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UNIFIED FACILITIES CRITERIA (UFC)

STANDARD PRACTICE MANUAL FOR FLEXIBLE PAVEMENTS

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STANDARD PRACTICE MANUAL FOR FLEXIBLE PAVEMENTS

U.S. ARMY CORPS OF ENGINEERS (Preparing Activity)

NAVAL FACILITIES ENGINEERING COMMAND

AIR FORCE CIVIL ENGINEER SUPPORT AGENCY

Record of Changes (changes are indicated by **1**\ ... /**1**/)

Change No.	Date	Location

This UFC supersedes TM 5-822-8/AFM 88-6, Chap. 9, dated July 1987.

FOREWORD

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The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD(AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States is also governed by Status of forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA.) Therefore, the acquisition team must ensure compliance with the more stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

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CHAPTER 1

INTRODUCTION

1. PURPOSE. This manual provides guidance for the preparation of drawings and specifications for road and airfield flexible pavements using asphalt cement materials. The term “asphalt” is used herein instead of bituminous (a generic term for both asphalt and tar materials) because this is the material most widely used in pavement construction. In current practice tar or coal-tar is used only in instances where fuel resistance is required. This manual also provides useful information for design engineers, laboratory personnel, and project managers concerning mix design, materials, production, and placement of the various asphalt mixtures.

2. SCOPE. This manual prescribes materials, mix design procedures, and construction practices for flexible pavements.

3. REFERENCES. Appendix A contains a list of references used in this manual.

4. UNITS OF MEASUREMENT. The unit of measurement in this manual is the International System of Units (SI). In some cases inch-pound (IP) measurements may be the governing critical values because of applicable codes, accepted standards, industry practices, or other considerations where the IP measurements govern, the IP values may be shown in parenthesis following a comparative SI value or the IP value may be shown without a corresponding SI value.

5. EXPLANATION OF SPECIAL TERMS. Special terms used in this manual are explained in the glossary.

6. BACKGROUND. Asphalt mixtures (hot- and cold-mix asphalt and other asphalt surfaces) provide a resilient, relatively waterproof, load-distributing medium that protects the base course and underlying pavement structure from the harmful effects of water and the abrasion of traffic. Wear, weathering, and deterioration from aging all act on asphalt pavements, and therefore, maintenance of these pavements is necessary for a long life. The flexibility of asphalt mixtures allows a pavement structure to adjust slightly to consolidation of underlying layers or deformation due to load without affecting pavement performance. Flexible pavements also allow stage construction and may use a wide range of construction materials, often leading to substantial savings through the use of locally available materials. Additional pavement courses can be placed on existing pavements to provide additional structural strength as total loads or traffic intensity increase. The paving engineer must design and construct the most economical pavement that will satisfy the objective of long pavement life.

7. SAFETY CONSIDERATIONS. The policy of the Departments of the Army and Air Force is to construct pavements that will provide the maximum safety for traffic. A non-skid surface is essential, and proper grade control is required to provide rapid removal of surface water to minimize the potential for hydroplaning. All pavement surfaces should exhibit a sufficiently coarse texture to provide skid resistance. Aggregate types known to have a history of polishing should be avoided because they are probably the greatest cause of low skid resistance, especially in surface treatments and seal coats. Construction techniques are important for surface treatments and seal coats to ensure good bond between the asphalt and aggregate providing for satisfactory aggregate retention. Pavement surfacings that do not include aggregate should not generally be applied in areas of high-speed traffic.

CHAPTER 2

HOT-MIX ASPHALT

1. GENERAL. Hot-mix asphalt is often used for high-performance pavements. The degree of performance required should be selected based on traffic conditions and the availability of satisfactory materials. Hot-mix asphalt mixtures consist of mineral aggregate and asphalt cement. These hot-mix asphalt mixtures are particularly suitable for airfield pavements, roads and streets, and storage areas. In general, from 3 to 6 percent asphalt is required for asphalt base or intermediate courses, 4 to 7 percent asphalt cement for surface courses, and 5 to 7 percent for porous friction courses. However, the optimum asphalt content should be determined according to appropriate mix design procedures. The aggregate gradations specified for hot-mix asphalt pavements are shown in table 2-1.

a. Advantages and Disadvantages. The hot-mix method of preparing paving mixtures provides for thorough coating of the aggregates with a uniform film of asphalt cement and accurate control of aggregate sizes and quantity of asphalt cement. Hot-mix pavements require no curing period after being laid and can be used as soon as the pavement has cooled. The paving mixture must be rolled to compact the mix while sufficiently hot because rolling is relatively ineffective after the mixture has cooled and the required density will not be achieved. Hot-mix pavements can be constructed rapidly with a minimum probability of damage to unfinished pavements from unfavorable weather conditions. Immediately after adequate rolling and a cooling period, the pavement has a high degree of stability from the interlocking of the coarse and fine aggregate and adhesion of the asphalt cement, as well as a high resistance to moisture penetration and frost damage.

b. Uses. Hot-mix asphalt paving mixtures can be designed that are satisfactory for an asphalt base course, intermediate course, surface course, or porous friction course. Wheel loads, wheel spacing, tire pressures, intensity of traffic, and subgrade strength (California bearing ratio (CBR)) dictate the thickness of pavement (TM 5-825-2/AFJMAN 32-1014). Normally, asphalt base courses of any desired total thickness may be constructed in layers up to 150 millimeters (6 inches) thick. For airfield pavement applications hot-mix asphalt will be used as the intermediate and surface courses on types A, B, C, and D traffic areas, blast areas, and any other areas (even non-traffic) where their use is economical. The four types of airfield traffic areas (A, B, C, and D) are described in TI 825-07 (AFMAN 32-1123(I)) and TM 5-824-1/ AFJMAN 32-8008 V1. Hot-mix asphalt can be used on any road or street classification A through F (see TM 5-822-2/AFM 88-7, Chap. 5 (Future AFJMAN 32-1125(I)). Porous friction courses shall be used primarily to prevent hydroplaning on runways or other high-speed pavements. Areas subjected to fuel spills will require an application of a coal tar sealer to protect the hot-mix asphalt pavement. When possible, the use of a rigid pavement should be investigated. Stone Matrix Asphalt is used in applications requiring a rut and abrasion resistant surfacing.

2. EQUIPMENT.

a. Plant Equipment. The purpose of an asphalt plant is to produce a mixture properly coated with asphalt cement that consistently meets the requirements specified in the job mix formula (JMF) for aggregate gradation, asphalt content, and temperature. Control of the asphalt mixture quality must be initiated at the aggregate stockpiles. Each aggregate stockpile should be stored to prevent segregation or mixing with adjacent stockpiles.

Table 2-1
Aggregate Gradations for Hot-Mix Asphalt Concrete Pavements

Sieve Size, mm	Gradation 1 19 mm Nominal Percent Passing by Mass	Gradation 2 12.5 mm Nominal Percent Passing by Mass	Gradation 3 9.5 mm Nominal Percent Passing by Mass
25.0	100	–	–
19.0	76-96	100	–
12.5	68-88	76-96	100
9.5	60-82	69-89	76-96
4.75	45-67	53-73	58-78
2.36	32-54	38-60	40-60
1.18	22-44	26-48	28-48
0.60	15-35	18-38	18-38
0.30	9-25	11-27	11-27
0.15	6-18	6-18	6-18
0.075	3-6	3-6	3-6
Sieve Size, inch	**Gradation 1 3/4 inch Nominal Percent Passing by Mass**	**Gradation 2 1/2 inch Nominal Percent Passing by Mass**	**Gradation 3 3/8 inch Nominal Percent Passing by Mass**
1	100	–	–
3/4	76-96	100	–
1/2	68-88	76-96	100
3/8	60-82	69-89	76-96
No. 4	45-67	53-73	58-78
No. 8	32-54	38-60	40-60
No. 16	22-44	26-48	28-48
No. 30	15-35	18-38	18-38
No. 50	9-25	11-27	11-27
No. 100	6-18	6-18	6-18
No. 200	3-6	3-6	3-6

(1) Batch plant.

(a) General. A batch plant is illustrated in figure 2-1. Cold feed hoppers have individual feeders for each of the aggregates to be used in the mixture. These feeders must be set so that the desired percentage of each aggregate is fed into the plant. The rate of feed may be controlled by the gate opening, belt speed, or other methods depending on the type of cold feed. If the aggregate feeders are improperly set, a combination of the following problems may occur:

— One of the aggregate hot bins will overflow with material while another hot bin runs low on material.

— The gradation of the aggregate in the mix being produced will not meet the design gradation.

— The amount of natural sand may vary from design proportion and may exceed the amount allowed in the specifications.

(b) Cold feed bin calibration. Before the start of a project the cold feed bins should be calibrated so that each bin will feed the desired rate of material. The cold feed calibration involves feeding one aggregate at a time onto a belt that is common to all aggregates. The speed of this belt should be determined prior to calibration of the feeders. One way to do this is to divide the belt length by the time required for one revolution. After the material is fed onto the belt, the material over a given length (for example; 2 meters (6 feet)) should be completely removed and weighed. The following relationship can be used to convert the weight of the sample taken to kilograms per hour (pounds per hour) and later to metric tons (tons) per hour:

$$R = \frac{3600\ WS}{L} \qquad \text{(eq 2-1)}$$

where

R = rate of feed, kilograms per hour (pounds per hour)

W = weight of sample, kilograms (pounds)

S = speed of belt, meters per second (feet per second)

L = length of belt sampled, meters (feet)

Each aggregate should be fed at four to five different feeder settings and the rate of feed determined; a plot of this data showing the relationship between rate of feed (kilograms or metric tons (pounds or tons) per hour) and feeder setting (gate opening, feeder belt speed, or other method for setting aggregate feeder) should be used for each aggregate. These plots can be used to set each cold feed bin to feed at the desired rate.

(c) Dryer. After the aggregate cold feed bins have been properly set, the aggregate is carried up the cold elevator and through the dryer. The dryer removes the moisture from the aggregate and heats the aggregate to the desired temperature.

(d) Dust collector. A dust collector collects the dust created in the dryer and other plant components and adds all or any portion of it back to the mix at the hot elevator. The plant should have the capability to remove any desired portion of the collected dust from the mixture.

(e) Screening. The aggregate exits the dryer and is carried, along with the returned dust, up the hot elevator, over the screening deck, and into the hot bins. Screen sizes are selected such that the oversize material will be rejected and the remaining aggregates are separated into various sizes. Ideally, the screen sizes should be selected so that the amount of material going into each hot bin is proportional to the relative volume of that hot bin. For example, suppose that hot bin No. 1 has a volume of 3 cubic meters (4 cubic yards), hot bin No. 2 has a volume of 1.5 cubic meters (2 cubic yards), and hot bin No. 3 has a volume of 1.5 cubic meters (2 cubic yards). Screens should be selected so that 50 percent of the material will go into bin No. 1, 25 percent into bin No. 2, and 25 percent into bin No. 3.

(f) Percentage of each hot bin. The percentage of each hot bin to be used in the mixture should be determined. Samples of each hot bin should be taken and the gradation for each sample determined. The percentage of each bin should be selected so that the gradation of the combined materials from the hot bins is equal to the JMF.

(g) Mixing aggregate and asphalt. After the cold feed and hot bins are properly set, the combined aggregate from the hot bins is mixed with the proper amount of asphalt. The mixing time, generally 5 seconds for dry mixing and 25 to 40 seconds for wet mixing, should be selected so that all aggregate particles are coated. The plant should now be set to produce a uniform asphalt concrete mixture having proper aggregate gradation, asphalt content, and temperature. The batch plant weighs the various nominal size aggregates and asphalt to produce a batch of material that is then mixed for a specified period of time.

(2) Drum mixer.

(a) General. The asphalt plant that has become popular throughout the paving industry is the drum mixer (figure 2-2). The drum mixer is less expensive than the batch plant and generally produces material at a higher production rate. When a drum mixer is used, the gradation must be closely controlled at the cold feed bins because no additional screening of the mixture occurs. The drum mixer is frequently used in the production of recycled hot-mix asphalt as well as conventional hot-mix asphalt.

(b) Cold feed bin calibration. The cold feed bins are set up much the same way as for the batch plant, but the drum mixers should have a weight sensor on the aggregate feed belt that weighs a given length of the loaded belt. The asphalt pump adds binder based on the belt measured weight of aggregate. Thus, to calibrate the cold feeds, each aggregate can be fed onto the belt at various gate openings or individual belt speeds, weighed, and the feed rate computed. These steps should be followed for each of the aggregates to be added to the mixture, and a calibration curve should be developed.

(c) Dryer. For the drum mixer the burner for the dryer is usually located on the high side of the drum. The aggregate enters the dryer just below the burner and helps to shield the asphalt binder from direct contact with the flame. The asphalt cement is added to the dryer at approximately the midpoint to two-thirds the length to prevent close contact with the flame, which could cause over-heating and damage the asphalt binder. A double barrel drum mixer has the burner on the low end of the drum and is more efficient than a conventional drum mixer. Information concerning the addition of a recyclable asphalt pavement to a drum mixer is available in paragraph 7, paragraph 4 “Recycled Hot-Mix Asphalt.”

(3) Asphalt mixture storage silo. Asphalt storage silos are used to store hot-mix asphalt mixture before loading onto trucks. Thus, plants can run continuously even when there is a temporary shortage of trucks. Material can be stored in silos for short periods of time, but if stored too long, the material may cool excessively or may oxidize excessively causing the bituminous binder to become hard

and brittle. With some mixes the asphalt cement may tend to drain from the aggregate. As a general rule, hot-mix asphalt mixtures should not be stored more than 4 hours regardless of the type of storage silo used. If segregation of aggregate or draindown of asphalt cement occurs in the silo, use of the silo should be disallowed or changes should be made to prevent segregation and draindown.

b. Placement Equipment.

(1) Asphalt spreader (Paver).

(a) Types of spreaders. An asphalt spreader is used to place most mixture types such as hot mix, cold mix, and base course material. Spreaders currently in use operate on either tracks or rubber tires and most have a vibrating screed to strike off and smooth the paving mixture. Some spreaders use a tamping bar in conjunction with the screed, or an oscillating screed with a vibrating compactor, and others use a vibrating screed for both strike-off and initial compaction. Conventional paving machines are capable of placing hot-mix paving mixtures satisfactorily, provided they are maintained in good mechanical condition, kept properly adjusted, and operated by experienced personnel. Poor pavement surfaces result if the screed plates are worn or rusty or if the tamping bars are worn or not properly adjusted.

