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M. Muthe

P. J. Ruckel,[1] L. L. Kole,[2] F. Abel,[3] R. E. Zator,[4] J. W. Button,[5] and J. A. Epps[5]

Foamix Asphalt Advances

REFERENCE: Ruckel, P. J., Kole, L. L., Abel, F., Zator, R. E., Button, J. W., and Epps, J. A., **"Foamix Asphalt Advances,"** *Asphalt Pavement Construction: New Materials and Techniques, ASTM STP 724*, J. A. Scherocman, Ed., American Society for Testing and Materials, 1980, pp. 93-109.

ABSTRACT: Research studies and road applications utilizing the Foamix process during the past four years were reviewed by a five-member panel. During that period, usage of foamed asphalt has expanded from two to 16 countries worldwide.

A small stream of water injected into hot asphalt cement results in a large-volume stream of foamed asphalt for easy mixing with cold wet aggregates. Conventional equipment is used for mixing and laydown. A wide range of aggregates, including, in particular, local marginal-quality materials, can be used.

Outside Australia and New Zealand, trial sections were constructed during 1977 in South Africa and Colorado, later in Botswana, France, and Germany, and most recently in Michigan. A full-depth, 9-km (5.6 mile) road was completed in North Dakota during the fall of 1979. Most use is for base sections ultimately given surface protection. One trial was an *in situ* application to recycled material. Foamixes have performed as unsealed liners for sewage lagoons and as stockpiled patch material.

Reviews of research studies in Colorado, California, and Texas provide a broad range of data from a variety of aggregates and test procedures. A counteragent has been developed to negate the effect of antifoam additives present in some asphalts.

KEY WORDS: foamed asphalt, foamed bitumen, foamed-asphalt pavements, mechanical properties, mix design tests, cold mixes, marginal aggregates, sand mixes, mixture properties, patch mix

This paper describes Foamix asphalt advances which have been made through research studies and road applications during the past four years to update a comprehensive 1976 review by Bowering and Martin [*1*].[6] That report summarized some eight years' experience gained primarily in Aus-

[1] Senior technologist, Conoco Inc., Ponca City, Okla. 74601.

[2] Manager, Asphalt/Fleet Contractor Marketing, Mobil Oil Corp., International Division, New York, N.Y. 10017.

[3] Assistant staff materials engineer, Colorado Division of Highways, Denver, Colo. 90723.

[4] Manager, Research and Development, Douglas Oil Company of California, Paramount, Calif. 90723.

[5] Assistant research engineer and research engineer, respectively, Texas Transportation Institute, Texas A&M University, College Station, Tex. 77843.

[6] The italic numbers in brackets refer to the list of references appended to this paper.

tralia and New Zealand with an improved version of the foaming process developed by L. H. Csanyi at Iowa State University around 1956 [*2,3*]. The first part of this report provides a description of the improved water foaming process, its applications, and a review of worldwide utilization of the process during recent years. The latter part provides data from three Stateside laboratory investigations into applications using asphalts and aggregates typical to certain locations. Methods of test reflect the usual variations between different states. The identity of each report, therefore, has been retained to maintain the validity of the conclusions presented in the separate studies.

Process Flow and Uses

The foamed-asphalt process offers an effective and economical means to prepare pavement mixtures. It harnesses for useful purposes a well-known phenomenon, the fact that a small volume of water added to hot asphalt yields an immense volume of foamed asphalt. Figure 1 shows how controlled-flow streams of hot asphalt cement and water are combined in a mixing chamber which discharges foamed asphalt through a spray header onto aggregate as it enters a pugmill. A side outlet on the spray header is used to sample the foamed asphalt. Typically, one part of water and 50 parts of hot asphalt cement expand into foamed asphalt with some 10-fold to 15-fold increase in volume. Properties of the foamed asphalt include a low apparent viscosity, substantial increase in surface area, and a change

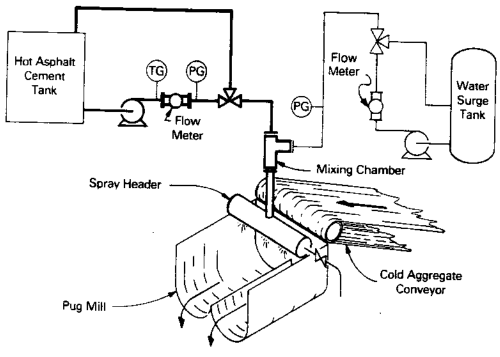

FIG. 1—*Foamed asphalt cold-mix schematic flow.*

in surface or interfacial tension. These properties enable foamed asphalt to coat moist, cold aggregate surfaces and, in particular, the "fines" fraction.

