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Foamed-Asphalt Paving Mixtures: Preparation of Design Mixes and Treatment of Test Specimens

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Foamed-asphalt paving mixtures are evaluated under a variety of testing procedures for design of field projects in different areas of the United States and in other countries. Laboratory results and correlations with field experience obtained in one area are often difficult to apply elsewhere. A standard design test procedure for foamed-asphalt mixtures would resolve many problems. Under road conditions, foamed-asphalt mixtures are similar in some ways to emulsion and cutback mixtures, for which design test procedures are available. As far as possible, use of established methods provided a logical approach to development of a design test method for foamed mixtures. Test routines for emulsion mixtures that simulate mix compaction during laydown and subsequent curing of the pavement, along with established criteria for test results, have proved equally applicable to foamed mixtures and their use is proposed. They would be preceded by new routines unique to foamed asphalt for the preparation of design test batches ready to be compacted into test specimens. Instructions are provided for tentative appraisals of aggregates and for defining the desired aggregate moisture level, operating conditions for the foamed-asphalt system, and asphalt contents of trial mixes. Acceptance of published emulsion mix design procedures has been hampered by the time required for specimen curing. A novel scheme applicable to both foamed and emulsion mixes is proposed that would provide specimens at three levels of curing yet require less laboratory test time and fewer molds. However, the criteria used to judge the test results may require some adjustment. A method is proposed for predicting the progress of pavement curing through correlation of pavement moisture level with test data obtained in the laboratory on specimens at different levels of curing.

Many test procedures have been used for the design of cutback and emulsion-treated materials. Foamed-asphalt mixtures, too, have been subjected to a wide variety of testing methods (1). The resulting test values are difficult to translate for application in different environments. As a first step toward solution of that problem, this paper proposes a standard laboratory procedure for the preparation of design mixes containing foamed asphalt and the treatment of test specimens to prepare them for evaluation tests.

Under road conditions, foamed-asphalt mixtures are similar in some ways to materials that incorporate emulsion or cutback binders. Both require curing in the field before reaching their ultimate strength. The applicability of some standard test procedures to the evaluation of foamed asphalt and other types of cold mixes has been established by Mobil Oil Australia Ltd. (2) and Acott (3), among others. However, because the asphalt is applied in a foamed condition, the mix preparation method does differ from methods used for emulsion and cutback binders.

A major advantage of foam-treated material is that the mix can be compacted immediately after mixing without aeration so that solvent or excess amounts of water are not trapped in the layer. In addition, the asphalt content of foamed mixes is immune to the leaching action caused by an untimely shower. Research studies have also shown that for certain aggregate mixtures, at asphalt contents greater than 1.5 percent, the specimens that incorporated the foamed binder had more desirable engineering properties than other types of cold mixes (3,4). An equitable appraisal of these potential benefits clearly requires that the different types of cold mixes to be considered for a project be evaluated in a similar manner.

A design procedure for foamed-asphalt mixtures developed by Bowering (5,6) in 1970 largely adapted California test procedures to the purpose. The California procedures were also the starting point for method 1 of the emulsion design procedures published by the Asphalt Institute (7). Despite that common ground, however, the test results obtained from the two procedures are not comparable because the different routines used for specimen compaction, curing, and moisture exposure yield dissimilar specimens for evaluation tests. The time required for a mix evaluation--8 or more days--is a problem, too. Those difficulties have been discussed, and further variations in test procedures have been proposed by Lee (8), Abel (9), Brennen and others (10), and Little (11).

Perhaps the wide variety of procedures can be standardized by first considering the less controversial portions of a complete design procedure for foamed-asphalt mixtures. The test method is in two sections. Section 1 covers the preparation of foamed-asphalt test mixes and simulates field operations up to compaction on a project. Laboratories that have an emulsion mix design procedure could substitute this section for corresponding routines in their method to obtain a foamed mix design procedure. Established criteria for emulsion mix designs have proved suitable for foamed mix designs (2,3) as long as the emulsion mix procedures were followed, starting with the compaction of briquettes.

Section 2 of the test method includes a novel scheme for specimen curing and moisture exposure applicable to both foam and emulsion mixes. It would provide specimens representative of three stages in the field cure process yet require less laboratory preparation time and less specimen time in molds than most present design methods. However, some adjustments may be needed in the criteria used to judge the test results.

The mix preparation procedures of section 1 cover the evaluation of aggregates and foaming properties of the asphalt cement and selection of aggregate moisture level and asphalt contents for the design mixes.