(b) Automatic grade control. Asphalt spreaders should have a means of automatically controlling the grade. If an automatic grade control device is used on the spreader for constructing pavements that consist of two paving lanes, it should include a sensing device for grade control of one end of the screed and a slope-control mechanism for control of the other end of the screed or a grade control sensing device on each end of the screed. Where the paver is used for constructing pavements with multiple paving lanes (more than two paving lanes), sensing devices will be used on each side of the spreader for control of the screed. The slope-control mechanism should not be used for grade control in multiple paving lane operation.

(2) Joint heaters. Joint-heating devices for attachment to asphalt spreaders have been used on construction projects. They are used to heat the edge of an adjacent pavement lane during placement so that a hot joint is obtained. Experience with joint heaters has shown that there is a danger of overheating the existing asphalt mixture. Accordingly, it is the policy of the Army and the Air Force that pavement joint heaters will not be used without the written authorization of the respective office. If a contractor should desire to use a pavement joint heater, a request will be submitted to USACE Transportation Systems Center (TSMCX) or the appropriate Air Force major command. To assure that the asphalt mixture will not be detrimentally affected, the request will include a description of the controls for the proposed joint heater.

(3) Asphalt distributor. Asphalt distributors are used to apply asphalt material evenly over a surface. All nozzles should be free and open, and should be the same size and at the same angle with reference to the spray bar to produce a uniform fan of bituminous material. The height of the spray bar above the surface is important for uniform application. When the bar is too high or too low, a difference in application rate in the middle of the spray fan and at the ends will occur, causing streaking. The height of the spray bar should be adjusted so that a double or triple overlap of the spray fan is obtained. The Asphalt Institute's Manual Series No. 13 offers guidance for calibrating and checking application equipment.

(4) Rollers.

(a) Roller types. A number of roller types are being used for paving operations. Rollers used to compact asphalt mixtures are static steel-wheel, vibratory steel-wheel, and rubber-tired rollers.

[1] Static steel-wheel rollers. The static steel-wheel rollers consist of two-wheel (tandem), and three-wheel (tricycle) versions. These rollers are generally used for breakdown and finish rolling. Static steel-wheel rollers leave a smooth finish on the pavement surface, but excessive rolling may result in lateral movement of the mixture causing surface cracking and a general loss in density. These rollers should be equipped with a system for watering the drums and should have scrapers to remove any material that sticks to the drums.

[2] Vibratory steel-wheel rollers. The vibratory steel-wheel rollers are commonly used for compacting hot-mix asphalt mixtures. They may consist of dual-drum vibration, single-drum vibration and single-drum static, or single-drum vibration and rubber tires on the rear axle. These rollers can be used for breakdown, intermediate, and finish rolling. Breakdown rolling can be performed in either static or vibratory mode. Intermediate rolling is performed in the vibratory mode while finish rolling is performed in the static mode. The Air Force requires a maximum of 2 passes in the vibratory mode. Although the vibratory roller is used for intermediate rolling, it does not replace a rubber-tired roller. The vibratory roller should have a watering system on steel drums and rubber tires (if applicable) along with scrapers on the steel drums and scrapers and pads on the rubber tires.

[3] Rubber-tire roller. Rubber-tired rollers are used for intermediate rolling of hot-mix asphalt mixtures. These rollers provide for an increase in compaction after breakdown rolling and produce a watertight surface. A large rubber-tired roller (capable of being loaded to a minimum of 2,043 kilograms, 4,500 pounds per tire and capable of minimum tire inflation pressure of 620 kPa, 90 psi) should be available for construction of heavy-duty pavements on roads or airfields. The rubber-tired roller should have a watering system for the tires and should have scrapers and pads to prevent accumulation of materials on tires. A large rubber-tired roller should be used for compaction of all heavy-duty hot-mix asphalt pavements.

(b) Operation of rollers. Rollers should generally be operated at or below a rate of 4.8 to 8 kilometers per hour (3 to 5 miles per hour) (fast walking speed). Starts and stops should be gradual to avoid damaging the freshly laid mixture. Quick turns or any turns that cause cracking on freshly laid mixture should not be allowed.

3. MATERIALS.

a. Asphalt Materials. Asphalt materials used in hot-mix paving operations include the products conforming to the specifications listed in table 2-2. The grades of asphalt specified by AASHTO MP-1 are the performance grades of asphalt developed as part of the Strategic Highway Research Program (SHRP). This grading system is currently being implemented and, within the U.S., is the method most often used to specify asphalt cement. The PG system has advantages over conventional grading systems. See the information given in the section SHRP Performance grading (PG) of asphalt-cements of this chapter.

The specific gravity of the asphalt cement shall be obtained using ASTM D 3142. This value is sometimes required to compute a theoretical maximum specific gravity and for mixture void calculations. The maximum theoretical specific gravity can also be determined using ASTM D 2041.

Asphalt cements for use in pavement design and construction are graded or classified in one of three ways. They can be graded on the basis of penetration ASTM D 946, on the basis of viscosity, ASTM D 3381; or by the performance grading system AASHTO MP-1. Currently, in the continental United States (CONUS), performance grades of asphalt are common. However, outside the continental United States (OCONUS), penetration grades of asphalt may be more easily obtained. When PG binders are used, paragraphs (1), (2), and (3) on asphalt selection should be disregarded and the procedures from AASHTO MP-1 and information given in paragraph (4) should be used for selection. In

Table 2-2
Specification References for Asphalt Materials

Bitumen Type	Specification
Asphalt cement (Performance graded asphalt binder)	ASTM D 946, D 3381 (AASHTO MP-1)
Cutback asphalt (slow-curing type)	ASTM D 2026
Cutback asphalt (medium-curing type)	ASTM D 2027
Cutback asphalt (rapid-curing type)	ASTM D 2028
Asphalt, emulsified	ASTM D 977
Asphalt, cationic emulsified	ASTM D 2397
Rubberized tar cement	ASTM D 2993
Tar	ASTM D 490 and D 2993

general, the softest grade of asphalt cement consistent with traffic and climate should be used. Selecting a grade of asphalt cement should be based on several items. Among the most important are climate, traffic conditions, economics of asphalt availability, and previous regional experiences. Traffic conditions and economic considerations will vary from project to project, but environmental conditions and regional experiences should have some similarity. For example, in warm and hot regions one should ensure that the mix is stable during the summer months, and in cold regions one should ensure that the mix is not prone to cracking during winter months. The Departments of the Army and Air Force have additional requirements for asphalt cements that will perform satisfactorily in very cold climates such as Alaska, Greenland, and the northern continental United States. These requirements are discussed in the following subparagraphs.

(1) Asphalt cement selection by temperature region.

(a) Determining temperature region. Table 2-3 gives guidance for selecting an asphalt cement by temperature region. Climatological data are required to provide input into the selection method. First, average monthly maximum temperature data are required to compute a pavement temperature index (PTI), when project locations have average monthly maximum temperatures above 23.9°C (75°F), the PTI is defined as the sum of the monthly increments exceeding 23.9°C (75°F). Conversely, when no average monthly temperature exceeds 23.9°C (75°F), the PTI is defined as the difference between the highest average maximum temperature for the warmest month and 23.9°C (75°F).

Table 2-3
Asphalt Cement Selection Criteria Based on Pavement Temperature Index

Pavement Temperature Index, Cumulative °C (°F)	Temperature Region	Asphalt Cement Selection Criteria
Less than 16.7 (30)	Cold	Penetration-viscosity method for cold regions (table 5)
16.7 to 44.4 (30 to 80)	Warm	85 to 100 penetration (original asphalt)
Greater than 44.4 (80)	Hot	60 to 70 penetration (original asphalt)

(b) Example of calculations for pavement temperature index. The method for calculating the pavement temperature index for two construction sites is given in this example. The average monthly maximum temperature and the difference above 23.9°C (75°F) for Site A and Site B are given below.

The temperature index at these sites is the sum of the increments of average monthly maximums above 23.9°C (75°F); therefore, the pavement temperature index for each site is as follows:

Site A = 54.2, cumulative °C (98.0, cumulative °F)
Site B = 1.1, cumulative °C (2.0, cumulative °F)

Based on the criteria shown in table 2-3, Site A is a hot region, and Site B is a cold region.

	Site A		**Site B**	
Month	**Average Maximum Temperature °C**	**Difference Above 23.9°C**	**Average Maximum Temperature °C**	**Difference Above 23.9°C**
January	15.8	--	-1.2	--
February	20.3	--	-2.3	--
March	23.2	--	6.1	--
April	26.6	2.7	14.6	--
May	31.4	7.5	19.6	--
June	34.7	10.8	21.3	--
July	36.4	12.5	25.0	1.1
August	33.3	9.4	23.4	--
September	32.3	8.4	19.4	--
October	26.8	2.9	14.2	--
November	23.3	--	6.3	--
December	15.7	--	2.7	--
Cumulative total		54.2		1.1

(c) Cold region requirements.

[1] Determining the design air freezing index. When it is determined that a project will exist in a cold region, as defined in table 2-3, additional climate data are required. For the project area under consideration, a design air freezing index (DFI) is also required to further satisfy cold region requirements. (Reference TI 825-01/AFM 32-1124(I)/NAVFAC DM 21.10 for determination of DFI.) DFI's are used to differentiate between climates in cold temperature regions. A DFI of 1,667 degree-Celsius-days or 3,000 degree-Fahrenheit-days (degree-days) is used as the delineation between moderately cold and severely cold (extremely cold) climates. Moderately cold climates have DFI's up to 1,667 degree-days, and severely cold climates have DFI's greater than 1,667 degree-days.

[2] Penetration-viscosity number. Cold regions are areas where the penetration-viscosity number (PVN) method is used to aid in selecting an asphalt cement. Site B in the previous example would require the use of the PVN method to select an asphalt cement. Asphalt cement factors considered in the original correlation were penetrations at 25°C (77°F), viscosity at 135°C (275°F), and penetration index. The PVN method is used to quantify temperature susceptibility of an asphalt cement and estimate its ability to resist low-temperature cracking. Required input data are penetration at 25°C (77°F) and kinematic viscosity at 135°C (275°F). Figure 2-3 allows estimation of PVN for asphalt cements in cold regions. Table 2-4 provides minimum PVN selection criteria for asphalts in cold regions. Table 2-4 and figure 2-3 should always be used when selecting asphalts for use in cold regions unless performance graded asphalt cements are used. Table 2-4 also shows requirements for airfields and

roads and other pavements. A design index is required for roads and other pavements; it is an index of the severity of traffic estimate and is defined in TM 5-822-5/AFM 88-7, Chap. 2. Temperature at a 5 centimeter (2-inch) depth of pavement can be estimated from a DFI for a given project location or site as shown in figure 2-4. This "minimum anticipated pavement temperature" and minimum PVN criteria of table 2-4 can be used with figure 2-3 to select an asphalt cement. An asphalt with given penetration and viscosity can be checked for satisfying PVN criteria of table 2-4 by plotting in figure 2-3. If this penetration and viscosity point falls on or above the minimum PVN value and to the right of the minimum anticipated pavement temperature, it is estimated that low temperature contraction cracking of the asphalt concrete layer will be prevented. If it plots to the left of the anticipated pavement temperature, the pavement will likely crack at low temperature. PVN values should be calculated for more accurate results.

Table 2-4
Minimum PVN Selection Criteria for Asphalt Cements in Cold Region Use

		Road and Other Pavement by Design Index	
Cold Region	Airfields	4	> 4
Moderate cold (DFI 1,667 degree-days[1])	- 0.5	- 0.5	- 0.5
Severe cold (DFI > 1,667 degree-days[1])	- 0.2	- 0.5	- 0.2

[1] Degree-Celsius-days (3,000 degree-Fahrenheit-days).

(2) Examples of asphalt cement selection in the three regions.

(a) Asphalt cement selection in a hot region. A parking lot is to be built in a region that has a pavement temperature index of 54.4, cumulative °C (98, cumulative °F). An asphalt supplier can provide asphalt cements that meet the requirements in table 2 from ASTM D 3381. Viscosity and penetration data for the asphalt cements are given below.

	AC-10	AC-20	AC-40
Viscosity, 60°C (140°F), P	872	2,200	4,104
135°C (275°F), cSt	298	435	605
Penetration, 25°C (77°F), 0.1 mm	123	70	46

From table 2-3, an asphalt cement that has a penetration of approximately 60 to 70 should be selected. The AC-20 asphalt cement should be selected for this pavement.

(b) Asphalt cement selection in a warm region.

[1] Asphalt cement (D 3381) original asphalt cement. A street is to be constructed in a region that has a pavement temperature index of 23.3, cumulative °C (42, cumulative °F). An asphalt supplier can provide asphalt cements that meet the requirements in table 2 from ASTM D 3381. Viscosity and penetration data for the asphalt cements are given below.

	AC-5	AC-10	AC-20
Viscosity, 60°C (140°F), P	560	1,120	2,170
135°C (275°F), cSt	180	335	450
Penetration, 25°C (77°F), 0.1 mm	145	96	70

Based on table 2-3, an asphalt cement that has a penetration of approximately 85 to 100 should be selected. The AC-10 asphalt cement is selected.

[2] Asphalt cement (D 3381 - residual asphalt cement). A parking lot is to be constructed in a region that has a pavement temperature index of 23.2, cumulative °C (42, cumulative °F). An asphalt supplier can provide asphalt cements that meet the requirements in table 3 from ASTM D 3381. Viscosity and penetration data for the asphalt cements are given below.

	AR-1000	AR-2000	AR-4000
Viscosity, 60°C (140°F), P	851	1,962	3,544
135°C (275°F), cSt	162	247	334
Penetration, 25°C (77°F), 0.1 mm			
Original	145	87	53
Residue	99	55	39

Based on table 2-3, an asphalt cement that has a penetration of approximately 85 to 100 should be selected. The AR-2000 asphalt cement is selected based on the original penetration of the material.

(c) Asphalt cement selection in a cold region. At a location in Watertown, NY, a heavy duty open storage area (design index of 0) for use by 22,680 kilogram (50,000 pound) forklift trucks has to be constructed in a region with a pavement temperature index of 1.1, cumulative °C (2, cumulative °F) and a DFI of 1,278 degree-Celsius-days (2,300 degree-Fahrenheit-days) calculated using TM 5-818-2. An asphalt supplier can provide two asphalt cements that meet the requirements in table 2 from ASTM D 3381. Viscosity and penetration data for the asphalt cements are given below.