Foamed paving mixtures provide an alternative to hot mixes, emulsion mixes, or cutback mixes in many applications. Which mixes are compared, and site conditions, will determine the advantages applicable to a specific job; see Table 1. Mixing and laying operations use standard equipment with the addition of only a small-volume water system and mixer-header assembly to the mixplant. Foamed mixes look and act most like damp aggregate during the paving operation. They handle cleanly and compact readily even after extended stockpile storage. Binder is standard asphalt cement with no added costs for hydrocarbon dilutents or emulsifying water and chemicals, or for transport of those fractions to the jobsite. Marginal, locally available, damp aggregates can be mixed cold with no emission or dust problems. Mix can be stockpiled or laid immediately without the need for aeration or concern about runoff or leeching of the binder. Lifts of 20-cm (8 in.) compacted thickness have been placed with no difficulty.

The wide range of aggregates which have been used satisfactorily in foamed mixes supports the criteria given in Table 2. Aggregates with properties outside the limits shown have been and can be upgraded, but those are more the exceptions than the rule. Mix design procedures are basically the same as those developed in the Pacific Coast states for emulsion-mix designs, which are published in The Asphalt Institute literature [*4*]. Further details may be found in Ref *1*.

Foamix in the United States

The foamed-asphalt process is proprietary. Licenses for its use on a nominal royalty basis are available from Conoco Inc. within the United States and from Mobil Oil Corp.-International Division outside the United States.

Laboratory evaluations of trial mixes are requisite to a good road job. Asphalt cement must be added to those mixes in the foamed state, and on a precisely metered, repeatable basis. Transportable, standard-design laboratory foam dispensers are available for lease or purchase from Conoco. The mass of foamed asphalt added per batch is quite small; 200 g (7 oz) of

TABLE 1—*Foamed mixes economic advantages.*

Binder	100% active AC, one formula
Aggregate	Cold, wet, marginal, local
Equipment	Conventional (minor mixer modification)
Mixing	batch, continuous, *in situ*
Mixture	no aeration, stockpile, mortar type
Laydown	optimum water, no rain leaching

TABLE 2—*General criteria for foamed mixes.*

Aggregate classifications	A-1, A-2, A-3
Pass 200 mesh	5-30%
Plasticity	NP-15
Typical AC content	2.5-5.0%

NOTES:
Filler or lime required some classifications.
Other aggregates can be upgraded.

asphalt plus 4 g (0.14 oz) of water is typical. The shared use of a dispenser is practical since the time required to prepare the mix specimen is short in comparison with the time required for subsequent tests.

Acceptance of foamed asphalt is slowly gaining momentum in the United States. The first laboratory tests were made by the Colorado Department of Highways two years ago. Subsequent studies have been made at Texas Transportation Institute and at Douglas Oil Co. Research projects currently underway at Iowa State and Purdue Universities are directed toward soil stabilization and recycled materials.

A test section was laid on a Denver quarry road in November 1977. Some 0.2 km (0.1 mile) was paved in one 10-cm (4 in.) compacted lift on a strong gravel base in 16°C (50°F) weather. The 4 percent foamed asphalt upgraded reject fractions from an underwater sand-and-gravel operation to usable material. Aggregate was wholly uncrushed, cohesionless material with 95 percent passing a No. 4 [4.75 mm (0.19 in.)] sieve but only 3 percent passing the No. 200 [0.075 mm (0.003 in.)] size. Aggregate contained about 4 percent moisture at a temperature of 19°C (54°F). Some of the mix, stockpiled with no protection from the weather, has since been used off and on for patchwork.

