, is transferred to a pouring can. It is then poured into the crack until the crack is slightly over-filled. Excess slurry is squeegeed off the surface leaving a level filled crack. As the slurry sets it shrinks slightly leaving a slight depression in the crack. Since the slurry does not adhere to tires, traffic can be allowed immediately.

Since the slurry can be varied in consistency from thick to thin, it may be adjusted to very liquid for fine cracks and very thick for wide, open cracks. On alligator cracking areas the slurry may be dumped upon the surface and broomed or squeegeed into the cracks.

The Maintenance Department of the Iowa Highway Commission requested the Bituminous Research Laboratory in October, 1958, to prepare about 4½ tons of asphalt paste and package same in 30 sealed top 50 gallon drums each containing about 300 pounds of paste. Some was used as a crack filler during the fall of 1958 with excellent results. To prepare the asphalt paste for crack filling purposes, it is placed into a small rotary drum concrete mixer or small paddle type mortar mixer and is mixed with enough water for the consistency needed for the size and character of cracks to be filled. When small quantities are needed, the paste may be placed in a pail and stirred with a paddle, while water is added.

Some of the drums of asphalt paste were stockpiled out of doors over the winter. Temperatures as low as 25°F below zero thoroughly froze the moist paste. Where the drums were kept tightly sealed the asphalt paste was ready for use the following spring. Wherever the drums had been opened and were not tightly resealed the paste set and could not be used.

During September, 1959, the Maintenance Department of the Highway Commission again requested the Bituminous Research Laboratory to prepare six tons of asphalt paste packaged as before. This material was distributed all over the state for further test. The Highway Commission is now contemplating building a small mobile plant for producing the asphalt paste.

While these tests were in progress a private company secured licenses for the preparation of such a crack filler in a number of states. This crack filler is now available under the trade name of Irontite and may be purchased in 30 gallon, 300 pound drums. Many cities and counties are now using this material for crack and joint-filling purposes.

HOT LIQUID ASPHALT MASTIC SURFACING

The application of a thin layer asphaltic surfacing on old worn concrete pavements had seldom been successful. Laboratory results secured with a hot liquid asphalt mastic mix, modified Gussasphalt, prepared by the Foamed Asphalt Process indicated that this mix could be successfully used in practice as a surfacing for old worn concrete pavements.

The City of Dubuque, plagued with the rapid deterioration of many of its old worn vibrolithic Portland cement concrete pavements decided to test the use of the foamed asphalt liquid mastic surfacing on these pavements in 1959. The streets selected for this test included White Street from 4th to 20th, paved with Portland cement concrete with brick intersections. This is a major street carrying about 13,000 cars a day, a large number of which are heavy trucks and semi-trailers. Also included were sections of Loras and University avenues which carry about 10,000 cars a day on hills having grades of 10, 11, and 12 percent. These sections were paved with concrete pavements laid about thirty years ago. It was decided to use a surfacing ¾ inch thick.

Contracts were let to the Schueller Construction Company of Dubuque, Iowa, which had a two ton batch type Madson Asphalt Plant adapted to the Foamed Asphalt Process, to do this work.

The foamed asphalt liquid mastic mix used a limestone aggregate having the following gradation and 9 to 10.5% of 120 to 150 penetration asphalt cement.

Sieve size	Total % passing
⅜″	100
¼″	92
No. 8	67
No. 16	52
No. 30	44
No. 50	35
No. 100	23
No. 200	13

The aggregates were heated to about 425°F in the plant drier and fed to the hot bins from which they were weighed into the mixer. About 10% of foamed asphalt at 280°F was then added, and mixing was continued for one minute. The mix was then discharged into a truck for transfer to the field. The mix in the truck had a consistency of molasses and assumed a liquid level. The temperature of the mix in the truck was about 400°F. Tests showed that this mix had an Iowa Hveem Stability of 55 and a specific gravity of 2.33. The maximum stability requirement for Iowa Type A Asphaltic Concrete is 60.

Prior to laying of the mix on the street, the street surface was thoroughly swept and flushed to remove dust and loose particles. No prime coat was used. The mix at about 375°F was laid by a Barber Green Finisher set to lay an average surfacing ¾ inch thick. Since depressions or chuck holes less than 3 inches in depth had not been filled and edges of the pavement at the gutters were feathered out, the depth varied from ⅛ inch to 3 inches with an average of ¾ inch. The mix flowed through the finisher easily leaving a smooth surface. When the mix had cooled to about 175°F it was rolled with pneumatic and steel rollers making a dense coating. The street was opened to traffic immediately behind the finishing roller (figure 26).