	AC-2.5	AC-5
Viscosity, 60°C (140°F), P	280	466
135°C (275°F), cSt	180	220
Penetration, 25°C (77°F), 0.1 mm	296	240

(3) Analysis and asphalt selection. The climatological data allow classification of the site by temperature region and allow an estimate of pavement temperature. According to table 2-3, the pavement temperature index classifies the site as a cold region where the PVN method should be used to select the grade of asphalt cement. The DFI allows the use of figure 2-4 to estimate a minimum pavement temperature at a 5 centimeter (2-inch) depth. From figure 2-4, a minimum anticipated

pavement temperature is about -30°C (-22°F). Table 2-4 shows that this cold region can be further classified as a moderately cold region since its DFI is less than 1,667 degree-Celsius-days. Table 2-4 also indicates that the required PVN of the asphalt selected must be greater than 0.5 for a design index of 10. This will minimize low temperature pavement cracking. Now, PVN values must be determined for the available asphalt cements. This can be done by either plotting penetration and viscosity at 135°C (275°F) in figure 2-3 or by using PVN equations. If the details of figure 2-3 are not sufficient to accurately determine PVN values, equations should be used. The general PVN equation is as follows:

$$PVN = \frac{(L - X)\ (-1.5)}{(L - M)}$$

where

L = logarithm of viscosity in centistokes at 135°C (275°F) for a PVN of 0.0 at the given penetration

X = logarithm of viscosity in centistokes at 135°C (275°F) of a given asphalt

M = logarithm of viscosity in centistokes at 135°C (275°F) for a PVN of -1.5 at the given penetration

Values of X can be determined directly from asphalt cement viscosity data as provided in this example, but values of L and M are a function of the penetration values of each asphalt. Equations for the values of L and M are:

$$L = 4.25800 - 0.79674\ LOG\ (PEN)$$

and

$$M = 3.46289 - 0.61094\ LOG\ (PEN)$$

where PEN = penetration at 25°C (77°F) of a given asphalt cement.

Calculated PVN values of the two available asphalt cements are:

PVN = -0.638 for AC-2.5

PVN = -0.081 for AC-5

Based on table 2-4, an asphalt cement that has a PVN greater than -0.5 and lies on or to the right of the minimum temperature diagonal line should be selected. The AC-5 asphalt cement is selected because it has a PVN of -0.081 and lies to the right of the -30°C (-22°F) temperature diagonal line. This asphalt cement satisfies the requirements of table 2-4 and should prevent low-temperature pavement cracking.

(4) SHRP performance grading (PG) of asphalt cements.

(a) General. The SHRP PG system (AASHTO MP1-93) classifies asphalt binders according to the temperatures at which certain performance-related properties are met (AASHTO PP6-93). These specifications will have replaced penetration and viscosity graded asphalts. The specifications can be applied to unmodified and modified asphalt cements. The SHRP performance grading procedures must be applied with caution to certain polymer modified asphalts binders (PMAB). The SHRP PG specifications are built around viscoelastic properties such as complex modulus, G*, phase angle, ä, low temperature stiffness, *S*, and creep rate, *m*. The criteria for G*/sin ä (the SHRP rutting parameter) are designed to insure a minimum stiffness of the binder immediately after placement to avoid "tender" mixtures and those mixtures with rutting potential early in the pavement life based on an estimated high pavement temperature. The high pavement temperature is determined from the mean 7-day high air temperatures to obtain an estimate for the pavement temperature. The maximum for G* sin ä (the SHRP fatigue parameter) helps to identify binders that may be susceptible to fatigue damage as well as those exhibiting excessive embrittlement with age. Temperature data for specification of a binder for a particular region can be obtained from local weather stations or from an extensive database compiled by the FHWA (Federal Highway Administration). The database contains information from thousands of locations in the U.S. and Canada and is available in the SHRPBIND software. The SHRPBIND program is available at no cost from the FHWA. The software calculates the 7-day mean maximum pavement temperatures and the lowest yearly one-day pavement temperatures to determine the SHRP PG for the area selected. The calculations are based on air temperatures, average sunlight, and location. The software does not contain the low temperature modification equation above. SHRP PG's are calculated by the SHRPBIND program along with the reliability for the given area. For example, a PG64-22 binder refers to a material with the following properties: (1) a minimum flash point of 230°C, (2) a maximum rotational viscosity of 3 Pa sec at 135°C, (3) a minimum of 1000 and 2200 Pa for G*/sin ä for the original (tank) and RTFOT-conditioned (Rolling Thin Film Oven Test) materials, respectively, at a 10 radian/sec oscillatory shear and 64°C, (4) a maximum of 5 MPa for G* sin ä for the PAV-aged (Pressure Aging Vessel) material at 10 radian/sec oscillatory shear and 25°C, and (5) a maximum stiffness of 300 MPa and a minimum creep slope of 0.3 at -12°C for the PAV-aged material. This binder would be suitable in areas with a maximum pavement temperature of 64°C and a minimum pavement temperature of -22°C.

(b) Use of performance graded binders on airfields. Performance graded binders can be used on airfields with some restrictions. A typical airfield pavement experiences much higher loads than a highway due to heavily-loaded cargo aircraft and high-performance fighter aircraft with high tire pressures. To avoid rutting, higher loads require a more stable asphalt binder, especially at higher pavement temperatures. In addition, most airfields suffer more from environmental distresses such as low temperature cracking and oxidative hardening of the asphalt (which leads to cracking). Thus, for airfields, use of SHRP performance graded asphalts above and below the recommendation for the given region is warranted. For example, if an airfield that is subjected to heavy cargo aircraft traffic is located in a region that requires a PG64-22, use of a PG 70-28 or 76-28 will provide additional insurance against rutting and cracking. The added cost of producing an enhanced PG asphalt must be balanced against expected benefits and life cycle costs.

(c) Polymer modification of asphalts. The addition of polymers to asphalts is a burgeoning industry. Many polymers greatly improve the stiffness and flow characteristics of asphalts at high temperatures and are being demonstrated in pavement applications to significantly reduce rutting where this has been a problem in the past. The higher temperatures often required by the modification can cause difficulty with mixing, placement, and compaction. New classes of polymers have become available that are designed to improve the low temperature characteristics of an asphalt and should improve the ability of the pavement to resist low temperature-induced cracking. The selection of a modifier may be based on a range of factors that include availability, cost, properties, and familiarity with the product. Due to differences in chemistry of asphalts, a particular polymer used with one asphalt source will likely not yield the same physical properties as the same polymer with a different asphalt source. Of primary importance in the selection of an appropriate polymer is the phase separation characteristics of the asphalt/polymer combination during storage to ensure homogeneity of the binder prior to mixing with aggregate and during testing of the material. Phase separation can occur in the storage tank if the PMAB is not properly dispersed, leading to a heterogenous binder in the binder/ aggregate mix which may affect performance. The SHRP PG specification is currently the best utility available for judging the expected performance of a PMAB. Although, not perfect, performance grading offers much more pertinent information about the properties of a PMAB than conventional grading. Many state highway agencies have produced specifications for local use of PMABs that are modifications of current conventional tests. However, these specifications are often built around specific asphalts and specific polymers, are not of general use, and can cause problems when asphalt or polymer sources change. The SHRP PG binder specification was originally intended to be a "blind" specification where all binder materials (modified and unmodified) would be evaluated on the basis of properties that relate directly to performance. However, many commercial asphalt modifiers cannot be properly evaluated using some of the SHRP aging practices due to phase separation and some of the performance-related properties may not be applicable to some PMABs. Additional research is underway to address these shortcomings. In the interim, use of SHRP PG on polymer-modified asphalts must be used with caution. The direct tension test must be employed according to current use practice (as of March, 1998, this is the horizontal test arrangement using deicing fluid as the bath medium and metal binder molds) on all PMABs to verify the low temperature grade determined by bending beam rheometry. The modified asphalts must be shown to not be prone to phase separation or gross morphology changes during the SHRP performance grading procedures. This may be addressed by applying phase separation testing (ASTM D-5892) to determine the ring and ball softening point difference between upper and lower sections of heated tubes of binder. A guideline is that this difference should be no more than 4°C. In general, the maximum range of temperatures that a typical unmodified asphalt (non air-blown) demonstrates in SHRP grading is between 80 and 90°C. For instance, a typical AC-20 or AC-30 viscosity graded asphalt may yield a PG58-22 or PG64-22 with a temperature use range of 80 and 86°C, respectively. To extend this range past 90°C, modifiers (primarily polymers) are added to asphalt binder. A typical polymer modified AC-20 or AC-30 will yield a PG70-22 or PG76-22 depending on the amount of polymer added. However, some modifiers may extend both the high and low temperature grades. Softer asphalt grades (such as an AC-5 or AC-10) combined with a polymer modifier can be used to yield a binder with better low temperature properties for a given region while maintaining the necessary high temperature properties.

b. Aggregates. Aggregates for use in hot mix asphalt should be clean, hard, and durable. Angular aggregates provide more stable hot mix asphalt mixtures than do rounded aggregates.

(1) Sieve analysis. Aggregates to be used in a paving mix, as listed in table 2-1, should be subjected to a sieve analysis. An experienced engineer can obtain information from an aggregate's grading curve concerning the suitability of the aggregate for a paving mix, the quantity of asphalt cement required, and whether mineral filler should be added. Sieve analyses of fine and coarse aggregates shall be conducted according to ASTM C 136.

(2) Specific gravity. Specific gravity values for aggregates used in paving mixture are sometimes required in the computation of percent voids total mix and percent voids filled with asphalt in the compacted specimens. Criteria have been established to specify limiting values for these void properties. Therefore, specific gravity values must be carefully determined following specified procedures to insure that the criteria are properly applied. Two different methods can be used for determination of the theoretical maximum specific gravity of a mixture. The selection of the appropriate test procedure depends in part on the water absorption of each aggregate blend.

(a) Apparent specific gravity of aggregate. The apparent specific gravity of the fine and coarse aggregate can be used to compute the theoretical maximum specific gravity with aggregate blends showing water absorption of less than 2.5 percent. The apparent specific gravity shall be determined as described in ASTM C 127 for coarse aggregate, ASTM C 128 for fine aggregate, and ASTM C 188 or D 854 (whichever is applicable) for mineral filler. Properly weighted values, based on the amount of each type of material in a given blend, should be used in computations subsequently discussed.

(b) Theoretical maximum specific gravity of mixture. The theoretical maximum specific gravity can be determined by the test method described in ASTM D 2041. This test is conducted on the asphalt mixture and does not require a specific gravity test on the individual aggregates. The theoretical maximum specific gravity can be used to back calculate the effective specific gravity of the aggregate. This method can be used for aggregate blends having any amount of water absorption.

(3) Abrasion and impact resistance of coarse aggregate. The determination of percent loss for coarse aggregates may not be necessary if the aggregate has been found satisfactory by previous tests and/or performance. However, coarse aggregates obtained from new or doubtful deposits shall be tested for resistance to degradation by evaluating the conformance to specification requirements for percent loss as measured using the Los Angeles Machine (ASTM C 131).

(4) Soundness test. The soundness test is used where damage from freezing is expected to be a problem. The soundness test should not be performed on aggregate that has been found satisfactory by previous tests or performance data. However, aggregate obtained from new or doubtful deposits will be tested for conformance to specification requirements using the sodium sulfate or magnesium sulfate solution tests (ASTM C 88).

(5) Percent crushed pieces. The percentage of crushed pieces in both the coarse aggregate and fine aggregate fractions must be sufficiently high to promote stability in hot-mix asphalt mixture. A description of a proper crushed face and the required percentage of crushed aggregate particles shall be specified in the contract specifications.

(6) Particle shape. The particle shape of crushed aggregates is required to be essentially cubical. Flat and elongated aggregate particles are susceptible to breakage under compaction and subsequent traffic. The quantity of flat and elongated particles shall be tested for conformance to specification requirements using ASTM D 4791.

(7) Natural sand content. Natural sand is defined as any fine aggregate material other than that produced by mechanically crushing larger rocks and aggregates. Natural sands tend to be rounded particles which, when used in excess, can cause instability in the hot-mix asphalt mixture. For airfield or high-pressure mixtures the percentage of natural sand shall not exceed 15 percent of the combined weight of the coarse aggregate, fine aggregate, and the material passing the 75 m (No. 200) sieve. This percentage can increase to 25 percent for roadway (low-pressure) mixtures. The limitation on the percentage of natural (uncrushed) sand in the mixture assures a strong and stable pavement under traffic.

(8) Fine aggregate effect. The uncompacted void content (C 1252, Method A) will help define the angularity of the fine aggregate. The lower limit should be 45, unless local experience indicates that aggregates with a lower value can provide good performance. Generally, a value of 43 should be the lowest value accepted.

(9) Voids in the mineral aggregate (VMA). The volume of intergranular void space between the aggregate particles of a compacted paving mixture that includes the air voids and volume of the asphalt not absorbed into the aggregates.

(10) Combining aggregates. When asphalt mixtures are produced, aggregates from two or more sources must be combined. Methods and procedures described in this manual will permit determination of the most suitable aggregate blend available and will prescribe the proper asphalt content for the particular aggregate blend determined to be the most suitable. Whenever an asphalt mixture does not meet established criteria, either the gradation of the aggregate must be improved, another aggregate must be used, or the asphalt content must be modified. The choice as to

improvement of gradation or the use of another aggregate is a matter of engineering judgment involving an analysis of the available aggregate supplies and cost considerations.

c. Mineral fillers.

(1) General. Some mineral fillers are more desirable in asphalt paving mixtures than others. For example, fine sands and clays are less suitable fillers than limestone filler or portland cement, and well-graded materials are more suitable than poorly graded materials. Satisfactory pavements may be designed using commercial fillers that conform to ASTM specifications. The apparent specific gravity of the mineral filler is required to perform a void computation except when ASTM D2041 is used. The specific gravity will be determined following ASTM D 854 or ASTM C 188 procedures (as appropriate), except when ASTM D 2041 is used, in which case the mineral filler shall be included in the blended aggregate.

(2) Addition of mineral filler. The filler requirements of each aggregate blend must be estimated after the blends to be tested in the laboratory have been selected. The quantity of mineral filler to be added generally depends on the amount of filler naturally present in the aggregate. The amount of filler that exists naturally in most aggregates is sufficient to produce satisfactory hot-mix asphalt. Research has indicated that under normal circumstances, the addition of mineral filler reduces the quantity of asphalt cement required for the paving mixture. The addition of a satisfactory mineral filler within practical limits also increases the stability of a paving mixture. Excessive amounts of filler, however, may decrease the durability of the paving mixture because of the decrease in asphalt cement film thickness. Practical considerations and optimum performance usually will dictate quantities of about 5 percent filler for hot-mix asphalt and 10 percent for sand-asphalt mixtures.

d. Antistrip agents.