The first full-scale road job was completed in late October 1979, near Linton, N. Dak. A 15.2-cm (6 in.) full-depth pavement was placed in two lifts on the graded soil subbase to a 9.75-m (32 ft) width in a 9.0-km (5.62 mile) project. A fog seal blotted with sand was applied five days after paving was completed. Aggregate from a glacial lens deposit was pit-run with all larger fractions crushed to pass a 16-mm (5/8 in.) screen. Typical gradation showed 85 percent passing a No. 4 [4.75-mm (0.19 in.)] sieve and 6.9 percent passing the No. 200 [0.075-mm (0.003 in.)] size. Binder was 200/300 asphalt cement at 4 percent with an additive to improve foaming property. Mixture was prepared in a pugmill with around 5+ percent water in the cold aggregate feed. Side experiments included extension of subbase shoulders on part of the project, several patch jobs, and some paving in the nearby town.

The last test to be reported was a small trial in Michigan that also took place in the fall of 1979. Foam equipment added to a 4-shaft rotary-type

stabilizer is reported to have markedly improved dispersion of asphalt cement in 11.4 cm (4½ in.) of recycled materials. No further details are known at this time.

During the past three years field projects have demonstrated the simplicity and merits of the foamed-asphalt process in the United States. Widespread interest has been generated and projects in several states should be completed during 1980. After a slow cautious start, acceptance of the process is accelerating in a growth pattern quite like what has happened overseas, as discussed next.

Foamix Internationally

Previously cited reports [1-3] have described the development of the foamed-asphalt process, the assessment of suitability of soils and aggregates to be stabilized with foamed asphalt, and construction of field trial sections to evaluate the structural capacity and long-term performance of foamed-asphalt mixtures. Although most recently published reports deal with work that has been done in Australia, there are a number of other countries where interest has been shown in foamed asphalt and various levels of evaluation are underway or have been completed. The purpose of this section is to provide an update of progress in the use of foamed asphalt as it exists in countries outside the United States.

Table 3 indicates that foamed asphalt is now under review, evaluation, or regular use in 16 countries. The construction of field trial sections in Japan and the United Kingdom are planned for 1980 and regular construction is also expected to begin in South Africa in 1980. The greatest quantities of foamed-asphalt mixtures used outside North America through 1979 are as listed in Table 4. Foamed-asphalt applications have been made continuously since 1969 in Australia and somewhat intermittently

TABLE 3—*Status of foamed-asphalt technology.*

Technology Reviewed	Mixtures Evaluated	Field Trials Constructed	Regular Construction
Egypt	Denmark	Botswana	Australia
Pakistan	Japan	France	Canada
Saudi Arabia	Nigeria	Germany	New Zealand
Sweden	United Kingdom	South Africa	United States

TABLE 4—*Foam-asphalt applications overseas.*

Australia	2 906 250 m^2 (3 475 960 yd^2)
New Zealand	269 420 m^2 (322 240 yd^2)
South Africa	15 510 m^2 (18 550 yd^2)

since 1972 in New Zealand; two major field trials were constructed in South Africa during the latter part of 1977.

Table 5 lists a variety of mix design and evaluation procedures that have been and are being used in a number of countries. This variety has led to difficulties in correlating and assessing results obtained in differing environments. Other factors which contribute to the mystique of foam mixes are their unique appearance and characteristics. However, the documented long-term performance of major test sections is contributing to a better understanding and awareness of foamed-asphalt's capabilities.

Table 6 lists the annual amounts of asphalt that have been used in Australia to produce foam mixes. The oil embargo in 1973 and subsequent crude price increases have had an impact on the amount of asphalt foamed. Also, the sharp drop experienced in 1978 was the result of discontinuing *in situ* stabilizing operations due to the loss of suitable equipment. The "Percentage of Sales" column in Table 6 reflects the amount of asphalt foamed as a percentage of all asphalt sold as penetration grades, cutbacks, and industrial or oxidized products.

Table 7 lists current cost comparisons between hot-mix asphalt and foamed-asphalt mixtures in Australia, New Zealand, and South Africa.