As the data in Table 1 indicate, a wide range of aggregates can be upgraded by foamed asphalt (6). Characterization of the aggregate by the Unified Soil Classification system (12) is recommended as a guide to establish the suitability of aggregates for use with foam. The Unified system is preferred over the AASHTO system because of the attention given to the fine fractions, which are critical to these mixes. Fines should be at least 3 percent, and >5 percent is preferred. Moisture is required on the aggregate to break down lumpy agglomerations, to achieve dispersion of the asphalt during mixing, and to aid field compaction. Limited plastic fines are acceptable (13), but lime pretreatment may be advisable and economic if the plasticity index exceeds about 8.

Moisture-density relations for the aggregate should be established by a standard method to guide formulation of trial mixes. Aggregate classification and fines content provide an indication of the optimum asphalt content.

Neat asphalt foam tests are made by using simple procedures to establish equipment operating conditions that achieve desirable foam properties. Figure 1 shows some typical results. Bowering and Martin (6) found that the physical properties of the foam that affected the final mix characteristics were expansion and half-life stability. Recommended limits are 8 to 15 for foam ratio and at least 20-sec half-life for 1-gal containers (container size has been found to affect the test results).

Asphalts treated with a silicone defoamant are commonly found in many areas of the United States, and some states stipulate its use. As Peterson (14) reported, an additive is available that will allow the asphalt to foam and sustain the desired foam. Details are provided in the procedure.

Next, trial mixes are prepared to select an aggregate moisture level for the design mixes. In addition to assisting compaction, moisture is required to break down aggregate agglomerations and aid asphalt dispersion during mixing. Optimum aggregate moisture content is determined by establishing the moisture content at maximum dry density. The moisture content is varied while the asphalt content is fixed at the estimated design asphalt content based on the following aggregate grading:

Passing No. 4 Sieve (%)	Passing No. 200 Sieve (%)	Foamed Asphalt Cement on Dry Aggregate (%)
<50	3.0 to 5.0	3.0
	5.0 to 7.5	3.5
	7.5 to 10.0	4.0
	>10.0	4.5
>50	3.0 to 5.0	3.5
	5.0 to 7.5	4.0
	7.5 to 10.0	4.5
	>10.0	5.0

The last procedure of section 1 is the preparation of design test mixes. The required mix batches for a given evaluation procedure are prepared at the previously determined optimum aggregate moisture content and at asphalt contents varying in half or whole percentage increments either side of the estimated asphalt content. The mix batches are ready for immediate molding into specimens and should be protected against moisture loss if molding is to be delayed.

Section 2 of the method suggests how molded foamed-asphalt specimens can be treated to simulate the condition in the field after short, intermediate, and long-term curing periods. In addition, it suggests that adequate intermediate and long-term specimens be molded for evaluation tests in both the dry and after vacuum saturation states. The short cure and vacuum saturation routines are taken from the method 1 procedure of the Asphalt Institute manual (7). The intermediate cure period and the out-of-mold curing conditions for both intermediate and long-term cures are changes proposed to provide needed additional data and to reduce testing time and the number of molds required for evaluation tests.

For structural design purposes, laboratory data obtained on fully cured specimens have been used for foamed mixes as they are for emulsion mixes. Considerable research effort has been devoted in Aus-

Table 1. Representative data for foamed-asphalt mixtures.

Soil Group[a]	Suitability for Use with Foam	Optimum Asphalt Range by Weight of Mix (%)	Comments
GW	Good	2.0-2.5	Permeable mixtures; crushed fractions helpful
GW-GC	Good	2.0-4.5	Permeable mixtures; crushed fractions helpful
GW-GM	Good	2.0-4.5	Permeable mixtures; crushed fractions helpful
GP-GC	Good	2.5-3.0	Low permeability; crushed fractions helpful
GC	Poor	4.0-6.0	Impermeable; asphalt content critical; crushed fractions helpful; can be improved by added small percentage lime
SW	Fair	4.0-5.0	Needs addition of minus No. 200 mesh filler
SW-SM	Good	2.5-4.0	
SP-SM	Poor	3.0-4.5	Needs more viscous asphalt and addition of minus No. 200 mesh filler
SP	Fair	2.5-5.0	May need addition of minus No. 200 mesh filler
SM	Good	2.5-4.5	
SM-SC	Good	4.0	
SC		4.0-6.0	Alone, poor for foam; needs small percentage of lime
		3.0-4.0	With lime, good for foam

[a]Unified Soil Classification system.

Figure 1. Foamed-asphalt quality controls versus foaming water addition rate.