(1) General. Several antistrip agents have been successfully used to reduce the probability of the asphalt stripping from the aggregate. Some antistrip agents are added to the asphalt binder before it leaves the refinery, while others are added directly into the mixer as mineral filler. The immersion compression test described in CRD-C 652-95 is used to evaluate the stripping property of a dense-graded bituminous hot mix.

(2) Recommended procedure. The recommended procedure for improving the resistance of an aggregate to stripping is to add approximately 1 percent by weight hydrated lime to the mixture. This 1 percent lime must be included in the determination of the aggregate gradation.

e. Antifoam agents. Silicone additives or modifiers can reduce the effects of moisture or other conditions in asphalt mixtures. Silicone additives have been successfully used to suppress foaming of asphalt in asphalt plants. The silicone that has been used for this purpose is mixed at a rate of 1 milliliter per 640 liters (1 ounce per 5,000 gallons) of asphalt. The recommended range is also given as 1 to 2 parts per million. Silicones have been used to reduce the hardening of hot-mix asphalt while in storage silos. Silicone additives have successfully prevented slumping of mixes in trucks, which sometimes occurs when the hot-mix gradation is such that the mix traps escaping steam. In addition, silicones have provided better finishing qualities to pavement mixtures. These qualities include improved workability, reduced tearing during placement, and a reduction in the amount of effort required for compaction. Testing by several agencies has revealed no detrimental effects on the properties of asphalts when silicone is used in the recommended concentrations. Silicones are very persistent materials and their effects may carry over from one tank of asphalt to another. Proper mixing and control is best achieved by addition of the silicone at the refinery.

4. DENSE-GRADED HOT-MIX ASPHALT.

a. General. Dense graded hot-mix asphalt concrete consists of a mixture of well graded aggregate and asphalt cement. There are several other possible non-asphalt binders including tar and rubberized tar. However, asphalt cement is the binder used in a wide majority of paving mixtures. The hot-mix asphalt is produced at a central plant, laid to the desired grade with an asphalt spreader, and compacted. Hot-mix asphalt provides a high-strength, water resistant, smooth riding surface.

b. Laboratory testing for mix design.

(1) Contractor provided job-mix-formula. Current practice is for the contractor to do the mixture design and develop the job-mix-formula (JMF) for the aggregates and asphalt used in the paving project. The contractor should supply a sufficient amount of aggregate and asphalt to the contract officer or his representative for possible verification tests. If verification tests are not performed, these material samples should be kept until the project is completed and accepted. The JMF supplied by the contractor should contain, as a minimum, the following information:

(a) Percent passing each sieve size of individual aggregate and combined gradations.

(b) Percent of optimal asphalt cement

(c) Percent of each aggregate and mineral filler to be used.

(d) Asphalt viscosity grade, penetration grade, or performance grade.

(e) Number of blows of hammer per side of molded specimen.

(f) Laboratory mixing temperature.

(g) Lab compaction temperature.

(h) Temperature-viscosity relationship of the asphalt cement.

(i) Plot of the combined gradation on the 0.45 power gradation chart, stating the nominal maximum size.

(j) Graphical plots of stability, flow, air voids, voids in the mineral aggregate, and unit weight versus asphalt content. (example MS-2).

(k) Specific gravity and absorption of each aggregate.

(l) Percent natural sand.

(m) Percent fractured faces (in coarse aggregate).

(n) Fine aggregate angularity.

(o) Percent flat or elongated particles (in coarse aggregate).

(p) Tensile strength ratio (TSR).

(q) Antistrip agent (if required) and amount.

(r) List of all modifiers and amount.

The JMF may be adjusted when field conditions warrant a change. The JMF should only be adjusted when changes in materials or procedures occur. The JMF should only be adjusted with the approval of the contracting officer.

(2) General procedure. Laboratory tests are conducted on laboratory-compacted samples with densities equal to densities anticipated in the in-place hot-mix asphalt after being subjected to traffic. A final selection of aggregate blend and asphalt content will be based on these data with due consideration to relative costs of the various mixes. The procedures set forth in the following paragraph are directly applicable to all mixes containing not more than 10 percent by weight of total aggregate retained on the 25 millimeter (1-inch) sieve.

(3) Preparation of test specimens. The selection of materials for use in designing the paving mix has been discussed earlier. As an example, suppose that an aggregate gradation for a hot-mix design shall be the median of the 19 millimeter (3/4 inch) maximum (high pressure) aggregate gradation given in table 2-1. Design data are required on this blend. The initial mix design tests will usually be conducted in a central testing laboratory on samples of stockpile materials submitted by the contractor. The procedure for proportioning stockpile samples to produce a blend of materials to meet a specified gradation is outlined below. The final mix design will be based on samples taken from the asphalt plant and will usually be conducted in a field laboratory near the plant.

(a) Proportioning of stockpile samples. As a preliminary step in mixture design and manufacture, it is necessary to determine the approximate proportions of the different available stockpiled materials required to produce the desired gradation of aggregate. This step is necessary to determine whether a suitable blend can be produced and, if so, the approximate proportion of each aggregate to be fed from the cold feeder bins into the dryer. Sieve analyses are conducted on material from each of the stockpiles, and the data are shown graphically in figure 2-5. Another method of plotting or graphically illustrating the data is through the use of the 0.45 power curve. This was developed in the early 1960's by the Federal Highway Administration using formula developed in a study by Fuller and Thompson. The equation developed by Fuller for maximum density was:

$$P = 100\ (d/D)^n$$

where d is the diameter of the sieve size in question, P is the total percent passing or finer than the sieve, D is the maximum size of the aggregate, and n is equal to 0.45 for maximum density. The FHWA recommends this chart be used as part of the hot-mix design process. The four aggregate fractions must be combined to produce the desired blend. The estimated percentage of each fraction needed to produce this blend is determined by trial-and-error calculations. Two or three trials are normally required to obtain the desired blended gradation.

(b) Proportioning of bin samples from batch plants. Once it is demonstrated that a suitable blend can be prepared from the available materials, samples of these materials can then be processed through the asphalt plant for verification of mix design. Sieve analyses must be conducted for each batch of processed aggregate. The data are shown graphically in figure 2-6. The hot-bin aggregates should be blended to produce the same gradation as that produced at the cold feeders. The percentage of each bin is estimated and calculations are made to determine the gradation produced from these estimated percentages. The gradation of this recombined blend is then checked against the desired gradation. Two or three trials are usually sufficient to produce a combined mixture having a gradation within the allowable tolerances.

(4) Asphalt contents for specimens. The quantity of asphalt required for a particular aggregate is very important to assure satisfactory performance. The procedures to follow are described in (5) (Selection of design compaction method) below. An estimate for the optimum amount of asphalt based on total weight of mix is normally made in order to start the laboratory tests. Laboratory tests usually are conducted for a minimum of five asphalt contents: two above, two below, and one at the estimated optimum content. Incremental changes of 1 percent of asphalt may be used for preliminary work, but increments of 0.5 percent are generally used when the optimum asphalt content can be estimated and for final design.

(5) Selection of design compaction method. The Department of the Army and Air Force allow two methods of compacting asphalt paving mixtures in the laboratory—the Marshall and the Gyratory Testing Machine methods. The procedures for conducting the Marshall mix design tests are described in CRD-C 649. The procedure for gyratory compaction is given in CRD-C 651 or the standard testing method of ASTM D 3387 except as follows:

(a) Use 101.6 millimeter (4-inch) diameter molds in lieu of 152.4 millimeter (6-inch) molds when Marshall stabilities and flows are to be determined.

(b) Use mixing and compaction temperature requirement as given in CRD-C 649.

(c) The Gyratory Testing Machine setting and equivalent compaction requirements shall be as listed in table 2-5.

Table 2-5
Traffic Type and Gyratory Compaction Requirements

Type of Traffic	Gyratory Compaction Requirement
Tire pressures less than 690 kPa (100 psi)	Gyratory compaction at 690 kPa (100 psi), 1-degree, 30 revolutions (50 blows Marshall equivalent)
Tire pressures 690 kPa (100 psi) and greater but less than 1,586 kPa (230 psi)	Gyratory compaction at 1,380 kPa (200 psi,) 1-degree, 30 revolutions (75 blows Marshall equivalent)
Tire pressures 1,586 kPa (230 psi) and greater	Gyratory compaction at 1,655 kPa (240 psi), 1-degree, 60 revolutions (preferred but not mandatory for Army and Air Force airfields)

In the event an airfield pavement is to be subjected to aircraft with tire pressures of 1,586 kPa (230 psi) or more, the Gyratory Testing Machine (GTM) method is mandatory for Army airfield pavements and is preferred but is not mandatory for Air Force airfield pavements. If the GTM method is used for design, it should also be used for control testing. If the GTM cannot be used for control testing, the Marshall apparatus can be used by developing a correlation between the GTM and Marshall specimens for the job mix. Care should be taken to insure that excess breakage of the aggregate particles does not occur during Marshall compaction.

(6) Tabulation of data. After the laboratory design method has been selected and test specimens have been prepared, data should be tabulated on forms similar to those shown in CRD-C 649 and CRD-C 650 if the Marshall procedure is used. These forms, along with the forms shown in CRD-C 651, are normally used for the gyratory procedure. Arranging data as shown in table 2-6 will facilitate tabulation of specimen test property data and is preferable to similar but less complete methods

Table 2-6
Computation of Properties of Asphalt Mixtures

Specimen No.	Asphalt Cement %	Weight - Grams: In Air	Weight - Grams: In Water	Volume cc	Specific Gravity: Actual	Specific Gravity: Theor.	AC by Volume - %	Voids - Per Cent: Total Mix	Voids - Per Cent: Filled	Unit Weight Total Mix Kg/cu m (lb/cu ft)	Stability - N (lb): Measured	Stability - N (lb): Converted	Flow of Units of 0.25 mm or 0.01 in.
A	B	C	D	E	F	G	H	I	J	K	L	M	N
				(C-D)	$\left(\frac{C}{E}\right)$		$\frac{(B \times F)}{(Sp. Gr. of AC)}$	$\left(100 - 100\frac{F}{G}\right)$	$\frac{H}{H+I}$	F×1000 (F×62.4)		*	
A-3.5 1	3.5	1228.3	716.3	512.0	2.399						8985 (2020)	8985 (2020)	11
2		1219.5	712.2	507.3	2.404						8283 (1862)	8612 (1936)	10
3		1205.5	705.3	500.2	2.410						8100 (1821)	8425 (1894)	8
4		1206.2	708.4	497.8	2.423						8416 (1892)	8754 (1968)	8
Avg					2.409					2,404 (150.3)		8696 (1955)	9
Curve					2.409	2.579	8.3	6.6	55.7	2,404 (150.3)			
A-4.0 1	4.0	1276.9	747.3	529.6	2.411						9386 (2110)	9012 (2026)	10
2		1252.6	733.3	519.3	2.412						9008 (2025)	9008 (2025)	9
3		1243.5	730.7	512.8	2.425						8874 (1995)	8874 (1995)	9
4		1230.4	722.8	507.6	2.424						8985 (2020)	9346 (2101)	9
Avg					2.418					2,418 (150.9)		9061 (2037)	9
Curve					2.421	2.559	9.5	5.4	63.8	2,421 (151.1)			
A-4.5 1	4.5	1254.4	738.2	516.2	2.430						9119 (2050)	9119 (2050)	12
2		1238.3	726.8	511.5	2.421						9319 (2095)	9319 (2095)	9
3		1239.0	724.9	514.1	2.410						9386 (2110)	9386 (2110)	10
4		1273.5	752.0	521.5	2.442						9097 (2045)	9097 (2045)	10
Avg					2.426					2,426 (151.4)		9230 (2075)	10
Curve					2.426	2.539	10.7	4.5	70.4	2,426 (151.4)			

Sp. Gr. of Bit. = 1.020

(Continued)

Table 2-6 (Concluded)

Specimen No.		Asphalt Cement %	Weight - Grams In Air	Weight - Grams In Water	Volume cc	Specific Gravity Actual	Specific Gravity Theor.	AC by Volume - %	Voids - Per Cent Total Mix	Voids - Per Cent Filled	Unit Weight Total Mix Kg/cu m (lb/cu ft)	Stability - N (lb) Measured	Stability - N (lb) Converted	Flow of Units of 0.25 mm or 0.01 in.
A		B	C	D	E	F	G	H	I	J	K	L	M	N
					(C-D)	$\left(\frac{C}{E}\right)$		$\frac{(B \times F)}{(Sp. Gr. of AC)}$	$\left(100 - 100\frac{F}{G}\right)$	$\frac{H}{H+I}$	F×1000 (F×62.4)		*	
A-5.0	1	5.0	1237.9	727.0	510.9	2.423						8340 (1875)	8340 (1875)	14
	2		1300.0	763.7	536.3	2.424						9475 (2130)	8812 (1981)	10
	3		1273.6	746.9	526.7	2.418						8452 (1900)	8114 (1824)	12
	4		1247.9	731.8	516.1	2.418						8251 (1855)	8251 (1855)	12
	Avg					2.421					2,421 (151.1)		8380 (1884)	12
	Curve					2.421	2.519	11.9	3.9	75.3	2,421 (151.1)			
A-5.5	1	5.5	1237.3	724.1	513.2	2.411						6450 (1450)	6450 (1450)	12
	2		1264.0	740.6	523.4	2.415						6806 (1530)	6534 (1469)	14
	3		1286.4	752.4	534.0	2.409						7184 (1615)	6895 (1550)	13
	4		1253.5	733.8	519.7	2.412						6695 (1505)	6695 (1505)	16
	Avg					2.412					2,411 (150.5)		6646 (1494)	14
	Curve					2.409	2.500	13.0	3.6	78.3	2,404 (150.3)			

Sp. Gr. of Bit. = 1.020

used in CRD-C 649 and CRD-C650. Plots of data from table 2-6 for stability, flow, unit weight, percent voids total mix, and percent voids filled with asphalt should be made, as shown in table 2-6. The average actual specific gravity is obtained for each set of test specimens, as shown in column G of table 2-6. Each average value is the core density in grams per cubic meter (g/m^3) at 10°C, 50°F. At this temperature the average values are multiplied by 62.4 to obtain density in pounds per cubic foot (pcf). These data are entered in column K. The density values thus obtained are plotted as shown in figure 2-7, and the best-fit smooth curve is then drawn. The data from columns I and J are used to plot curves for percent voids total mix and voids filled with asphalt, respectively, in figure 2-7. The corrected stability values in column M and the flow values in column N of table 2-6 are plotted on figure 2-7 to evaluate stability and flow properties of the mixture.