Asphalt technologists are doubtful of the effects of high temperature mixing on the asphalt in a mix. Tests were made by the Iowa State Highway Commission to determine what effects, if any, this method of producing the liquid asphalt mastic had upon the asphalt in the mix. The results of these tests are as follows:

Original Asphalt

Penetration, 77°F, 100 gr. 5 sec.	128
Softening Point (R & B)	109.0°F

Recovered Asphalt extracted from mix

	Test Results	ISHC Spec.
Thin Film loss on heating, 5 hrs. at 325°F	0.07%	0.75% max.
Pen. of Thin film res. at 77°F, 100 gr. 5 sec.	85	64 min.
% Original Pen. (Thin Film Residue)	66.4	50% min.
Ductility at 77°F	150+cm	100+cm
Ductility at 77° (Thin Film Residue)	150+cm	75+cm
Softening Point (R & B) (Thin Film Residue)	118.5°F	---- ----

All the recovered asphalt met Iowa State Highway Commission Specifications and the high temperature mixing had no greater effect upon the asphalt than normal mixing used in producing Type A Asphaltic Concrete. In fact, very little increase in softening points was noted, which is rather unusual when compared with results secured from normal mixing.

Although the surfacing was quite plastic it did not mark or shove or displace under heavy trucking, nor at the foot of the steep grades. Some concern was expressed about the skid resistant character of the pavement which appeared very smooth. Skid tests showed that the surfacing was more resistant to skidding than the asphaltic concrete pavements on neighboring streets.

Since these surfacings were laid Dubuque has had temperatures as high as 105°F and as low as 25°F below zero. An inspection made during April,

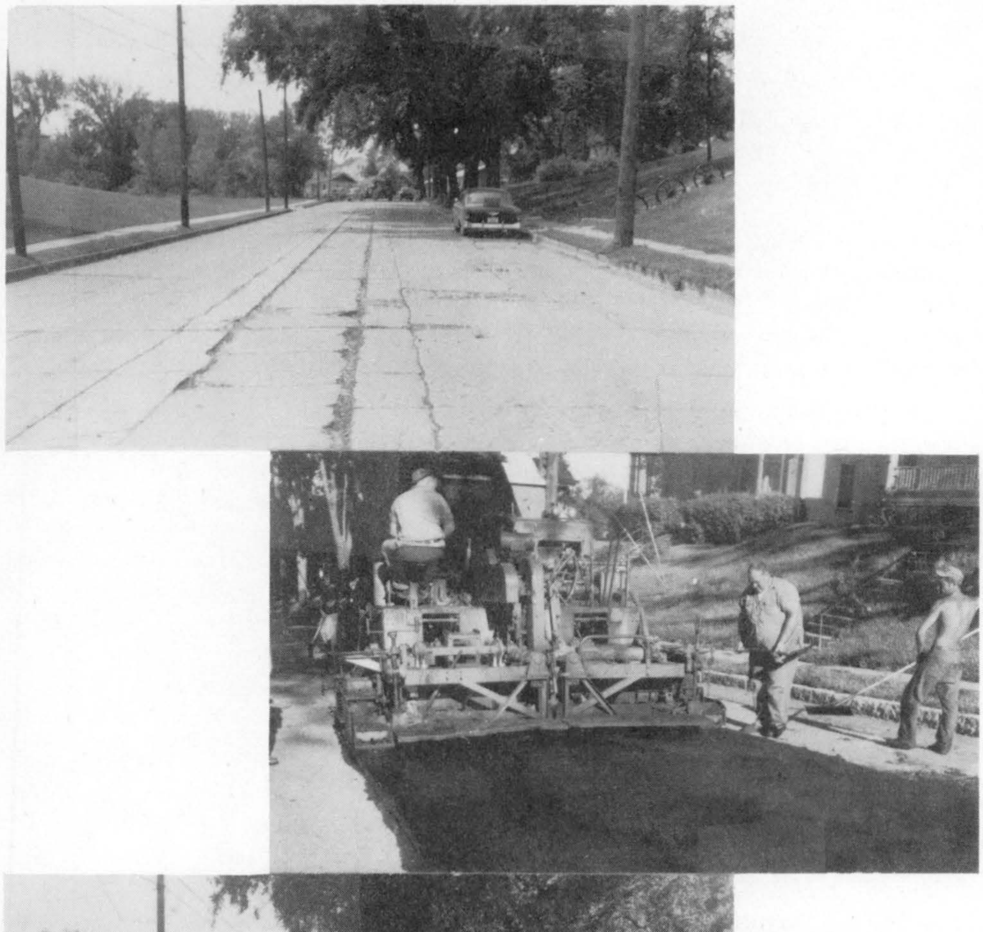


Fig. 26. At top, concrete pavement before surfacing. Center, surfacing with hot asphalt liquid mastic. Bottom, finished surface.

1960, nine months after laying and after one of Iowa's severest winters showed no distress on any parts of the surfacings. Portions of the surfacing cut out for test showed that it adhered so firmly to the concrete that upon removal small pieces of concrete stuck to the bottom of the surfacing.