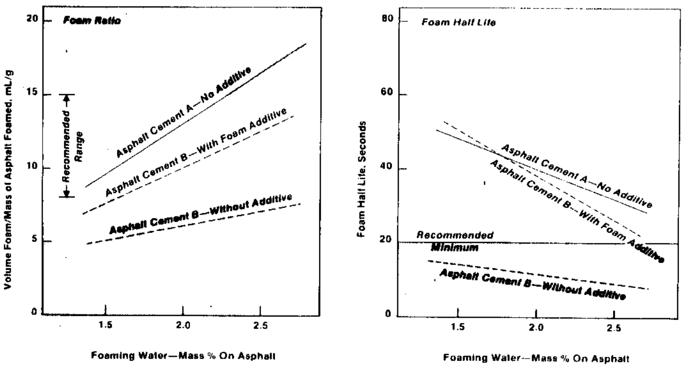


Figure 2. Increase in field strength with time.

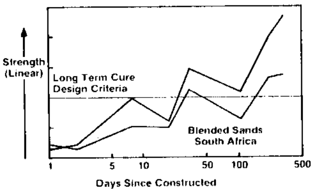
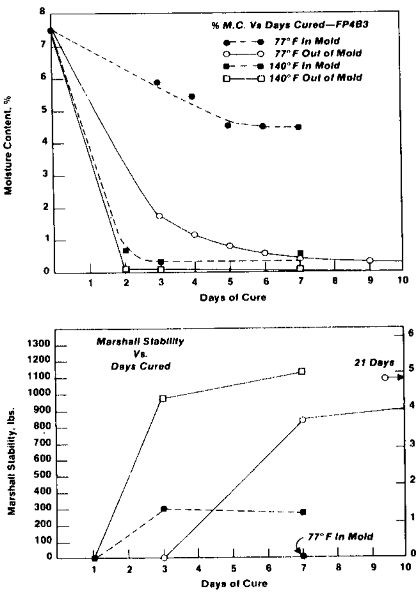


Figure 3. Effect of curing conditions on moisture content and stability.



tralia and South Africa to correlation of those results with field experience. Acott (3) found that the time required for the mix to develop strength in the field equal to laboratory long-term-cure strength ranged from 23 to 200 or more days (see Figure 2). This time period varied according to road temperature, precipitation, and evaporation. After 4 years of service the test sections have performed most satisfactorily. Similar data have also been reported by Bowering (2,6). The design criteria were met satisfactorily over time.

However, when foamed-asphalt pavements exhibit some form of premature distress, it tends to occur in days rather than in weeks or months after construction (3,6,15,16). The ultimate strength that a road develops does play a role in the design process, but the strength after early or intermediate cure represents the most critical time period. Emphasis, therefore, has been placed on systematizing an early and intermediate curing procedure.

The choice of whether the specimens are cured in or out of the mold does affect the condition of the samples. Because cold mixtures can initially be quite fragile, a procedure was developed at Purdue University (10,17) in which specimens were cured initially in the mold followed by an out-of-mold cure period. Results obtained by Lee (13) and shown in Figure 3 suggest that Marshall stability was affected more by whether the specimens were cured in or out of the mold than by curing temperature if curing times were adjusted. Studies in Australia (2) showed that, for a curing temperature range of 68° to 140°F (20° to 60°C), the major factor affecting the test results was the moisture content to which specimens had been cured. Lee's work appears to confirm those findings.

Similar research on emulsion mixes is in progress at the Asphalt Institute. Tentative but unpublished data suggest that curing temperatures above 120°F (48°C) appear to seal the surface of some specimens, which then develop internal pressures that distort and damage them. Asphalt Institute work also indicates that a 1-day cure at 100°F (38°C) relates to a 7-day cure at room temperature.

After a review of these studies, it appears that the sample moisture content is the parameter that has the most important effect on mix strength and that the wide range of curing procedures merely represents alternative methods that can be used to reduce the moisture level of the specimen. If this statement is accepted, then the various procedures are, in fact, compatible and any reproducible procedure could be adopted that does not alter the basic nature of the mix in comparison with changes occurring under field conditions. Furthermore, the specimen relation between moisture content and strength can be related to the mix condition in the field and can be used to define when the road can be subjected to traffic.

To define such a relation, the following standard cure procedures are proposed:

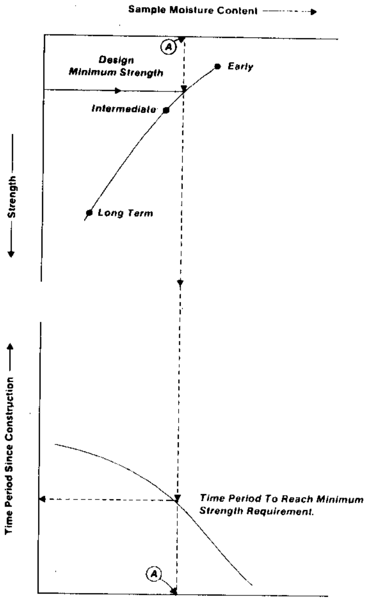
1. All specimens would be given a cure in molds placed on their sides for 24 hr at room temperature. All specimens would then be removed from the molds. The short-term-cure specimens would be set aside and the balance would be cured out of the mold at 104°F (40°C). The short-term cure approximates 1 day of field curing under dry, temperate conditions, and the specimens would be evaluated without further treatment.