TABLE 5—*Mix design/evaluation procedures.*

Hveem	Australia, New Zealand, South Africa
Resilient modulus	Australia, South Africa
Marshall	Germany, United Kingdom, Japan
Split tensile	France
Vane shear	South Africa
CBR	Australia, New Zealand
Unconfined	France

TABLE 6—*Australian foam experience.*

Year	Asphalt Foamed, kg	Percentage of Sales
1970	1846×10^3	2.86
1971	1912	3.72
1972	3447	7.17
1973	2561	5.74
1974	2407	5.32
1975	2485	4.24
1976	2828	5.78
1977	4180	6.93
1978	2039	3.57
1979 (6 months)	1005	4.87

Conversion factor: 1×10^3 kg = 1 tonne = 1 metric ton = 1.1 short ton.

TABLE 7—*Cost comparisons overseas.*

	$U.S./Short Ton	
	Hot-Mix	Foamed Asphalt
Australia		
Melbourne	22.97	15.95
Adelaide	18.82	10.62
New Zealand	28.98	15.46
South Africa	18.12	9.31

The comparisons for Australia are for mixtures using equivalent aggregate and asphalt contents, but represent only equivalent asphalt content mixtures in New Zealand and South Africa. No comparison can be made of cost differentials between countries because of differing aggregate and asphalt prices.

Although hundreds of miles of foamed-asphalt surface course mixtures have been produced in North America, most of the mixtures produced elsewhere have been used in constructing base or subbase courses. Foamed-asphalt bases have been exposed to traffic for extended periods of time, but most eventually are surfaced with a seal coat or hot mix.

The original concept of foamed asphalt was of interest as a means of stabilizing materials with asphalt at a cost which could be competitive with lean cement-treated materials. Since that time it has been found to be competitive with a wider range of materials. As a consequence, foamed-asphalt mixtures are providing good service in a number of countries—on highways, freeways, car parks, subdivision streets, heavy-duty industrial areas, and as unsealed liners for water-retention ponds or lagoons. These diverse projects demonstrated that foamed mixes were competitive with hot mixes, emulsion mixes, or cutback mixes over a broad range of applications.

Selection of mix type for a project involves consideration of many variables which may differ from one area to another. Three reports which follow consider use of the foam process with the asphalt cements and aggregates typical to specific locations in the United States and discuss the variables to be assessed in comparison with other types of mixes. The data and conclusions provided are unique to each report; hence identities have been retained. The test procedures reflect some of the usual variations in design test methods used in different areas of the United States.

Foamed Asphalt Use and Research in Colorado

The Colorado Department of Highways became interested in the foamed-asphalt process in 1976, due to its desirable environmental characteristics and potential economic advantage (see Table 8). A small research

TABLE 8—*Construction variables versus type of mix.*

	Aggregate	Asphalt Cement	Laydown	Haul	Special Processing of Asphalt
Hot mix	hot	hot	hot dry	asphalt 100%	no
Emulsion mix	cold	cold	cold wet	asphalt 60% water 40%	yes
Foam mix	cold	hot	cold wet	asphalt 100%	no

project was initiated to investigate the use of foamed asphalt with local aggregates. The Department also cooperated in the planning and testing of a test section placed in Denver, Colorado, by Brannan Sand and Gravel Co.

Colorado has two major types of terrain, the mountain area and the eastern plains. In the mountain area a crushed quarry aggregate or a crushed and screened stream aggregate is usually used for roadway construction. On the eastern plains of Colorado, most of the local aggregates consist of stream- and wind-deposited sands. Four types of aggregates used in the study were selected to represent a broad range of locally available material. Typical gradations are shown in Fig. 2. The aggregates had the following characteristics:

1. Grading E (AASHTO A-1-a, Unified GW)[7] is a well-graded crushed aggregate used in high-quality hot bituminous pavement.
2. Grading Good F (AASHTO A-1-a, Unified GM) represents aggregates used in eastern Colorado for hot bituminous paving with good results.
3. Grading Poor F (AASHTO A-1-a, Unified GM) represents aggregates used in eastern Colorado for hot bituminous pavement with varied success.
4. Soil (AASHTO A-2-4(0), Unified SW) aggregate is found in eastern Colorado and has a good potential for local use in foamed-asphalt stabilized base.