About 25,000 square yards of surfacing was laid during this test on these streets. The cost of this surfacing, including engineering, clean up, patching of holes deeper than 3 inches and all incidental costs, was $0.618 per square yard for an average depth of ¾ inch[13].

The Foamed Asphalt Method of producing a hot asphalt liquid mastic gives promise as an economical material that can be used in surfacing and rehabilitating old worn concrete and other pavements with thin layer surfacings.

COLD STOCKPILE MIX

The Foamed Asphalt Process can produce a number of unusual mixes that cannot be produced by normal mixing procedures. Among these is an asphaltic concrete mix that can be stockpiled for long periods of time.

Although any standard gradation of aggregates may be used for this mix, the best results are secured with ½ inch maximum size gradations. Asphalt cements of 85-100, 100-120 or 120-150 penetration grade may be used, however 100-120 penetration appears to function best generally. About 5 to 7% of foamed asphalt cement, depending on aggregate characteristics, is used in the mix.

The stockpile mix is produced in the usual manner with aggregates heated to 280°F and mixed with the proper amount of foamed asphalt cement in the mixer. As the mix leaves the mixer it is sprayed with cold water both as it drops from the mixer and in the truck. The purpose of this spray of cold water is the rapid chilling and setting of the thin films of asphalt cement coating the aggregate particles. The rapid cooling and setting of the films prevents the coalescence of the particles of aggregates, leaving the mix loose and friable. The mix may be dumped from the trucks into stockpiles not over four to five feet in height. Greater heights of stockpile will create high pressure on aggregates at the bottom and coalesce them into a compacted mass. The mix stockpiled in this manner will remain friable for long periods of time. Mixes of this type have been stockpiled in this manner for over a year.

When this mix is used for patching, the depression is thoroughly cleaned, then primed or painted with an asphalt. The mix is then deposited in the hole and raked level slightly above grade and rolled. During warm weather the mix is loose and may be used directly. In cold weather the moisture in the mix may freeze causing the mix to be lumpy. Slight warming to thaw the moisture in a truck tail gate heater mixer will revive the mix for easy handling.. Rolling of the mix applies pressure and softens the asphalt so that the mix becomes well bonded. Patches made in this manner will not shove out of the hole under traffic.

The contractor in the city of Dubuque, while experimenting with different applications of the foamed asphalt process, found that this process can be used for making precoated aggregate for use with normal single layer seal coat construction. The ½ inch or ⅜ inch cover aggregate is heated to 250°F and mixed with ¾ of one percent of 100-120 penetration foamed asphalt, creating the precoated aggregate which can be stockpiled indefinitely. The advantages noted in such a precoating are: elimination of wetting agents needed with damp aggregates, reduction of quantity of asphalt in prime coat, elimination of set aggregate problems, assurance of good embedment of aggregates, elimination of dusting and scatter of aggregates, and a black seal coat.

This operation has proved so successful that the contractor is shipping such precoated aggregate to neighboring counties and cities for normal seal coat operations.

COLD MIX ASPHALTIC CONCRETE

In the laboratory the Foamed Asphalt Process was used for cold mix asphaltic concrete mixes. An aggregate of standard gradation or a local ungraded aggregate with up to 10 or 11 percent moisture was mixed at room temperature with foamed asphalt cement to make a low cost, asphaltic concrete suitable as a wearing surface on light travelled roads.

During February, 1960, a test road project was laid in Maricopa County, Arizona, by the county and the Arizona Highway Department as a test. The cold asphaltic concrete mix was to conform with standard specifications except that foamed asphalt was to be used instead of cutback asphalt.

The mixes were prepared in the Hetherington & Berner Moto-Paver belonging to the Arizona Highway Department. The machine was adapted to the Foamed Asphalt Process by installing fifteen foamed asphalt nozzles and a small steam jenny. The system operated at 25 pounds asphalt pressure and 40 pounds steam pressure.

Two different types of aggregates were used. One was a river gravel secured from the nearby Salt River. The other was a crushed volcanic rock known as "Cinders", shipped in from the state pit near Drake, Arizona, for this test. The gradation of these aggregates conformed with State Specifications.

	Total % Passing	
Sieve No.	Salt River	Cinders
¾	95	100
⅜	78	80-82
¼	72	67-71
4	69	61-64
10	59	46-49
40	24	26
200	8	10

The aggregates were delivered to the job in trucks and dumped into the hopper of the Moto-Paver. As the aggregates passed through the Paver, water was added if necessary and then mixed with the desired quantity of foamed asphalt in the mixer. The mixed material was discharged from the mixer onto the ground where it was then spread by screws across the front of a screed. The surfacing was rolled immediately. Capacity of the Moto-Paver was 125 tons of mix per hour.