2. Intermediate-cure specimens for both dry and damp tests would be cured 24 hr in the 104°F (40°C) oven after removal from the molds. This procedure would produce a mix moisture level that might be achieved some 7 to 14 days after field laydown under dry, temperate conditions.

3. Long-term-cure samples for both dry and damp tests would be cured 72 hr in the 104°F (40°C) oven after removal from the molds. This procedure simulates a cure condition that is dependent on the climatic region and weather variations. Under dry, temperate conditions, it simulates approximately 30 days of field curing. Although this does not represent the ultimate strength because further increases will occur due to traffic action and binder stiffening, it does provide a tie with previous work on fully cured specimens. However, as experience is gained with this curing procedure, it may be found that the cure period can be shortened to 48 hr or even eliminated for many routine mix evaluations.

The moisture exposure procedure proposed for inter-

Figure 4. Interpretation of relation between moisture content and strength.



mediate- and long-term-cure samples is the procedure published for emulsion mixes by the Asphalt Institute (7). This procedure is desirable from the standpoint of testing time but, because it is more severe than what has usually been used on foamed mixes, new criteria may be needed. Despite the severity of the procedure, it does appear to yield finite test values for which criteria can be established.

As suggested earlier, it is proposed that evaluation data for samples provided under this method may be used to establish field curing procedures for any locale. The stability of samples at each cure condition may be plotted against moisture level in the manner shown in Figure 4 and moisture level readout for the desired minimum acceptable shear strength. Field data on in-service moisture levels would then be charted versus days since laydown to develop a plot from which curing time for the pavement to reach the desired moisture level would be predicted.

STANDARD TEST METHOD

Scope

This test method covers (a) selection and evaluation of components and their incorporation into mixes for design tests on cold-mixed foamed-asphalt paving mixtures and (b) treatment of test specimens compacted from those mixes to simulate the effects of curing time and moisture on a foamed-asphalt pavement.

Applicable Standards

The following ASTM standards are used: D698, D1557, D2216, and D2487 (12, Part 19) and D1559, D1560, D1561, and D3387 (12, Part 15). The Asphalt Institute manual (7) is also used.

Summary of Method

The two sections of the method can be summarized as follows:

1. Preparation of design test mixes--(a) evaluation of aggregates, (b) definition of foaming properties of asphalt cement (bitumen), (c) selection of design test mix proportions, and (d) preparation of design test mixes.
2. Treatment of design test specimen--(a) short-term curing of specimens, (b) intermediate curing of specimens, (c) long-term curing of specimens, and (d) exposure of specimens to water.

Significance and Use

The routines for preparation of the test mixes provide guidance by which to simulate actual field conditions as far as possible in the mixing of test batches for laboratory evaluations. As in the field, mixtures are ready to be compacted immediately into test specimens by using procedures appropriate or adapted to cold mixes, such as ASTM D1559, D1560, D1561, D3387, and others. The procedures used in this section can be substituted for all routines preceding those used for compaction of test specimens in a design procedure for cold emulsion mixes, such as those provided in Manual Series 19 of the Asphalt Institute (7) to obtain a comparable design procedure for foamed-asphalt mixes.

The procedures for treatment of test specimens yield specimens for evaluation tests that approximate the characteristics of a completed foamed-asphalt pavement in the field after curing. Replicate specimens for the two longer curing periods may be subjected to a vacuum saturation with water before evaluation tests are performed to obtain an indication of the effects of moisture on the pavement at that stage of curing. These procedures are not intended for use in comparative tests with other mixes of like characteristics such as emulsion mixes unless test specimens for those mixes are treated in the same manner.

Terminology

1. Foamed asphalt (bitumen) is hot asphalt cement (bitumen) into which water has been dispersed to convert it temporarily from a liquid to a foam state.
2. Foamed asphalt (bitumen) paving mixture is a mixture of foamed asphalt (bitumen) and moist unheated aggregate prepared in a central mixing plant or by special road-mixing equipment on the job site. The mix is at or near ambient temperature and may be spread and compacted on the job site immediately or stockpiled for future application.
3. Foam ratio is the ratio (in milliliters per gram) of maximum foam volume for a given sample to mass of asphalt cement in the sample (any remaining moisture is neglected).
4. Foam half-life is the time (in seconds) required after the discharge of the sample is completed for the foam to collapse to half of the maximum level attained.