The objectives of the research project were to develop a procedure for calculating strength coefficients and construction specifications for the foamed-asphalt base. The strength coefficients were calculated for the foamed-asphalt mixes, using the following assumptions in the Chevron *n*-layer computer program [*5,6*]:

1. Pavement layers are equivalent if their fatigue lives are the same.

[7]Soil group determined, respectively, by the American Association of State Highway and Transportation Officials (AASHTO) Practice for Classification of Soils and Soil Aggregate Mixtures (M 145-73), and the ASTM Method for Classification of Soils for Engineering Purposes (D 2487-69).

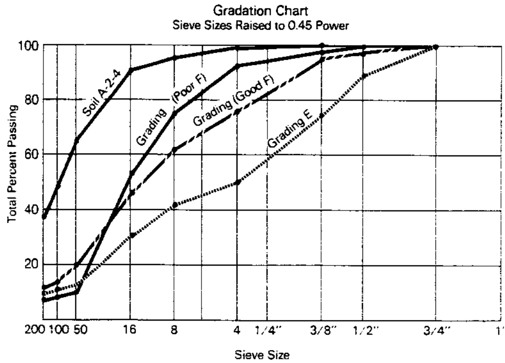

FIG. 2—*Gradation of aggregates tested (Colo.) (1 in. = 25.4 mm).*

2. Fatigue life is reduced as the percentage of air voids increases either from reduced asphalt content, reduced densification, or a combination of the two.

The strength coefficients for the foamed-asphalt mixes varied from 0.13 to 0.34 and for the hot mixes from 0.25 to 0.44 as shown in Table 9. It appears that foamed-asphalt base construction may show economic advantages especially when used with marginal aggregates. The savings would be due to the use of less asphalt cement and the cold-mixing and laying operation.

The second phase of the research project will investigate and document the foamed-asphalt process in several construction projects. The first project will be in Denver, Colo., on Parker Road, from Mississippi to Iliff Streets [FCU 083-1-(14)]. The foamed-asphalt base will be placed in a section approximately 1000 m (0.6 mile) long, 8 m (24 ft) wide, and 0.23 m (9 in.) thick. The foamed asphalt section using a marginal aggregate (reject of crushing operation) will be compared with the normal section of high-quality plant mix bituminous pavement 0.15 m (6 in.) thick. The foamed-asphalt base will be prepared in a local central plant using aggregates from one of the reject stockpiles of a crushing operation in the Denver area. The plans call for AC-10 asphalt cement, 4.0 percent by weight of dry aggregate.

The objectives of the experimental construction will be to evaluate the foamed-asphalt process, construction procedure, and to compare the performance with the standard design under local field conditions. The specifications will be modified based on the results for mixing, handling,

TABLE 9—*Summary of test results (Colo.) on cured specimens.*

Aggregate	Mix Type	AC 10 Asphalt, % Mix	Voids, % Mix	Stabilometer, *S*-Value	Resilient Modulus, Load Time 0.1 s, ksi	Strength Coefficient
E	hot	5.5	5.0	40	350	0.44
	foam	4.0	12.0	50	600	0.27
Good F	hot	6.0	7.0	38	360	0.34
	foam	4.0	11.0	40	800	0.25
Poor F	hot	7.0	10.0	28	130	0.25
	foam	4.0	16.0	40	300	0.13
Soil	hot	7.5	8.0	37	300	0.34
	foam	4.0	11.0	65	1,000	0.34

Conversion factor: 1 ksi = 1000 psi = 6.894 kPa.

laying, compaction, and curing of foamed-asphalt mixes. Post-construction evaluation will include pavement deflection and cracking surveys. Core samples will be extracted from the roadway for modulus and stability testing. An analysis of the energy consumption in the mixing and laydown operation of the foamed asphalt base will be made.

Laboratory Examination of Foamed Asphalt (Douglas)

In the event of widespread energy shortages, one of the first industries scheduled for curtailment of its fuel supply is the asphalt paving industry. With that in mind, Douglas Oil Co. has always been interested in alternative asphalt paving techniques. Over the years emulsified asphalt base stabilization has been promoted and a proprietary system has been developed utilizing an asphalt emulsion.