The physical properties of the mixes using asphalt cement of 125 penetration are:

	Salt River Aggregate	Cinders	
Asphalt Cement %	4.2	5.0	7.5
Moisture Content %	3.5	9.5	9.4
Hveem Stability value	33	23	9
Hveem Cohesion value	243	84	105
Density, lbs./cu. ft.	140	120	119

After ten weeks in service, all mixes in this two inch surfacing were found to be functioning satisfactorily under traffic. The results of this test were so encouraging that seventeen miles of road is to be paved in the same way at another location.

PATENTS

The Foamed Asphalt Process was patented by the Iowa State University Research Foundation. All patents covering the process were assigned to the Foundation by Professor Ladis H. Csanyi, the inventor.

Two patents covering the process have been issued by the United States Patent Office. One, "Apparatus for Mixing Finely-Divided Solids with Liquids" No. 2,861,787 covering the apparatus aspects of the process, was issued on November 25, 1958. The other, "Method for Combining a Bituminous Binder with an Aggregate Material", No. 2,917,395, dealing with the theory and numerous applications of the Foamed Asphalt Process, was issued on December 15, 1959.

Other patent applications are pending in Canada, England, Germany, and Australia.

Licenses are issued to equipment manufacturers and producers as follows:

1. Equipping and selling new stationary plants operating under the Foamed Asphalt Process.

2. Equipping and selling new mobile plants operating under the Foamed Asphalt Process.

3. Conversion of either stationary or mobile plants for operation under the Foamed Asphalt Process.

The licenses for these three are non-exclusive and are available to any equipment manufacturer desiring to adapt his equipment to the Foamed Asphalt Process. The license grants the use of the Foamed Asphalt Process for the production of any paving mixture sold in bulk produced by the plant during its useful life. The equipment manufacturer pays a nominal royalty which covers each plant under license during its useful life. The license cannot be transferred from one plant to another.

4. The fourth type of license deals with a plant owner licensed under the patent who desires to sell the product of the plant in any form of packaging, for example, drums of Foamed Asphalt Crack Filler. Under this license an exclusive territorial license is granted to produce and sell the packaged material within a prescribed area. The royalty is adjusted by negotiation based on area and cost of product and is paid on a unit production and sale basis.

Licenses have been granted to the Iowa Manufacturing Company of Cedar Rapids, Iowa, under categories 1 and 3; the Harnischfeger Company of Milwaukee, Wisconsin, and the Hetherington & Berner Company of Indianapolis, Indiana, under category 2, and the Irontite Corporation of Omaha, Nebraska, under category 4.

CONCLUSIONS

The developments made at the Bituminous Research Laboratory of the Iowa Engineering Experiment Station, Iowa State University have harnessed the unusual properties of asphalt foams and have applied them to the production of a wide variety of asphaltic mixes. Asphalt cements may now be used for the production of both old and new mixes in many ways. The Foamed Asphalt Process has been applied, tested, and found effective and advantageous.

1. More even and uniform distribution of an asphalt upon and throughout an aggregate may be secured during mixing.

2. Ungraded local aggregates may be used in producing satisfactory mixes for paving purposes.

3. Aggregate temperatures may be lowered to 240°F during hot mixing without serious adverse effects.

4. Cold, damp or wet aggregates may be used in the production of cold mix asphaltic concretes.

5. Stockpile mixes containing asphalt cement, which will stockpile for months and years may be produced.

6. Asphalt cement slurry seal coat mixes may be produced under American practices and in American equipment.

7. A new asphalt cement slurry crack filler has now been made available which is better than other asphaltic fillers.

8. A hot asphalt liquid mastic mix that adheres tenaciously to concrete pavements and provides thin layer surfacings for old worn pavements can be made.

9. Clayey, sandy or granular soils may be stabilized in a moist or wet condition with asphalt cements by either stationary plants or mobile road mix plants.

10. No doubt other uses such as precoating aggregates may yet be found for foamed asphalt.

ACKNOWLEDGMENTS

The execution of a project of the size of this one in the laboratory and in the field tests is beyond the efforts of any one individual. The teamwork of many persons was needed to carry it forward to a successful conclusion. Therefore this opportunity is taken to extend appreciation to all who assisted in carrying out this work during the past eight years:

To Professor R. M. Nady and Professor H. P. Fung, who at first as assistants and later as collaborators worked on this and other related projects, and to all of the students who worked hard and diligently at tasks that were at times disagreeable and dirty.

To many county engineers of Iowa who made suggestions, gave materials, and whose interest and encouragement helped the work over some rough spots.

To the material suppliers who furnished asphalts and aggregates without cost for research purposes, to the equipment manufacturers who loaned pilot plants and equipment to the project for research purposes, and without whose help the small field tests could not have been made.

And especially to the Iowa Highway Research Board and its members who through the years gave encouragement and continued faith in the progress of the work and sponsored the project to a successful and practical conclusion.

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