(7) Relationship of test properties to asphalt cement content. Test property curves, plotted as described above, have been found to follow a reasonably consistent pattern for mixes made with penetration and viscosity grades of asphalt cement. Trends generally noted are outlined as follows:

(a) Flow. The flow value increases with increasing asphalt content at a progressive rate except at asphalt contents significantly below optimum.

(b) Stability. the Marshall stability increases with increasing asphalt content up to a point, after which it decreases.

(c) Unit weight. The curve for unit weight of total mix is similar to the curve for stability, except that the peak of the unit-weight curve is normally at a slightly higher asphalt content than the peak of the stability curve.

(d) Voids total mix. Voids total mix decreases with increasing asphalt content. The void content of the compacted mix approaches a minimum void content as the asphalt content of the mix is increased.

(e) Voids filled with asphalt. Percent voids filled with asphalt increases with increasing asphalt content and approaches a maximum value in much the same manner as the voids total mix discussed above approaches a minimum value.

(8) Requirement for additional test specimens. The curves in figure 2-7 are typical of those normally obtained when penetration or viscosity grades of asphalt cement are used with aggregate mixes. Aggregate blends may be encountered that will furnish erratic data such that plotting of the typical curves is difficult. In most of these cases, an increase in the number of specimens tested at each asphalt content will normally result in data that will plot as typical curves.

c. Optimum asphalt and design test properties.

(1) Selection of asphalt content. Previous testing has indicated that the optimum asphalt content is one of the most important factors in the proper design of an asphalt paving mixture. Extensive research and pavement behavior studies have resulted in establishment of certain criteria for determining the proper or optimum asphalt content for a given blend of aggregates. Criteria have also been established to determine whether the aggregate will furnish a satisfactory paving mix at the selected optimum asphalt content.

(2) Determination of optimum asphalt content and acceptability of mix by Marshall method. Data plotted in graphical form in figure 2-7 are used to determine optimum asphalt content. In addition, optimum asphalt content and acceptability of the mix are determined based on table 2-7. Separate criteria are shown for use where specimens were prepared with 50- and 75-blow compactive efforts. As

Table 2-7
Design Criteria

Section 1. Procedure for Determining Optimum Asphalt Content

	Point of Curve		
Property	Type of Mix	50 Blows	75 Blows
Marshall stability	Hot-Mix Asphalt surface course	Peak of curve	Peak of curve
	Hot-Mix Asphalt intermediate course	Peak of curve	Peak of curve
	Sand asphalt	Peak of curve	______[a]
Unit weight	Hot-Mix Asphalt surface course	Peak of curve	Peak of curve
	Hot-Mix Asphalt intermediate course	Not used	Not used
	Sand asphalt	Peak of curve	______[a]
Flow	--	Not used	Not used
Percent[b] voids total mix	Hot-Mix Asphalt surface course	4	4
	Hot-Mix Asphalt intermediate course	4	4
	Sand asphalt	6	______[a]
Percent[b] voids filled with asphalt	Hot-Mix Asphalt surface course	80[c]	75[c]
	Hot-Mix Asphalt intermediate course	80[c]	75[c]
	Sand asphalt	70	______[a]

(Continued)

[a] Sand asphalt will not be used in designing pavements for traffic with tire pressures in excess of 690 kPa (100 psi).

[b] The theoretical maximum specific gravity can be determined either with the apparent specific gravity as determined in ASTM C-127 and C-128 or by the use of ASTM D 2041. ASTM D 2041 will be used for absorptive aggregate.

[c] If inclusion of asphalt contents at these points in the average causes the voids total mix to fall outside the limits, then the optimum asphalt content should be adjusted so that the voids total mix is within the limits.

Table 2-7 (Concluded)

Section 2. Procedure for Determining Acceptability of Mix			
	Criteria		
Test Property	Type of Mix	50 Blows	75 Blows
Marshall stability	Hot-Mix Asphalt surface course	500 pounds or higher	1,800 pounds or higher
	Hot-Mix Asphalt intermediate course	500 pounds or higher	1,800 pounds or higher
	Sand asphalt	500 pounds or higher	______[a]
Unit weight	--	Not used	Not used
Flow	Hot-Mix Asphalt surface course	20 (0.01 inch) or less	16 (0.01 inch) or less
	Hot-Mix Asphalt intermediate course	20 (0.01 inch) or less	16 (0.01 inch or less
	Sand asphalt	20 (0.01 inch) or less	______[a]
Percent[b] voids total mix	Hot-Mix Asphalt surface course	3-5 percent	3-5 percent
	Hot-Mix Asphalt intermediate course	3-5 percent	3-5 percent
	Sand asphalt	5-7 percent	______[a]
Percent[b] voids filled with asphalt	Hot-Mix Asphalt surface course	75-85 percent	70-80 percent
	Hot-Mix Asphalt intermediate course	75-85 percent	70-80 percent
	Sand asphalt	65-75 percent	______[a]

[a] Sand asphalt will not be used in designing pavements for traffic with tire pressures in excess of 690 kPa (100 psi).
[b] The theoretical maximum specific gravity can be determined either with the apparent specific gravity as determined in ASTM C-127 and C-128 or by the use of ASTM D 2041. ASTM D 2041 will be used for absorptive aggregate.

shown in table 2-8, the optimum asphalt content (average) for the example provided is computed as 4.6 percent. Table 2-9 shows the criteria for acceptability of the mix for a 75-blow compactive effort at the optimum bitumen content of 4.6 percent.

(3) Determination of optimum bitumen content when using the Gyratory Testing Machine method.

(a) The criteria for selecting the optimum bitumen content when using the GTM method of compaction are the same as used for the Marshall method and are as follows:

[1] Gyratory compaction at 690 kPa (100 psi), 1-degree, 30 revolutions shall use the mix design criteria contained in Sections 1 and 2 of table 2-7 for the 50-blow mix. Additionally, the mix shall have a gyratory stability index (GSI) equal to or less than 1.

Table 2-8
Computation of Optimum Asphalt Content[1]

Criteria	Percent
Peak of stability curve	4.3
Peak of unit-weight curve	4.5
4 percent voids in total mix (hot-mix asphalt)	4.8
75 percent total voids filled with asphalt (hot-mix asphalt)	4.9
Average	4.6

[1] Based on data in figure 2-7.

Table 2-9
Evaluation of Acceptability of Design Mix

Test Property	4.6 Percent Asphalt	Criteria for Acceptability
Flow 0.025 centimeters (0.01 inch)	11	Less than 16
Stability, kN (psi)	9.1 (2,050)	More than 8.0 (1,800)
Percent voids in total mix	4.3	3-5 percent (hot-mix asphalt)
Percent total voids filled with asphalt	72	70-80 percent (hot-mix asphalt)

[2] Gyratory compaction at 1,380 kPa (200 psi), 1-degree, 30 revolutions shall use the mix design criteria contained in Sections 1 and 2 of table 2-7 for the 75-blow mix. Additionally, the mix shall have a gyratory stability index (GSI) equal to or less than 1.

[3] Gyratory compaction at 1,655 kPa (240 psi), 1-degree, 60 revolutions shall use the mix design criteria combined in Sections 1 and 2 of table 2-7 or 2-8 for the 75-blow mix. Additionally, the mix shall have a GSI equal to or less than 1.

(b) If the optimum bitumen content selected by using the design parameters in Sections 1 and 2 of table 2-7 or table 2-8 does not produce a GSI equal to or less than 1, the asphalt content shall be reduced slightly to meet the GSI requirement.

(c) Laboratory densities, for field control, shall be determined in the field by GTM compaction or by Marshall compaction correlated to GTM compaction. The correlation will be made as part of the mix design effort and will result in establishing the required number of Marshall blows to achieve the same density as the GTM compactor provided there is no significant additional aggregate breakage with the hand hammer than with the GTM. The correlation may also be established by determining the difference in unit weight between the GTM compaction curve and the 75-blow Marshall compaction curve at the desired asphalt content. This difference can be added to the 75-blow field density for comparison with the GTM density. Laboratory densities for field control can then be determined using the Marshall hammer.

(d) If the 1,655 kPa (240 psi), 1-degree, 60 revolutions compaction effort is used for the mix design, greater field compaction effort will be required by the contractor to achieve the specified density. Also, the compaction effort to determine the field control density is likely to be greater than the standard 75-blow compaction effort.

(e) When two or more paving mixes have been investigated, the one used for field construction should be the most economical mix that satisfies all of the established criteria.

(4) The final evaluation of the design mixture involves a test for moisture susceptibility. The tensile strength ratio (TSR) of the mixture at the selected optimum will be performed according to ASTM D 4867. A TSR value of less than 75 percent will require the use of an antistrip additive in the mixture.

d Mixture control.

(1) The aggregates and asphalt must be fed through the plant at a constant rate to obtain efficient plant operation and to produce a mixture conforming to requirements. The approximate proportion of aggregates and asphalt to be fed into the plant is determined from the laboratory mix design. However, some adjustment in these proportions is usually required because gradations of the stockpile aggregates generally will not entirely duplicate the gradation of the aggregate samples obtained for laboratory design use; fines may be lost or manufactured while passing through the dryer; aggregate may degrade in the dryer; and material mixed at an asphalt plant is more uniformly coated with asphalt than materials mixed in the laboratory.

(2) To evaluate the quality of the material produced and to insure the best possible paving mixture, a reasonably complete plant laboratory is necessary. The laboratory should be located at the plant site and should contain about the same equipment listed in CRD C 649 and CRD C 650. Because of the capacity of most asphalt plants, at least two technicians should be assigned to conduct control tests; otherwise, all necessary testing cannot be completed in a timely manner.

(3) The heaviest demands on plant laboratory facilities occur at the initiation of plant production. For batch plants, preliminary computations may be made to determine the weight of material from each bin that will provide the gradation on which the mixture design is based. However, the gradation of the aggregate supplied by the plant may not precisely reproduce the desired gradation. The gradation of the plant-produced aggregate generally approximates the gradation used in design, within reasonable tolerances, if initial sampling for design purposes has been accomplished properly and if the plant is operated efficiently. Certain steps should be taken, however, to insure that satisfactory mixtures are produced from the beginning and throughout the period of plant production. Procedures subsequently outlined will insure that satisfactory paving mixes are produced.

(4) The aggregates obtained from the hot bins of batch plants sometimes cannot be proportioned to satisfactorily reproduce the gradation of the aggregate used in the laboratory design. It is then necessary to redesign the mix using plant-produced aggregates. Specimens are prepared and tested for the new design in the same manner as for the original design tests. Optimum asphalt content and acceptability of the mix produced by the plant are determined. Occasions may arise where the gradation of the plant-produced aggregate will differ from that on which the laboratory design was based to the extent that specified criteria cannot be met. Necessary steps should be taken to produce a asphalt mixture meeting the specification requirements. **Sufficient additional tests should be performed to establish optimum asphalt requirements and to insure that the mix will meet applicable criteria.**

(5) After the aggregate and asphalt binder qualities have been determined to be satisfactory and a proper mix design has been completed, the next step is to insure that the JMF is produced at the

asphalt plant. Several items must be routinely controlled during the production and laydown operation to provide an acceptable pavement. The mixture items include aggregate gradation, asphalt content, voids, and voids filled. To a great extent these items are interdependent on each other and they should be analyzed as a group. The laydown items include density, smoothness, and final grade. Departments of the Army and Air Force require that five of these items be measured and analyzed statistically. These items are air voids, asphalt content, density, smoothness, and final grade. *A new guide specification, CEGS-02749, that bases payment on air voids, density, grade, and smoothness is currently being developed. If this specification is used, the results of the items tested should be employed in the same manner as the current items.* When these items do not meet the specified requirements, the contract unit price is reduced or the mixture is rejected. Small projects of less than 1,000 metric tons of hot-mix can be constructed without the pay reduction clause for economic reasons.

(6) In order to evaluate the quality of a job, the work is divided into lots. Each lot is considered as a separate job and as such is evaluated solely on the test results for that lot. A lot should generally not exceed 2,000 metric tons (2,000 tons) of production or one normal day's production. The lot should be subdivided into four equal sublots, and a random sample should be taken from each sublot for evaluation of air voids, asphalt content, and density. The random sublot sample for these properties will include one sample of uncompacted asphalt mixture, one field core from a pavement joint area and one field core from the compacted hot-mix asphalt at least 0.3 meter (1-foot) away from the joint.

(7) The asphalt content and aggregate gradation will be determined from samples of the asphalt mix taken somewhere between the production and the laydown operation. The exact location of the sample is not important, but the sample should be taken from the same location each time (for example, truck at asphalt plant, truck, at laydown site, bituminous storage bin, or other locations). The same sample of asphalt mixture should be used for determining asphalt content and aggregate gradation.

(8) If a lot size equal to 1,000 metric tons (1,000 tons) is selected, a sample of asphalt mix will have to be taken for each 250 metric tons (250 tons) produced. Any approved method for locating random samples can be used. As an example, suppose that a random number is selected between 1 and 250 and is determined to be 200. This selection means that the 200th ton batched will be sampled.

(9) After the four aggregate gradations and asphalt contents are determined for a lot, these results are compared with the JMF and the absolute difference is determined. Suppose the design asphalt content is 5.5 percent and the four extracted asphalt contents are determined to be 5.2, 5.4, 5.5, and 5.8. The mean absolute deviation from the JMF is determined to be:

$$\textit{Mean absolute deviation} = \frac{0.3 + 0.1 + 0.0 + 0.3}{4} = 0.175$$

The same procedure is used to determine the mean absolute deviation for each sieve size for the aggregate gradation. After the mean absolute deviation is determined for the asphalt content and aggregate gradation of a lot, the maximum percent payment for that lot can be determined from the tables provided in the specification requirements.

(10) Density must be determined within the mat and at the joints between mats. One sample should be obtained in the mat and one in the joint for each sublot. The total linear length of joint constructed for a given lot will be divided into quarters and one random sample taken for each sublot. These sample locations can be determined in a similar way as that for aggregate gradation and asphalt content. All mat samples should be taken at least 0.3 meter (1 foot) from the edge of mat or joint. In order to determine sample locations in the mat, each sublot must be divided into grids. The number of

possible sampling locations will be approximately equal to the length in meters times 2 minus 1 times the width in meters time 2 minus (length in feet - 1 foot) 1 (width in feet - 1 foot).