Preparation of Test Mixes

Apparatus and Materials

The equipment and materials used in the preparation of the test mixes are summarized below:

1. The foamed-asphalt dispenser is a device used to mix repeatable, precisely controlled proportions of hot liquid asphalt cement (bitumen) and water into batches of foamed asphalt, 50 to 400 g/batch as desired, which are discharged into a mixing bowl or other container. The mass of a batch must be within ±5 g of the target. The asphalt cement (bitumen) temperature must be within ±9°F (±5°C) of any desired temperature in the range from 300° to 375°F (150° to 190°C). The water flow rate must be controlled within ±5 percent of the desired volume in ratio to the asphalt cement flow within the range from 1 to 3 g water to 100 g of asphalt cement. A small stream of compressed air may be used to assist dispersion of the water or steam into the bitumen.
2. An asphalt foam additive is used. An addition rate of 0.45 percent mass on asphalt mass has proved effective in use on asphalt previously treated with customary levels of antifoam additive.
3. Containers should be expendable, with open top, uniform in size, of about 1-gal (3.8-L) capacity, suited for 320°F (160°C) neat foamed-asphalt tests.
4. Mechanized mixing equipment is required that is capable of producing intimate mixtures of job aggregate, water, and foamed asphalt (bitumen).

Precautions

Appropriate safety practices should be established and observed for portions of these procedures that require handling and transport of hot liquid or foamed-asphalt cement in containers, spraying of hot foamed asphalt into mixing bowls or containers, and working around heated equipment.

Evaluation of Aggregates

1. Aggregate properties are the determining factor in many of the choices made concerning the optimum mixture. Thorough testing of the aggregate is therefore necessary. A wide range of materials is suitable for use with foamed asphalt, including crushed stone, rock, gravel, sand, silty sand, sandy gravel, slag, reclaimed aggregate, ore tailings, and other inert materials.
2. The sample mass required will be determined by test procedures selected to be performed on test mixes prepared under these routines. The minimum recommended sample weight is 40 lb (18 kg). Allowance should be made for mixes prepared under the procedure described later for preparing aggregate batches for mix proportion tests. Fines should be 3±percent mass but 5±percent mass is preferred.
3. The moisture content of the as-received aggregate is determined according to ASTM D2216.
4. Procedures used in ASTM D2487 are followed in sampling and classifying the aggregate. Group separations provided by this method best define differences among aggregates related to particles passing the No. 3 (0.6-mm) sieve, which are significant in the use of aggregates for this purpose.
5. Determine from Table 1 (by using the soil group symbol obtained in the preceding step) the suitability of the aggregate for foamed-asphalt paving mixtures or the possible need for addition of a filler or lime pretreatment. (This procedure provides qualitative data only. It must be supplemented by laboratory design tests on foamed-asphalt/aggregate mixtures to evaluate the performance characteristics of those mixes under simulated field conditions. Some materials exhibit a temperature threshold in the ambient region above which a marked improvement in mix quality can be achieved.)
6. Moisture-density relations for the aggregate are established by using ASTM D698 or D1557. Differences in the results obtained are not significant to these procedures. A record should be made of the method used.
7. Aggregate is prepared in accordance with the design test procedure selected and mixing equipment limitations. If required by the chosen procedure, all fractions retained on the 0.75-in. (0.19-mm) sieve may be separated and omitted, but their mass should be included in all final calculations. Division of the aggregate into a plus No. 4 (plus 4.75-mm) fraction and a finer fraction may be desirable.

Definition of Foaming Properties of Asphalt Cement (Bitumen)