Attention was focused on foamed asphalt after one of the present authors heard a report [*1*] on its use in Australia and met later with one of the authors of the report. The information presented here shows some of the work that has been done in the interest of Douglas and of our parent company, Conoco Inc.

Initial tests examined a foamed-asphalt mix relative to an equivalent hot mix. A California 12.5-mm (½ in.) maximum aggregate was selected from a commonly used local source (see Table 10, Column A). The asphalt used was an AR-2000. Both hot mixes and foam mixes were made and various test results compared before and after a vacuum water saturation (see Table 11). Results were encouraging except for the moisture sensitivity of the foamed asphalt. Similar aggregates have been used successfully in Australia; however, these had more fine material [pass 50 mesh (300 μm)] present.

A second set of tests was conducted on two North Dakota aggregates

TABLE 10—*Aggregate gradation and classification (Douglas).*

Sieve Size, mm	in.	Aggregate A	B	C
25.0	(1)	100	100	100
19.0	(¾)	100	100	100
12.5	(½)	92.0	81.1	97.5
9.5	(⅜)	74.0	70.1	91.7
4.75	(4)	52.0	52.0	71.1
2.36	(8)	36.5	40.5	57.6
1.18	(16)	24.8	31.1	47.4
0.60	(30)	16.5	22.2	36.3
0.30	(50)	10.0	12.1	25.3
0.15	(100)	5.7	5.6	8.4
0.075	(200)	2.0	3.2	2.5
Classification				
Unified		GW	SW/GW	SW
AASHTO		A-1-a	A-1-a	A-1-b

TABLE 11—*Comparison of foamed asphalt and hot-mix strength (Douglas).*

Asphalt, % Mix	Cured—Unsaturated: Modulus, ksi Load Time 0.1 s	0.05 s	Stabilometer *S*-Value	Cohesion	Vacuum Saturated: Modulus, ksi Load Time 0.1 s	0.05 s	*R*-Value
Foamix							
3	503	625	46	140	——	fell apart	——
4	557	638	37	117	——	fell apart	——
5	399	444	35	114	...	...	82
6	358	399	39	123	19	36	70
7	286	325	34	121	22	51	74
Hot-mix							
3	519	850	39	121	131	229	93
4	547	702	41	148	234	367	89
5	537	617	46	205	251	406	87

Conversion factor: 1 ksi = 1000 psi = 6.894 kPa.

characterized by the Unified Soil Classification System as SW/GW for Aggregate B and SW for Aggregate C (see Table 10).

The strength characteristics of Aggregates B and C after "foamixing" are given in Table 12. The properties of the Aggregate B mix are obviously very good. Aggregate C contains considerable hydrated iron oxide, which may account for its sensitivity to water.

The asphalt used with these materials was an 85/100 grade known to contain a silicone antifoam additive, which unfortunately prevented the intentional foaming desired for mixing. Therefore, the asphalt had to be

TABLE 12—*Strength properties of Aggregates B and C foamed asphalt (Douglas).*

Asphalt, % Mix	*S*-Value		*R*-Value		Cohesion		Modulus, ksi 0.1 s Load Time		Permeability, ml
	Before MVS	After MVS	Before Vacuum Soaking	After Vacuum Soaking	Before MVS	After MVS	Before Vacuum Soaking	After Vacuum Soaking	
Aggregate B									
3	74	64	96	95	334	278	...	...	8
4	60	63	96	95	342	263	...	...	4
5	43	41	94	94	322	306	514	427	3
Aggregate C									
3	75	17	94	...	556	35	...	...	500
4	64	13	96	...	343	140	...	...	500
5	71	17	96	77	163	186	...	...	500

Conversion factor: 1 ksi = 1000 psi = 6894 kPa.

doped with what was called an antifoam counteragent. Table 13 shows that the desired improvement in foaming characteristics of the asphalt was obtained. The foam ratio and the half-life improved dramatically with the addition of only 0.15 percent by weight of chemical. Various surface-active materials were screened in the Douglas and Conoco laboratories before that efficient and cost-effective material was selected. A proprietary formulation, Asphalt Foam Additive AN 480, has since been developed to provide a nontoxic, easily handled liquid for addition to hot asphalt cement when needed.