(11) As an example, suppose that 1,000 metric tons (one lot) of hot-mix asphalt were placed in two adjacent lanes, one lane 2,000 meters long and the other 1,000 meters long. The joint length between the two lanes would be 1,000 meters; thus, one sample would be taken at random for each 250 meters of joint length to evaluate joint density. The total length of the two lanes would be 3,000 meters; therefore, one random sample should be taken from the mat for each 750 meters of hot-mix asphalt. The first 750 meters would have [750 x 2 - 1] x [3 x 2 - 1] possible sampling locations if a 3-meter-wide paver was used. (Possible sample locations are at 0.5 meter or 2 every meter intervals longitudinally and transversely and no closer than 0.5 meter from the edge.) Hence, there are 7,495 (1,499 x 5) possible sampling locations for each of the 4 cores to be taken from the mat. Suppose that the random number selected was 3,108. Divide 3,108 by 5 to get 621 with a remainder of 3 [0.6 x 5]. Hence, the sample should be taken 311 meters (621 ÷ 2 + 0.5, possible horizontal sample locations + 0.5 meter) from the origin and 2.0 meters (3 ÷ 2 + 0.5, possible transverse sample locations + 0.5 meter) from the edge (since the start point is 0.5 meter from the edge and 0.5 meter from the beginning). The random samples do not have to be precisely located, but it is important that the surface appearance does not affect the selection of sample locations.

(12) The average mat density and average joint density will each be expressed as a percentage of the laboratory density. The laboratory density for each lot will be the average density determined from at least two sets of samples representing the in-place material compacted in the laboratory. Suppose that the average laboratory density is 2,404 kilograms per cubic meter (150 pounds per cubic foot), the four mat samples have individual densities of 2.324 grams/centimeter^3, 2.356 grams/centimeter^3, 2.348 grams/centimeter^3, and 2.373 grams/centimeter^3, and the four joint samples have individual densities of 2,311 grams/centimeter^3, 2.324 grams/centimeter^3, 2.343 grams/centimeter^3, and 2.325 grams/centimeter^3. Based on these results the average mat density would be:

$$Mat\ density = \frac{2.324 + 2.356 + 2.348 + 2.373}{4(2.404)} = 97.8\ percent$$

and the average joint density would be

$$Joint\ density = \frac{2.311 + 2.324 + 2.343 + 2.325}{4(2.404)} = 96.8\ percent$$

The average density in the mat and the average density in the joint can be used along with the tables in the specifications to determine the maximum percent payment for the lot of material being evaluated.

(13) The surface of the completed pavement will be evaluated on a systematic basis to determine the acceptability of grade and smoothness. The results will be compared with the specification requirements to determine percent payment for grade and smoothness.

(14) In order to properly evaluate quality control of a mixture and maintain up-to-date records of test results, control charts should be maintained. It is recommended that the control charts be plotted for each sieve size specified in the gradation requirements, asphalt content, laboratory density, stability, flow, voids in total mixture, voids filled with asphalt, mat density, and joint density. A plot should be made of individual values and for the running average of four samples.

(15) An example of the use of control charts follows. Assume the density results shown in table 2-10 were obtained from the in-place mat.

Table 2-10
Lot Density as a Percent of Laboratory Density

Lot 1	Lot 2	Lot 3	Lot 4	Lot 5
95.2	98.4	99.5	98.1	100.0
96.4	99.1	98.0	96.8	99.1
97.8	97.3	97.5	99.8	98.3
96.6	98.1	98.3	98.6	98.9
Average				
96.5	98.2	98.3	98.3	99.1

(16) Figure 2-8 shows the control charts for mat density. The first test result obtained is plotted in figure 2-8a. Note that this measurement falls below the desired range. At this point, it should have been concluded that the process was out of control; thus, the operation should be stopped until the cause of the deficiency is identified and corrected.

(17) The second, third, and fourth samples were obtained after corrections were made to the process and found to be higher but still below the desired range. At this point, the weight of the rubber-tired roller used in compacting the mat was increased from 20 to 25 metric tons (20 to 25 tons), and the tire pressure was increased from 480 kPa (70 psi) to 620 kPa (90 psi). After these changes, the density results were generally within the desired range.

(18) The moving average is determined for the last four samples tested (figure 2-8b). Plotting the moving average smooths out the plot of individual values and allows trends to be spotted earlier.

e. Significance of changes in mixture properties.

(1) General. As a general rule, the flow and stability values are obtainable quickly and are reasonably reliable indicators of the consistency of the plant-produced mix. A measurable increase in flow value generally indicates that either the gradation of the mix has changed sufficiently to require a revision in the optimum asphalt content for the mix, or too much asphalt is being incorporated in the mix. A review of the control charts should indicate the problem. Substantial changes in stability or void content also may serve as an indication of these factors. Mix proportions shall be adjusted whenever any test property consistently falls outside of the specified tolerances. In the case of batch plants, the use of faulty scales and the failure of the operator to accurately weigh the required proportions of materials are common causes for paving-mixture deficiencies. Improper weighing or faulty scales may be detected readily and corrective measures taken by maintaining a close check of load weights. Figure 2-9 lists other probable causes of paving-mixture deficiencies.

(2) Extraction tests.

(a) Representative samples of paving mixture should be obtained for extraction tests to determine the percentage of bitumen in the mix and the gradation of the extracted aggregates. Extraction tests shall be made according to ASTM D 2172. Sieve analyses of recovered aggregates shall be determined according to D 5444.

(b) Nuclear gages are currently being used to determine asphalt content in accordance with ASTM D 4125. After the nuclear gage is calibrated, it can be used to check the asphalt content of a mixture in a few minutes. Results indicate that this procedure is more accurate than the conventional extraction test, but the aggregate gradation is not determined by this test. Therefore, extraction tests must also be conducted to determine the aggregate gradation.

(c) Asphalt content can be determined with the Ignition Method in accordance with ASTM PS 090. The asphalt content obtained may be more accurate than that obtained by the conventional extraction method. The aggregates remaining after the asphalt binder is burned off may be used for gradation purposes; however, there is a correction factor that must be determined for each type of aggregate and gradation used.

(3) Hot-bin gradations. Hot-bin gradation tests should be made on the aggregate in the fine bin at least twice daily during operation. Hot-bin gradations shall be determined on all bins in conjunction with sampling of the pavement mixture. Washed sieve analyses shall be determined initially.

(4) Construction control. Well-designed mixes can be compacted by adequate field rolling to about 98 percent or greater of the density obtained by compacting specimens with previously specified laboratory procedures. Asphalt intermediate, base course, or surface course mixes shall be rolled to the density specified in applicable Department of the Army and Air Force guide specifications.

(5) Pavement sampling. Samples for determining pavement density and thickness may be taken either with a coring machine (at least 100 millimeters, (4 inches) nominal diameter) or by cutting out a section of pavement at least 100 millimeters (4 inches) square with a concrete saw. These samples should include the entire thickness of the pavement. Density samples of each day's production should be taken and delivered to the project laboratory by noon of the following day, and the density determinations made by the end of the day. Any changes in placing technique necessary to obtain the required density can be made before a large amount of pavement is placed.

(6) Testing pavement samples.

(a) Pavement samples shall be prepared for testing by carefully removing all particles of base material or other foreign matter. All broken or damaged edges of sawed samples for density tests shall be carefully trimmed from the sample. Thickness measurements shall be made before separating the sample into layers. A sample consisting of an intermediate course and surface course shall be split at the interface of these layers before testing. The density of the sawed samples shall be determined by weighing in air and in water as previously described. Samples from which density measurements are desired shall be discarded if damage is apparent. Additional samples will be taken from the same sublot.

(b) Nuclear gages are currently being used to check density of hot-mix asphalt. This method is fast, but the results are often questionable. Some factors which affect the results of density measurements with the nuclear gage are thickness of asphalt mixture, density of material below asphalt mixture, and smoothness at test location. The nuclear gage is useful for developing roller patterns, but density tests for acceptance should be conducted by removing samples from the pavement and weighing in air and water.

(7) Density data. Density data obtained from specimens in the manner previously described will be compared with the average laboratory density determined for the same lot.

(8) Pavement imperfections and probable causes. Many types of pavement imperfections result from improper laying and rolling operations as well as from improper mixes or faulty plant operation. These imperfections can be controlled only by proper inspection. Figure 2-10 presents the

pavement imperfections that may result from laying unsatisfactory mixes or using faulty construction procedures.

5. POROUS FRICTION COURSE.

a. General. A porous friction course (PFC) is an open-graded, free-draining asphalt paving mixture that can be placed on an existing pavement to minimize hydroplaning and to improve skid resistance in wet weather. This surface should not be used for low speed applications or in areas subjected to tank traffic (especially tank turning areas). The thickness of the finished course can vary from approximately 19 millimeters (3/4 inch) to 25 millimeters (1 inch). A PFC has a coarse surface texture and is sufficiently porous to permit drainage of water internally as well as along the surface. A combination of water pressure relief through the internal and surface voids and the rough surface texture promote tire-to-aggregate contact. PFC paving mixtures are produced in hot-mix asphalt plants and placed with conventional asphalt paving machines. They should be placed on pavements which are in good condition. A leveling course may be required to achieve the desired conditions before construction of the PFC.

b. Materials.

(1) Aggregates. High quality aggregates are required for PFC's with a maximum LA abrasion loss (ASTM C 131) of 25 percent and 40 percent for high and low tire pressure loadings, respectively. A crushed aggregate is required and shall have a minimum of 90 percent by total weight of aggregate with one crushed face and 70 percent with two crushed faces. Antistrip agents shall be specified when required. The Air Force currently requires an antistripping agent in all PFC and the underlying hot-mix asphalt layer regardless of the results of the immersion compression test. Table 2-11 presents the aggregate gradation requirements for porous friction courses.

Table 2-11
Aggregate Gradation for PFC's

	Percent Passing by Weight of Total Aggregates	
Sieve Designation (Square Openings)	Gradation "A" 19 mm (3/4-inch) Maximum (Compacted Nominal Thickness, 25 mm, 1 inch)	Gradation "B" 12.5 mm (1/2-inch) Maximum (Compacted Nominal Thickness, 19 mm, 3/4 inch)
19 mm (3/4 inch)	100	100
12.7 mm (1/2 inch)	70-100	100
9.5 mm (3/8 inch)	35-75	80-100
4.75 mm (No. 4)	25-40	25-40
2.36 mm (No. 8)	10-20	10-20
600 m (No. 30)	3-10	3-10
75 m (No. 200)	0-5	0-5

(2) Asphalt cement. Test requirements for asphalt cements are outlined in the appropriate specification (ASTM D 946, D 3381, or AASHTO MP-1). The asphalt type should be selected as indicated in paragraph *asphalt cement selection by temperature region* of this chapter. Several PFC's with latex rubber added to the asphalt have been constructed. The addition of a latex rubber additive

should improve the ability of the asphalt to hold the aggregate in place and reduce oxidation deterioration in the porous mat. When economically available, the use of a latex rubber modified binder should be specified.

c. Mixture design.

(1) Proportioning of aggregates. The proper aggregate gradation should be selected from table 2-11.

(2) Asphalt content. The asphalt content of PFC's is expressed as a percentage of the total mix by weight. A surface area constant, K_c, as described in the centrifuge kerosene equivalent (CKE) test (ASTM D 5148), is used to determine the optimum asphalt content. The K_c value is used in the relation $2K_c + 4.0$ to determine the Estimate of Asphalt (EOA). This asphalt content is valid for aggregates with an apparent specific gravity in the range of 2.60 to 2.80 and with a water absorption less than 2.50 percent when tested by ASTM C 127 for coarse aggregate and ASTM C 128 for fine aggregate. A slight increase in asphalt content (up to 0.5 percent) is required when the absorption is greater than 2.50 percent. The EOA is inversely proportional to the specific gravity of the aggregate used and adjustments must be made when the specific gravity is outside of the 2.60 to 2.80 range.

(a) K_c factor. The K_c factor indicates the relative particle roughness and surface capacity based on porosity of the aggregate to be used for the PFC. The K_c factor is determined from the percent of SAE 10 oil retained, which represents the total effect of the coarse aggregate's absorptive properties and surface roughness. The K_c factor is determined from that portion of the aggregate sample which passes the 9.5 millimeter (3/8-inch) sieve and is retained on the 4.75 millimeter (No. 4) sieve using the procedure as described in ASTM D 5148. If the specific gravity for the aggregate is greater than 2.70 or less than 2.60, apply a correction to oil retained, using the formula given in ASTM D 5148. No correction need be applied for asphalt viscosity.

(3) Mixing temperature. The mixing temperature shall be chosen to provide an asphalt viscosity of 275 ± 25 centistokes. To obtain this temperature, the temperature-viscosity relationship must be evaluated for the type of asphalt selected at a minimum of three temperatures (ASTM D 2170 and ASTM D 2171). Plotting this information on a graph with temperature versus log viscosity will normally result in a straight-line relationship, and the temperature for the correct viscosity can be chosen from the graph.

d. Plant control.

(1) Plant laboratory. A plant laboratory is needed to insure that the aggregate is properly graded and that the mix contains the prescribed percentage of asphalt binder. The laboratory should be located at the plant to minimize the time between production and testing. If the laboratory is not located at the plant, testing could fall behind and cause considerable quantities of unsatisfactory mix to be produced.

(2) Sieve analysis. All sieve analyses should be conducted by the method described in ASTM C 136. Recommended sieve sizes for plant sieve analysis are: 19 millimeter (3/4 inch), 12.5 millimeter (1/2 inch), 9.5 millimeter (3/8 inch), 4.75 millimeter (No. 4), 2.36 millimeter (No. 8), 600 m (No. 30), and 75 m (No. 200). For batch-mix plants, sieve analyses shall be made on material from each plant hot bin. Samples for these sieve analyses shall be obtained after a few tons of aggregate have been processed through the dryer and screens in order that the sample will be representative. For drum mixers, the sieve analysis must be made directly from the cold feeds. Final mix proportions may be determined on the basis of these analyses.

(3) Extraction tests. Extraction tests shall be made in accordance with ASTM D 2172 using trichloroethylene as the extraction solvent. A nuclear gage can be used to determine the asphalt content, when tested in accordance with ASTM D 4125, provided it is calibrated. The asphalt content can also be determined by the ignition method in accordance with ASTM PS 090. Sieve analysis of recovered aggregates shall follow procedures specified in ASTM D 5444.