1. Standard specification asphalt cements (bitumen) of any grade suited to the pavement design conditions are used in all mixes.
2. About 4 gal (15 L) of asphalt cement is required under these routines, about half of which is used in neat foamed-asphalt tests and half in preparation of asphalt-aggregate mixes.
3. The foamed asphalt dispenser is readied for use in accordance with operating instructions. [Whenever 5 min or more has elapsed between production cycles for batches of foamed asphalt, one batch of foam (75 g minimum) should be produced and discarded into a waste container to refill and reheat the foam delivery system.]
4. An operating temperature is established for the asphalt cement and an addition rate for the water admixed with it to yield foamed asphalt whose foam ratio is from 8 to 15 mL/g and whose half-life is at least 20 sec.
5. Usually a series of neat foamed-asphalt batches at different operating conditions is required. At least one neat foamed-asphalt test should be made on every bitumen sample. Duplicate runs at given operating conditions are advised until experience establishes the test results are repeatable. Combinations of operating variables for neat foamed-asphalt tests are defined. Six variations will usually establish the desired conditions: asphalt cement temperatures of 325° and 350°F (163° and 177°C) and foam water addition rates of 1.5, 2.0, and 2.5 percent on asphalt mass. Other combinations may be selected within the ranges of 300° to 375°F (150° to 190°C) for bitumen temperatures and 1.0 to 3.0 percent on asphalt mass for foam water added. An asphalt temperature of 325°F and a foam water addition rate of 2.0 percent mass on bitumen are satisfactory for many samples.
6. The capacity (in milliliters) of sufficient sample containers for the desired foam tests is determined by calculations based on the container dimensions or by weight of water (a density of 1.00 g/mL should be used) to fill a can almost to the brim. Dry all moisture from the cans and tare them.
7. The dispenser is adjusted to a desired test condition. The unit is set to deliver foamed-asphalt batches with about 5 percent mass on the water capacity of the sample container, which provides for a foam ratio up to 20 mL/g. Asphalt specific gravity is considered to be 1.00 at operating temperature, a negligible error. Nozzle flush sequences are programmed to use foam water before and after the foam production cycle at minimum possible intervals (0.2 sec for some units) rather than

the 0.5- and 1.5-sec or longer cycles used for foam batches applied to aggregates. In the latter instances, extra foam water applied is of no consequence.

8. The series of neat foam tests is completed. Foam half-life values are obtained and recorded in seconds for each test by using a stop watch. Foam ratio (FR) in milliliters per gram is calculated to the nearest whole number as follows:

$$FR = A/B \quad (1)$$

where A is the maximum foam volume (in milliliters), calculated from the average high level attained by the foam as evidenced by the film left inside the container and the height and capacity of the container, and B is the mass of asphalt in the container (in grams), determined by neglecting any remaining moisture.

9. Dispenser operating conditions are established as specified in step 7 above or, if these conditions are not met, tests are performed at other conditions (step 5) or one proceeds to step 10. See Figure 1 for test results typical of two different source asphalts.

10. If the quality parameters of item 4 have not been met in step 8 or if the asphalt cement has been treated with antifoam additive, perform a series of neat foamed-asphalt tests as in step 8 by using asphalt admixed with asphalt foam additive at one or more levels of dosage. If significant benefits are noted (Figure 1), use of additive is advised.

Selection of Design Test Mix Proportions

1. Moisture levels on the aggregate at the time of mixing with the foamed asphalt and in the mix when the test specimens are molded are major variables. A suitable level for both mix preparation and specimen molding is established by determination of moisture-density relations for compacted but uncured specimens from three or more mixes by using aggregates with different moisture levels and a fixed foamed-asphalt content. Visual examination of uncompacted fresh and cured samples from those mixtures provides a check on asphalt dispersion and guidance for field operations.

2. The foamed-asphalt dispenser is readied at the desired conditions and the mixing equipment is prepared. For safety considerations, applications of foamed asphalt to aggregate must be made in a mechanical mixer. Some mixers, such as the Model N50 Hobard rotary mixer with a steel paddle, are best operated when foamed asphalt is applied only to the aggregate fractions passing a No. 4 sieve (minus 4.75 mm) during a mechanical mixing period. Dampened larger fractions are then stirred in during about 30 sec of hand mixing. No deleterious effects on the total mix have been observed for this two-step mixing procedure.

3. Aggregate batches are prepared for mix proportion tests. Batch mass must equal the estimated mass for one specimen compacted in accordance with the selected procedure plus about 100 g for step 6 in this listing. A batch of approximately 1250 g would be typical for preparation of one 4-in (101.6-mm) diameter by 2.5-in. (63.5-mm) high specimen. Batch size can be increased as needed for good mixing if a two-step mixing routine is used (step 2 above). In the standard procedure, three aggregate batches are used but that can be changed as desired with experience. Next, three batches of aggregate of known moisture content are weighed into tared mixing bowls. The moisture content of the batches is adjusted by drying or adding water so that one batch has about 50 percent of the aggregate optimum moisture content, one has about 65 percent, and one has about 80 percent. The batches are mixed thoroughly and covered to retain moisture. Overnight storage is advisable to permit complete dispersion of water into any lumpy agglomerations of fines.

4. Asphalt content for mix proportion tests is established. The center of the asphalt range for the test aggregate is estimated from experience or from the text table on page 89 by using gradation data. The required mass of foamed asphalt is calculated based on the aggregate batch mass and then the asphalt mass is increased by 5 percent (or some other factor based on experience) to allow for material clinging on the mixing bowl and blade. Program the foamed-asphalt dispenser for the desired mass of foamed asphalt per batch.