The preceding data suggest that:

1. Foamed asphalt may be a viable alternative for conventional asphalt/aggregate mixing techniques.
2. Various measures of the foam mix strength or load-bearing characteristics compare quite favorably with conventional hot mix.
3. Any currently used paving-grade asphalt likely can be adapted to the process.
4. High-type densely graded aggregates may not be as satisfactory as a more sandy-type material.
5. Individual aggregate sources should be tested in the laboratory.

Foamix and Texas Sands

This research, sponsored by the Texas State Department of Highways and Public Transportation, was conducted to study the ability of foamed asphalt to stabilize marginal aggregates for base materials which could make use of locally available materials and ultimately reduce transportation costs. A second objective was to evaluate foamed-asphalt paving mixtures in comparison with emulsion and hot mixtures.

TABLE 13—*Improvement of foam characteristics with antifoam counteragent (Douglas).*

Counter Agent, %	Foam Ratio, cm^3/g	Half-Life, s
0	4.5	25
0.05	6.9	19
0.15	11.4	165
0.25	14.9	205

Materials

Locally available sands from various locations in Texas were mixed with foamed asphalt and tested in the laboratory. Asphalt contents ranged, in general, from 3 to 7 percent. Tests included resilient modulus, Hveem stability, and Marshall stability. Three of the aggregates were fine-grained sands. The fourth was a subrounded siliceous gravel [ASTM Specification for Hot-Mixed, Hot-Laid Bituminous Paving Mixtures (D 3515-79), Mix Designation 5A), which is a laboratory standard aggregate [*7*] at the Texas A&M University Materials Laboratory. These aggregates were coded herein according to the following list:

Code	Type of Aggregate	Location
5	Poorly graded, one-sized blow sand	West Texas
11	Well-graded field sand	East Texas
21	Fairly well-graded "off-beach" sand	South Texas
L.S.	Densely graded siliceous river gravel	Central Texas

The laboratory standard [*7*] asphalt cement utilized in these experiments was an AC-10 from American Petrofina in Mt. Pleasant, Texas.

Specimen Preparation

During the mixture design phase of this laboratory study the aggregates were first brought to their optimum moisture content for mixing or, in other words, the "fluff point," which represents the moisture content where a soil aggregate has its greatest loose volume. After several trials it was determined that a higher moisture content aided dispersion of the foamed asphalt during mixing. Therefore, 8 percent moisture was used with the sands and 5 percent with the densely graded gravel while mixing the foamed asphalt. The wet mixtures were set aside for about 20 min and periodically stirred to allow evaporation of some of the moisture prior to compaction. Test specimens were compacted at room temperature [approximately 25°C (77°F)], or otherwise in accordance with Texas Department of Highways and Public Transportation Test Method TEX-206-F, Part II, "Motorized Gyratory-Shear Molding Press Operating Procedure" [8].

The specimens were extracted from the mold and allowed to cure 72 h at room temperature, then placed in a vacuum dessicator for four days. Upon removal from the dessicator the specimens were subjected to the tests mentioned in the preceding.

Test Results

Figure 3 indicates that stiffer mixtures were obtained with the well-graded sands. This was not surprising as the asphalt appeared to be dispersed more uniformly and completely in those specimens. The larger aggregates (+No. 4 and larger) in the laboratory standard were hardly coated. Asphalt content was not a critical factor regarding resilient modulus of most of these mixtures. This may have been due to the fact that these specimens were not totally "bound" by asphalt and that additional asphalt tended to concentrate still more in the fine aggregate and did not coat more aggregate particles. Generally, the resilient modulus of the sand-foamed asphalt specimens (measured by a Schmidt device) was comparable to that of hot-mixed sand specimens; however, the foam mixtures made with gravel exhibited much lower resilient moduli than would be expected for a hot mixture.