(4) Mix proportions. Mix proportions shall be adjusted whenever tests indicate that specified tolerances are not being met. In the case of batch plants, faulty scales, and failure of the operator to accurately weight the required proportions of materials are common causes for mixture deficiencies. Improper weighing or faulty scales may be detected readily and corrective measures taken by maintaining a close check of load weights. Figure 2-9 presents other probable causes of mixture deficiencies due to improper plant operations.

(5) Controlling plant production. The plant inspector should obtain a sample of the PFC mix after the plant has been in production about 30 minutes. The sample should be tested as rapidly as possible for compliance with gradation and asphalt content requirements.

e. Construction.

(1) Pavement control. A PFC pavement has no density requirements. A characteristic of this overlay is its rapid cooling. If minimum asphalt drainage is desired, the roller should closely follow the paver to initially set the PFC so that asphalt drainage is minimized. If more drainage is desired, the roller should wait longer before rolling the PFC. Rich spots will tend to drain if rolling is delayed. Two passes with a 10-metric ton (10 ton) steel-wheel roller should be satisfactory to properly seat the PFC mix.

(2) Pavement sampling. Samples for determining thickness (ASTM D 979) may be taken either with a coring machine or by cutting out a sample of pavement at least 100 millimeters (4 inches) square with a concrete saw. The sample should include the entire thickness of the PFC.

(3) Storage silos. Storage of PFC mix should be avoided whenever possible; the maximum allowable storage time under any circumstance should not exceed 15 minutes. Excessive storage time will allow the asphalt to drain, causing segregation of the mixture. Proper coordination between the plant and the laydown operations will eliminate the need for extended storage.

(4) Pavement operations under normal conditions. The Army and Air Force guide specifications do not permit placement of PFC when the surface temperature of the existing pavement is below 60°F. The most important consideration is whether the contractor can apply the necessary rolling before the mixture becomes too cool to be properly seated. Generally, all rolling should be performed before the PFC mixture cools to 80°C (175°F). A PFC will cool quickly because of the thin layer of material and high void content in the thin PFC layer. Thus, judgment should be used in the application of the temperature limitations in the guide specifications to avoid shutting down operations during periods when satisfactory final pavement properties could be obtained.

6. STONE MATRIX ASPHALT.

a. GENERAL. Stone matrix asphalt (SMA) is a mixture of aggregate, mineral filler, asphalt cement, and a stabilizer (cellulose or mineral fiber and/or modified asphalt). SMA is designed to prevent rutting and abrasion even under high loads and/or high tire pressures. SMA mixtures depend on aggregate to aggregate contact to support traffic loads thereby requiring a large percentage of coarse aggregate. Excess fine aggregate or too much mastic can prevent the coarse aggregate particles from obtaining full contact and therefore lower the mixture's resistance to rutting. The high void content of the mix is occupied by fine aggregate, mineral filler, asphalt cement, and a stabilizer (polymer, cellulose, or mineral fiber) which forms a mastic portion of the SMA mixture. This mastic stabilizes the coarse aggregate and reduces the final air voids in the SMA to about 3 to 4 percent. SMA is comparable to hot-mix asphalt in regards to structural design, mix design, and construction. SMA originated in Europe and has recently been placed by state and federal agencies on projects throughout the country. The design and construction of SMA pavements are described in this appendix.

b. MATERIALS.

(1) Aggregates. The gradation used for SMA is gap-graded for the coarse aggregate retained on the 4.75 millimeter (No. 4) sieve. This coarse aggregate will make up from 72 to 80 percent of the aggregate in the mix. The coarse aggregate should be 100 percent passing the 19 millimeter (3/4-inch) sieve. The amount of the fine material passing the 75 m (No. 200) sieve will be from 8 to 10 percent. Table 2-12 lists the gradation as recommended by the FHWA. This gradation is based on the recommendations of a technical working group that reviewed the performance of SMA mixtures in place. Table 2-13 lists the recommended coarse and fine aggregate properties for SMA.

Table 2-12
SMA Gradation Guideline (After NAPA 1994)

Sieve Size	Percent Passing
19 mm (3/4 inch)	100
12.7 mm (1/2 inch)	85-95
9.5 mm (3/8 inch)	75 maximum
4.75 mm (No. 4)	20-28
2.36 mm (No. 8)	16-24
600 m (No. 30)	12-16
300 m (No. 50)	12-15
75 m (No. 200)	8-10

(2) Filler. As presented in table D1 for SMA mixtures, the recommended amount of aggregate filler (dust) passing the 75 m (No. 200) sieve is 8 to 10 percent. This amount of filler in the SMA is higher than that usually found in dense graded hot mix asphalt (HMA). The amount of filler is important in terms of obtaining the desired mixture air voids and in affecting the optimum asphalt content. The SMA asphalt content is sensitive to the aggregate fines and filler content. In Europe, SMA mixtures commonly employ a filler-to-asphalt ratio of approximately 1.5. In contrast, conventional dense graded hot mix in the United States typically recommend a filler-to-asphalt ratio of less than 1.2. A well-graded filler with no more than 20 percent of the total filler smaller than 20 microns is required. Commercial fillers are added by mineral filler feeder systems. Fly ash, limestone dust, and other types of rock dust have been used successfully as fillers for SMA applications.

(3) Stabilizer.

(a) General. There is a tendency for the asphalt binder to drain from the aggregate during storage, transportation, or placement because of the high asphalt content in the mix, the thick asphalt coating on the coarse aggregate, and the high voids in the aggregate skeleton. In order to reduce this drainage potential, stabilizers are used to stiffen the mastic or to increase the asphalt binder viscosity. These stabilizers can be categorized into two groups: either (cellulose fibers or mineral fiber) or

Table 2-13
Recommended SMA Coarse and Fine Aggregate Properties (After NAPA 1994)

Property	Specifications	Requirement
Coarse Aggregate:		
Los Angles abrasion, %	ASTM C 131, AASHTO T 96	30 max.
Flat and elongated, + No. 4	ASTM D 4791	
3 to 1 (length to thickness), %		20 max.
5 to 1 (length to thickness), %		5 max.
Fractured faces, + No. 4		
One fractured face, %		100 min.
Two fractured faces, %		90 min.
Absorption, %	ASTM C 127, AASHTO T 85	2 max.
Coarse and fine durability index	ASTM D 3744, AASHTO T 210	40 min.
Sulfate soundness loss, 5 cycles	AASHTO T 104, ASTM D 3744	
Sodium sulfate, %		15 max.
or Magnesium sulfate, %		20 max.
Fine Aggregate:		
Crushed manufactured fines, %		100 min.
Sulfate soundness loss, 5 cycles		
Sodium sulfate, %		15 max.
Liquid limit	AASHTO T 89, ASTM D 4318	25 max.

polymers. A large percentage of SMA has been placed with a combination of fibers and asphalt polymer.

(b) Fiber stabilizers. Tables 2-14 and 2-15 provide the requirements and test procedures to be used with cellulose and mineral fibers, respectively. The dosage rates normally used for cellulose fibers is 0.3 percent by weight of the total mix and for mineral fibers is 0.4 percent by weight of the total mix. The recommended tolerance for the fibers is approximately 10 percent of the required fiber weight.

(c) Asphalt-polymer stabilizers. SMA mixtures have been placed using a polymer to modify the asphalt cement and stabilize the mixture so that fibers are not required. There have also been instances where a polymer and a fiber have been used in conjunction to stabilize SMA mixtures. Manufacturer's design and construction recommendations should be followed as the standard SMA guidelines may not be applicable for asphalt-polymer stabilizers.

(4) Asphalt. The asphalt cement shall comply with the requirements of ASTM D 946, ASTM D 3381, or AASHTO MP-1. The asphalt cement used shall be the grade normally used in the area. The temperature of the asphalt cement at the time of mixing shall be that required to achieve a viscosity of 170 ± 20 centistokes. Where a polymer modified asphalt cement is used, manufacturer's recommendations for mixing temperature shall be followed.

c. MIXTURE DESIGN. The optimum asphalt content shall be determined with procedures similar to those outlined in Hot-Mix Asphalt. Table 2-16 contains the recommended mix design requirements

Table 2-14
Properties of Cellulose Fibers (After NAPA 1994)

Properties	Requirement
Sieve Analysis	
Method A	
Alpine Sieve[1] Analysis	
Fiber length	6 mm (0.25 in.) (max.)
Passing 150 m (No. 100) sieve	70% (± 10%)
Method B	
Mesh Screen[2] Analysis	
Fiber length	6 mm (0.25 in.) (max.)
Passing 850 m (No. 20) sieve	85% (± 10%)
425 m (No. 40) sieve	65% (± 10%)
106 m (No. 140) sieve	30% (± 10%)
Ash Content[3]	18% (± 5%) non-volatiles
pH[4]	7.5 (± 1.0)
Oil Absorption[5]	5.0 (± 1.0) (times fiber weight)
Moisture Content[6]	< 5% (by weight)

[1] Method A, Alpine Sieve Analysis. This test is performed using an Alpine air jet sieve (Type 200 LS). A representative 5 gram sample of fiber is sieved for 14 minutes at a controlled vacuum of 75 kPa (11 psi). The portion remaining on the screen is weighed.
[2] Method B, Mesh Screen Analysis. This test is performed using standard 850, 425, 250, 180, 150, 106 m (No. 20, 40, 60, 80, 100, 140) sieves, nylon brushes, and a shaker. A representative 10 gram sample of fiber is sieved using a shaker and two nylon brushes on each screen. The amount retained on each sieve is weighed and the percentage passing calculated. Repeatability of this method is suspect and needs to be verified.
[3] Ash Content. A representative 2-3 gram sample of fiber is placed in a tared crucible and heated between 595° and 650°C (1100° and 1200°F) for not less than 2 hours. The crucible and ash are cooled in a desiccator and reweighed.
[4] pH Test. Five grams of fiber is added to 100 ml of distilled water, stirred, and let sit for 30 minutes. The pH is determined with a probe calibrated with pH 7.0 buffer.
[5] Oil Absorption Test. Five grams of fiber is accurately weighed and suspended in an excess of mineral spirits for not less than 5 minutes to ensure total saturation. It is then placed in a screen mesh strainer (approximately 0.5 square millimeter hole size) and shaken on a wrist action shaker for 10 minutes (approximately 1 1/4 inch motion at 240 shakes/minute). The shaken mass is then transferred without touching, to a tared container and weighed. Results are reported as the amount (number of times its own weight) the fibers are able to absorb.
[6] Moisture Content. Ten grams of fiber is weighed and placed in a 121°C (250°F) forced air oven for 2 hours. The sample is then reweighed immediately upon removal from the oven.

Table 2-15
Properties of Mineral Fibers[1] (After NAPA 1994)

Properties	Requirement
Sieve Analysis	
Fiber length[2]	6 mm (.25 in.) max. mean text value
Thickness[3]	5 m (0.0002 in.) max. mean test value
Shot content[4]	
250 m (No. 60) sieve	95 percent passing (min.)
63 m (No. 230)	65 percent passing (min.)

[1] The European experience and development of the above criteria are based on the use of basalt mineral fibers.
[2] The fiber length is determined according to the Bauer McNett fractionation.
[3] The fiber diameter is determined by measuring at least 200 fibers in a phase contract microscope.
[4] Shot content is a measure of non-fibrous material. The shot content is determined on vibrating sieves. Two sieves, No. 60 and No. 230, are typically utilized; for additional information see ASTM C612.

Table 2-16
SMA Mix Design Requirements (After NAPA 1995)

Design Parameter	Value
Marshall[1]	
(1) VTM, percent[2]	3-4
(2) Asphalt content, percent[3]	6.0 min.
(3) VMA[4]	17 min.
(4) Stability, N (lbs)	6200 (1400) suggested minimum
(5) Flow, 0.25 mm (0.01 inch)	8-16
(6) Compaction, number of blows at each side of test specimen	50
(7) Draindown, percent[5]	0.3 max. (1 hour reading)

[1] Marshall procedures are in accordance with AASHTO T 245 (ASTM D 1559).
[2] VTM (voids in total mix or air voids) (see figure 2-12) is based on AASHTO T 166, T 209 (ASTM D 2041), and T 269 (ASTM D 3203). Maximum density will be based on AASHTO T 209 (ASTM D 2041).
[3] Based on weight of total mix.
[4] VMA (see Asphalt Institute Manual Series No. 2 (MS-2).
[5] NCAT SMA asphalt draindown test (see paragraph 2.7,c, (1))

for SMA. These requirements are based on work done with the Federal Highway Administration (FHWA) and others and published by the National Asphalt Pavement Association (NAPA).

(1) SMA asphalt draindown test. For the purpose of this test method, draindown is considered to be that portion of the asphalt cement which separates itself from the sample as a whole and is deposited outside the wire basket during the test. (Note, any noticeable aggregate particles that

are deposited outside the basket should be added back into the mixture and not counted as draindown. Alternatively, the test should be rerun.) This test method can be used to determine whether the amount of draindown measured for a given SMA mixture is within acceptable levels. It also provides an evaluation of the draindown potential of an SMA mixture produced in the field.

(a) Scope. This test method covers the determination of the amount of draindown in an uncompacted SMA mixture sample when the sample is held at elevated temperatures comparable to those encountered during the production, storage, transport, and placement of the mixture.

(b) Summary of Method. A sample of the SMA mixture to be tested is prepared in the laboratory or obtained from field production. The sample is placed in a wire basket which is positioned on a pre-weighed paper plate. The sample, basket, and plate are placed in a forced air oven for one hour at a preselected temperature. At the end of one hour, the basket containing the sample is removed from the oven along with the paper plate and the paper plate is weighed to determine the amount of draindown that occurred.

(c) Equipment.

[1] Oven, capable of maintaining the temperature in a range from 120°-175°C (250°-350°F). The oven should maintain the set temperature to within ± 2°C (± 3.6°F).

[2] Paper plates of appropriate size. The paper plates used should be of appropriate durability to withstand the oven temperatures.

[3] Standard cylindrical shaped basket meeting the dimensions shown in figure 2-11. The basket shall be constructed using standard 6.3 millimeter (0.25 inch) sieve cloth as specified in ASTM E 11.

[4] Spatulas, trowels, mixer, and bowls as needed.

[5] Balance accurate to 0.1 gram.

(d) Sample preparation. For each mixture tested, the draindown characteristics should be determined at the anticipated plant production temperature. Duplicate samples should be tested.