5. Trial mixtures are prepared. One foamed-asphalt batch is wasted (see step 3 in definition of properties of asphalt cement). After the mixer blade is tared, the mixer is positioned with one aggregate batch under the dispenser outlet, the mixer is started, and the foamed asphalt is applied to the aggregate. Mixing is continued as needed to disperse the foamed asphalt. The time required depends on the mixer used; 2 min is ample for some units. If the mix darkens noticeably in appearance, in comparison with the moistened raw aggregate, the mixing time should be shortened. The mixer blade is removed, and the loose mix on it that can be readily removed with light brushing is returned to the test batch. If a two-step mix cycle is to be used, the larger moist aggregate should be added at this time and mixed by spoon for 30 sec or more. The mix is covered to prevent moisture loss. The mixer blade is weighed and the amount of material left on it is determined. The mass of the dirty blade is the tare weight for the next mix. The remaining two aggregate batches are mixed with like mass of foamed asphalt.

6. A small sample, 50 to 100 g, of mix is removed for examination. These routines also are used as quick tests for control of field operations. The mixture should be uniform in color and texture with little or no change in appearance from premoistened raw aggregate. Little or no balling of uncombined asphalt should be detected. A small portion of mix is spread approximately one particle deep on a filter paper or similar piece of white paper. This is then cured on a warm surface or in an oven, neither of which should have a temperature exceeding 230°F (110°C), for 20 min or so until dry. The cured mix should have darkened and be free of uncombined asphalt particles larger than 1/16 in. (1.6 mm) in size. Essentially all asphalt should be concentrated effectively in fine sand and silt fractions of the aggregate with little or no coating of 3/8 in. (0.5 mm) or larger particles. The paper should be only sparsely speckled by the asphalt, and there should be few specks as large as 1/16 in. (1.6 mm) in diameter. The balance of the sample is compacted by hand into a firm ball. The ball should break cleanly. Hands should have few asphalt spots and those should be small.

7. Moisture-density relations are developed for mixes in step 5 above. One specimen from each trial batch is molded by using the selected procedure. Static leveling load is applied. Compaction should be stopped if fluids exude from the compaction mold and one should proceed to determine the height of each specimen (still in the mold) to the nearest 0.01 in. (0.25 mm). All of the mix (specimen) is removed from the mold and the mass is immediately weighed and recorded. This process is repeated for each specimen. Each mix from this process is dried to a constant mass in an oven at a temperature of 230 ± 9°F (110 ± 5°C) and cooled to room temper-

ature. Mass is immediately weighed and recorded. Dry density is calculated for each specimen and the results are plotted. Optimum moisture content is estimated to give a maximum-density specimen. That value is used in the preparation of all design test mixes and implied errors are accepted. Mixing bowls are emptied of all material that can be easily removed with light brushing, the bowls are weighed, and the amount of clinging material for each batch made is determined.

8. Use data obtained in step 7 above (determining specimen height and weighing the specimens after removal from the molds) to arrive at the mass of loose mix required for molding design test specimens of the desired height.

9. Asphalt content levels for design test mixes are defined based on experience gained with these mixes and in accordance with the chosen procedure. Three or more levels at increments from 0.5 to 1.0 percent mass on dry aggregate with the estimated center of the asphalt range as midrange are usual.

10. By using data obtained on the amount of material clinging to the blade and the bowl for each trial mix, the amount of clinging material to be allowed for during preparation of design test mixes is established.

Preparation of Design Test Mixes

1. The required mass for design test mixes (determination of the required specimen is addressed later in the specifications) at each selected level of foamed asphalt content is established. About 100 g of each test mix is allowed for the performance of routines in step 6 of the preceding listing and additional amounts as desired. Mixing equipment limitations may require preparation of more than one batch for a given test mix.

2. The required aggregate batch(s) of known moisture content for each test mix is weighed out. All batches are adjusted to optimum moisture content, mixed thoroughly, and then protected against moisture loss.

3. Design test mixes are prepared as in step 5 of the preceding listing at the selected asphalt levels. Replicate batches made for a given design test mix are combined and mixed thoroughly and then covered to retain moisture until specimens are molded.

4. Each mix is evaluated as in step 6 of the preceding routine.

Treatment of Test Specimens

The earlier discussion regarding use of these routines for comparative tests with other types of mixes should be noted.

Molding Specimens

Selected procedures are followed to mold specimens. Step 8 of selection of design test mix proportions is followed for estimating mass of mix to yield a specimen of the desired height. The mass and height of each specimen in the mold are determined immediately after compaction for calculation of density and moisture content.

Short-Term Cure of All Specimens

1. All specimens in the molds are cured with each mold on its side to expose both ends of the specimens for 24 ± 0.5 hr at a temperature of 73 ± 5°F (23 ± 2.8°C). All specimens are then pressed from the molds.