Figure 4 shows resilient modulus as a function of temperature. The most outstanding characteristic of this plot is the difference in the shape of the curves for mixtures made with the sands and those made with the gravel, especially at the lower temperatures. Between the temperatures of −1 and 24°C (30 and 75°F), the temperature susceptibility of the sand specimens was significantly less than that of the gravel specimens. By comparison, the temperature susceptibility of the foamed asphalt specimens was much less

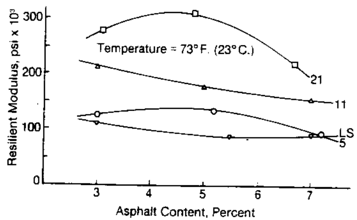

FIG. 3—*Resilient modulus as a function of foamed-asphalt content (Tex.) (1 psi = 6.8948 Pa).*

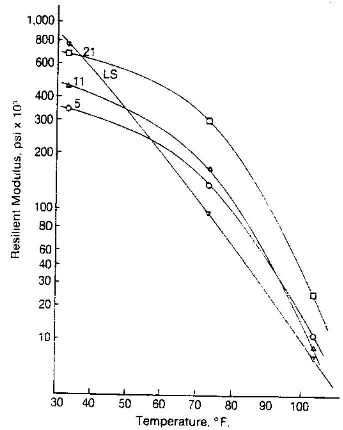

FIG. 4—*Resilient modulus as a function of temperature for the foamed-asphalt specimens (Tex.) (1 psi = 6.8948 Pa).*

than that of hot-mixed specimens [9]. This was likely due to the discontinuous nature of the foamed-asphalt binding mechanism of these sandy aggregates; that is, the binder formed a discontinuous random matrix of primarily fines and asphalt.

It was suspected that these specimens would fail in handling or conducting Hveem stability at 60°C (140°F) or both; therefore, the test was conducted at 22.8°C (73°F). Similarly, in order to obtain measurable values, the Marshall stability test was conducted at 22.8°C (73°F).

Figure 5 shows Hveem stability at 22.8°C (73°F) decreasing with increasing asphalt content for the two well-graded sands while the opposite occurs for the "one-sized" blow sand. As expected, for adequate stabilization the well-graded sands required less asphalt than the poorly graded sand. The poorly graded sand was difficult to adequately stabilize even with unrealistic quantities of asphalt.

Figure 6 shows Marshall stability at 22.8°C (73°F) increasing with asphalt content for all the sands. The well-graded sands exhibited greater stability than the "one-sized" blow sand and were about equal in stability to the gravel specimens at aphalt contents above 5 percent.

Test results indicated foamed asphalt to be an easily handled method of

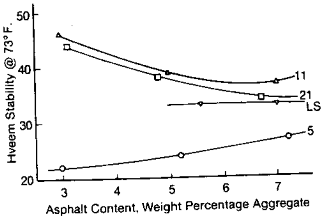

FIG. 5—*Hveem stability as a function of foamed-asphalt content (Tex.).*

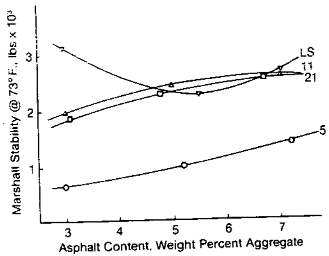

FIG. 6—*Marshall stability as a function of foamed-asphalt content (Tex.) (1 lb = 0.45 kg).*

stabilizing locally available and marginal soil-type aggregates. Data for comparison with hot mixtures and emulsion mixtures of these aggregates will not be available until approximately mid-1980.

Conclusions

Interest in the foamed-asphalt process has expanded during recent years from two to 16 countries. Four countries have full-scale paving projects in service, and at least one country and more states in the United States will soon be added. Foamed mixes have proved suitable for a broad range of uses and are fully competitive with other types of mixes under many conditions.

Examples of mix problems were reported which involved aggregates that had too few fine fractions or a high iron oxide content or too little water. Marginal quality soil-type aggregates have made good mixes. Some asphalt

cements have foamed inadequately but have responded to treatment with an additive which has been developed.

Correlation and assessment of results obtained in different environments have been and continue to be hampered by lack of uniform procedures for laboratory evaluations.

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