2. Selected specimens or all specimens are weighed and moisture content is calculated.

3. The required number of specimens from each test mix for short-term cure design tests is selected and protected to minimize change in moisture level before testing. Specimens at this stage provide a measure of the degree of curing that might be achieved in the field within 24 hr after construction under dry, temperate conditions. The test results obtained provide guidance for timing the placement of a surface treatment or a layer of another type of mix.

4. Immediately after their removal from the molds, the rest of the specimens are placed in a drying oven at a temperature of 104 ± 2°F (40 ± 1°C) for further curing into intermediate or long-term cured specimens (see below).

Intermediate-Cure Specimens

1. Specimens for intermediate-cure tests are removed from the oven (step 4 of the preceding listing) after 24 ± 0.5 hr and cooled to room temperature. Specimens at this stage provide a measure of the degree of curing that might be achieved in the field within 7 to 14 days under dry, temperate conditions with most aggregates.

2. Selected specimens or all specimens are weighed and moisture content is calculated.

3. Intermediate-cure specimens are separated into a group for design tests dry, which is protected against further moisture change, and a group for the moisture exposure routine (step 2 of the process outlined below for exposure of specimens to water).

Long-Term-Cure Specimens

1. Foamed-asphalt pavements continue to gain significantly in strength and stability whether exposed to wet or dry conditions over long periods of time. For that reason, evaluation procedures applied previously to foamed mixes have relied on test data from more fully cured specimens than those provided for in step 1 of the routine for intermediate-cure specimens. Long-term-cure specimens of this routine provide a tie with those procedures. The number of specimens required is determined by the test methods used. Both dry and wet specimens should be tested. The test results obtained on these specimens provide a measure of changes in pavement properties that will occur in the field over time. That time period may be as short as 30 days or longer than 200 days. The primary variables are environmental conditions, traffic, and aggregate properties.

2. Long-term-cure specimens placed in the drying oven under step 4 of the process for intermediate-cure specimens are further cured for 72 ± 0.5 hr and then removed from the oven and cooled to room temperature. As experience is gained with this procedure, a further curing period of 48 hr rather than 72 hr may prove adequate for the purpose. For routine mix evaluations, test data obtained on short-term and intermediate-cure samples may satisfy the purpose without tests on long-term-cure samples.

3. Specimens are weighed and moisture content is calculated.

4. Specimens are selected for long-term-cure tests in the dry condition.

5. The rest of the specimens are subjected to the exposure routine outlined in step 2 below.

Exposure of Specimens to Water

1. Appraisal of the potential effects of moisture intrusion on properties of foamed-asphalt pavements is essential. This vacuum saturation pro-

cedure simulates the effect of prolonged exposure to subsurface water such as might occur in the field during extended heavy rainfalls, a relatively harsh condition. Despite that severity, tests to date on a variety of mixtures have yielded a range of finite values that are indicative of different sensitivities to moisture. However, some specimens may fail either during the vacuum saturation procedure or during subsequent tests, and some specimens may yield much lower values than others from subsequent tests. Conditions imposed by this procedure have not yet been correlated sufficiently with pavement performance under field conditions to justify a pass-or-fail decision for proposed moisture based on results from laboratory tests. Moisture sensitivity of foamed-asphalt pavement is related to the degree to which a mix has cured at the time of exposure. This test, therefore, is only applied to the specimen provided in step 3 for intermediate-cure specimens and step 5 for long-term-cure specimens.

Vacuum Saturation Procedure

1. The selected specimen is placed in a vacuum desiccator from which all desiccant has been removed or a similar suitable container.
2. The preweighed specimen is covered with 0.5 in. (13 mm) of water at room temperature, the lid is closed, and the vacuum system is connected.
3. The desiccator is evacuated to 100-mm Hg absolute pressure and held for 60 ± 5 min.
4. The vacuum is released slowly and the specimen is allowed to soak in water for 60 ± 5 min.
5. The specimen is removed, surface dryed, and reweighed and the moisture change of the specimen is calculated.
6. The specimen is tested by using the selected procedures. If the specimen is stored before being tested, it should be protected against moisture loss.

Reporting

1. For each design test mix prepared, the following items are tabulated and reported: (a) mix proportions and (b) visual appraisal obtained in step 6 of selection of design test mix proportions.
2. For each specimen treated by these routines, the following items are tabulated and reported, where appropriate: specimen height, mass, and moisture content obtained in step 2 of the routines for molding specimens, short-term-cure specimens, and intermediate-cure specimens; step 3 of the routine for long-term-cure specimens; and step 5 of the routine for exposure of specimens to water.

Precision

No test values are obtained in this procedure for which precision data are needed.

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