[1] Laboratory sample preparation. Dry the aggregate to constant mass and sieve it into appropriate size fractions as indicated in ASTM D 1559. Determine the anticipated plant production temperature or select a mixing temperature in accordance with ASTM D 1559. The asphalt cement supplier's recommendations should be sought when using modified asphalt cement. Weigh into separate pans for each test sample the amount of each size fraction required to produce completed SMA mixture samples having a mass of 1200 grams. The aggregate fractions should be combined such that the resulting aggregate blend has the same gradations as the job mix formula. Place the aggregate samples in an oven and heat to a temperature not to exceed the mixing temperature established above by more than approximately 28°C (50°F). Heat the asphalt cement to the established mixing temperature. Place the heated aggregate in the mixing bowl. When a stabilizer is used it should be added as directed by the supplier. Some types of stabilizers such as fibers or some polymers must be added directly to the aggregate prior to mixing with the asphalt cement. Other types must be added directly to the asphalt cement prior to blending with the aggregate. The aggregates and any other components should be thoroughly mixed together. Form a crater in the aggregate blend and add the required amount of asphalt. The amount of asphalt shall be such that the final sample has the same asphalt content as the job-mix-formula. At this point, the temperature of the aggregate and asphalt cement shall be within the limits of the mixing temperature. Using a spatula (if mixing by hand) or a

mixer, mix the aggregate (and stabilizer) and asphalt cement quickly until the aggregate is thoroughly coated.

[2] Plant produced samples. For plant produced samples, duplicate samples should be tested at the plant production temperature. Samples may be obtained during plant production by sampling the mixture at the trucks prior to the mixture leaving the plant. Samples obtained during actual production should be reduced to the proper test sample size by the quartering method.

(e) Procedure. The following procedure can be used for both laboratory and plant produced SMA mixtures.

[1] Transfer the uncompacted SMA mixture sample to a tared wire basket described in figure 2-17. Place the entire sample in the wire basket. Do not consolidate or otherwise disturb the sample after transfer to the basket. Determine the mass of the sample to the nearest 0.1 gram.

[2] Determine the record the mass of a paper plate to the nearest 0.1 gram. Place the basket on the paper plate the place the assembly into the oven at the temperature as determined in paragraph [3] for 1 hour ± 1 minute.

[3] After the sample has been in the oven for 1 hour, remove the basket and paper plate. Determine and record the mass of the paper plate to the nearest 0.1 gram.

(f) Calculations. Calculate the percent of mixture which drained by subtracting the initial paper plate mass from the final paper plate mass and divide this by the initial total sample mass. Multiply the result by 100 to obtain a percentage.

(g) Report. Report the average percent drainage at the test temperature.

(2) Job-mix formula requirements. It is the contractor's responsibility to ensure that, in addition to the aggregate gradation requirements, the produced material will provide an asphalt mixture that conforms to the applicable design parameters listed in table 2-16. The contractor shall submit in writing the proposed job-mix formula (JMF) for approval including the following:

(a) The percentage (in units of 1 percent) of aggregate passing each specified sieve (except the 75 m (No. 200) sieve), based on the total dry weight of aggregate as determined by ASTM C-117 and C-136.

(b) The percentage (in units of 1/10th of 1 percent) of aggregate passing the 75 m (No. 200) sieve, based on the dry weight of aggregate as determined by ASTM C-117.

(c) The percentage (in units of 1/10th of 1 percent) of aggregate finer than 0.020 millimeter in size, based on the dry weight of aggregate as determined by ASTM D 422.

(d) The percentage (in units of 1/10th of 1 percent) of asphalt material to be added, based upon the total weight of mixture.

(e) The proposed percentage of each stockpile to be used, the average gradation of each stockpile, and the proposed target value for each sieve size. The target values and the combined average gradation of all the stockpiles when combined in accordance with the contractor's recommended stockpile combinations shall be within the gradation ranges for the designated grading in table D1.

(f) The type and amount by weight of mix of stabilizer additive to be used.

(g) Additional information required as part of the JMF shall include the following:

[1] The material sources for all ingredients.

[2] The material properties, as listed, for all ingredients:

[a] The specific gravities of the individual aggregates and asphalt.

[b] The L.A. Abrasion of the aggregates.

[c] The sand equivalent value of the combined aggregate.

[d] The flat and elongated percent of the coarse aggregate (3 to 1 and 5 to 1 ratios), retained above the 4.75 mm (No. 4) sieve.

[e] The plastic index of the aggregate.

[f] The absorption of the aggregates.

[g] The asphalt temperature/viscosity curves.

[3] The mixing temperature.

[4] The mix design test property values and curves used to develop the job mix in accordance with those provided for hot-mix asphalt in this chapter and also in the Asphalt Institute's Manual Series No. 2 (MS-2).

[5] The plot of the gradation on the FHWA 0.45 power gradation chart.

d. MIXING PLANTS. SMA has been mixed in both batch and drum mix plants. These plants can be utilized with none or minor adaptations required to mix the SMA components.

(1) Batch plants. The mineral filler will be added directly into the weigh hopper. Most batch plants have an existing mechanism for accomplishing this. However, special attention is required to assure accurate proportioning of the relatively large amounts of filler required for SMA. The fiber is also added directly into the weigh hopper and should occur when the hot aggregate is also being placed into the hopper. An alternative method of adding the fibers directly to the pugmill as the hot aggregates are added has also been used successfully.

(2) Drum-mix plants. The mineral filler will be added directly into the drum mixer. Special attention is required to assure accurate proportioning of the relatively large amounts of filler added. The fiber is also added directly into the drum mixer. A separate feeding system is usually employed especially in the case of loose fibers. These fibers are added to the aggregates far enough down the drum to avoid direct contact with the burner flame.

(3) Mixing time. The time required to mix SMA is usually greater than dense-graded hot-mix asphalt. For batch plants the dry-mixing time will be increased from 5 to 15 seconds and wet-mixing will be increased at least 5 seconds for cellulose fibers and up to 5 seconds for mineral fibers.

(4) Storage. Temporary (less than 1 hour) storage of SMA in surge bins will be used only for balanced production capacity. Storage in heated and insulated storage bins should be limited to 4 hours unless laboratory testing indicates additional time is acceptable. Acceptability must be based on no adverse changes in binder properties and excessive draindown not occurring. No mixture shall be stored overnight.

e. TEST SECTION. The construction of a test section is important to allow examination of the contractor's mixing and placement procedures. This is especially true if the contractor has not had experience in mixing or placing SMA.

f. PLACEMENT.

(1) Equipment. The trucks, pavers, distributors, and other general equipment are the same as those used for any asphalt concrete construction. Only steel-wheel rollers are used for SMA. Rubber-tire rollers are not used for SMA. Vibratory rollers can be used but care must be taken to prevent breakdown (fracture) of the aggregate.

(2) Surface preparation. The surface shall be cleaned of all loose or deleterious material. A tack coat shall be applied as described in paragraph *TACK COAT* in chapter *SPRAY APPLICATIONS*. The atmospheric temperature shall be a minimum of 7°C (45°F) and rising at the time of placement.

(3) Paving. The SMA mixture, when delivered to the paver, shall be a minimum temperature equal to the laboratory compaction temperature as determined in ASTM D 1559.

(4) Compaction. The SMA shall be compacted to a minimum of 94 percent of maximum theoretical density. Rolling shall be accomplished with steel-wheel rollers. Vibratory rollers can be used provided the aggregate is not crushed. Rubber-tire rollers will not perform well with SMA due to the high amounts of asphalt cement in the mixture causing asphalt build up on the wheels. Rolling should continue until the required density is obtained. This is usually controlled through the use of a nuclear density gage. Due to the large amount of binder coating the aggregate particles it is important that the roller drums be properly moistened with water containing small amounts of detergent to prevent adhesion. Traffic should remain off the SMA surface until it has cooled below a minimum of 60°C (140°F). Flooding with water from a truck after the completion of all rolling has been used to increase the rate of cooling to allow for earlier trafficking.

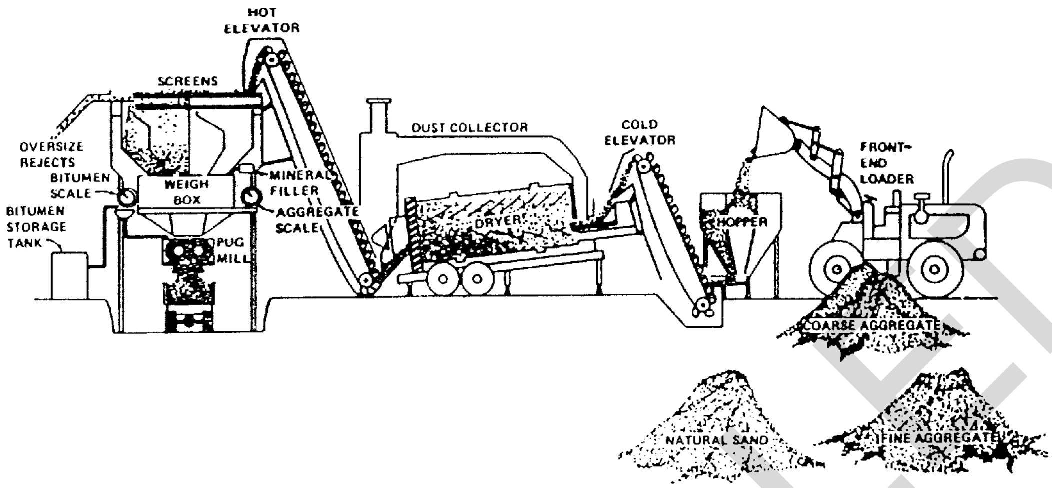

Figure 2-1 Batch plant

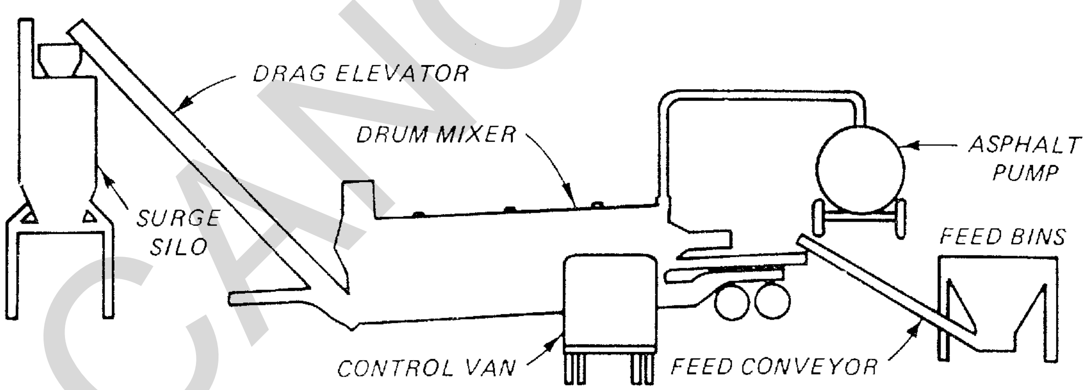

Figure 2-2 Drum mixer

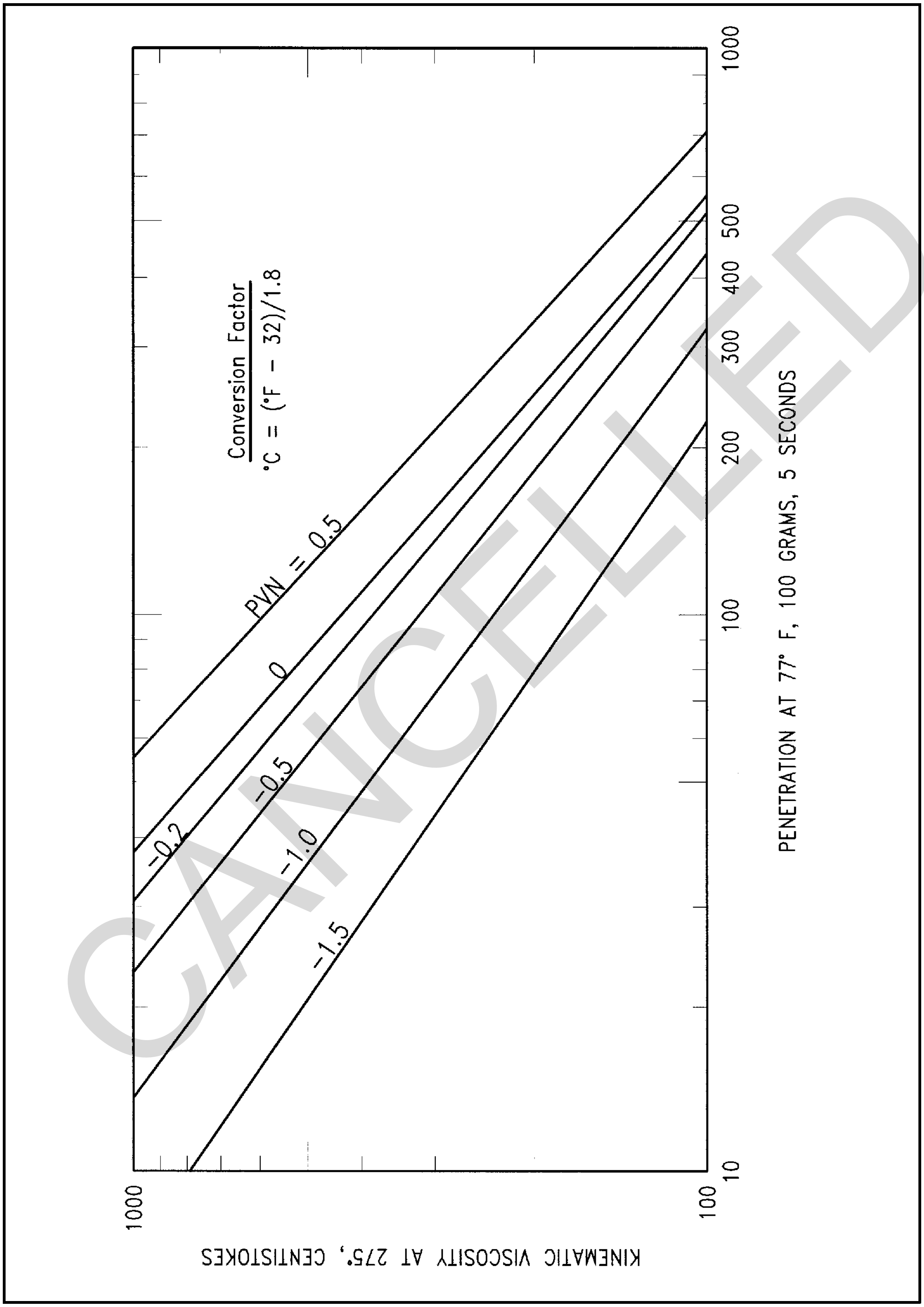

Figure 2-3 Pen-Vis numbers of asphalt cement

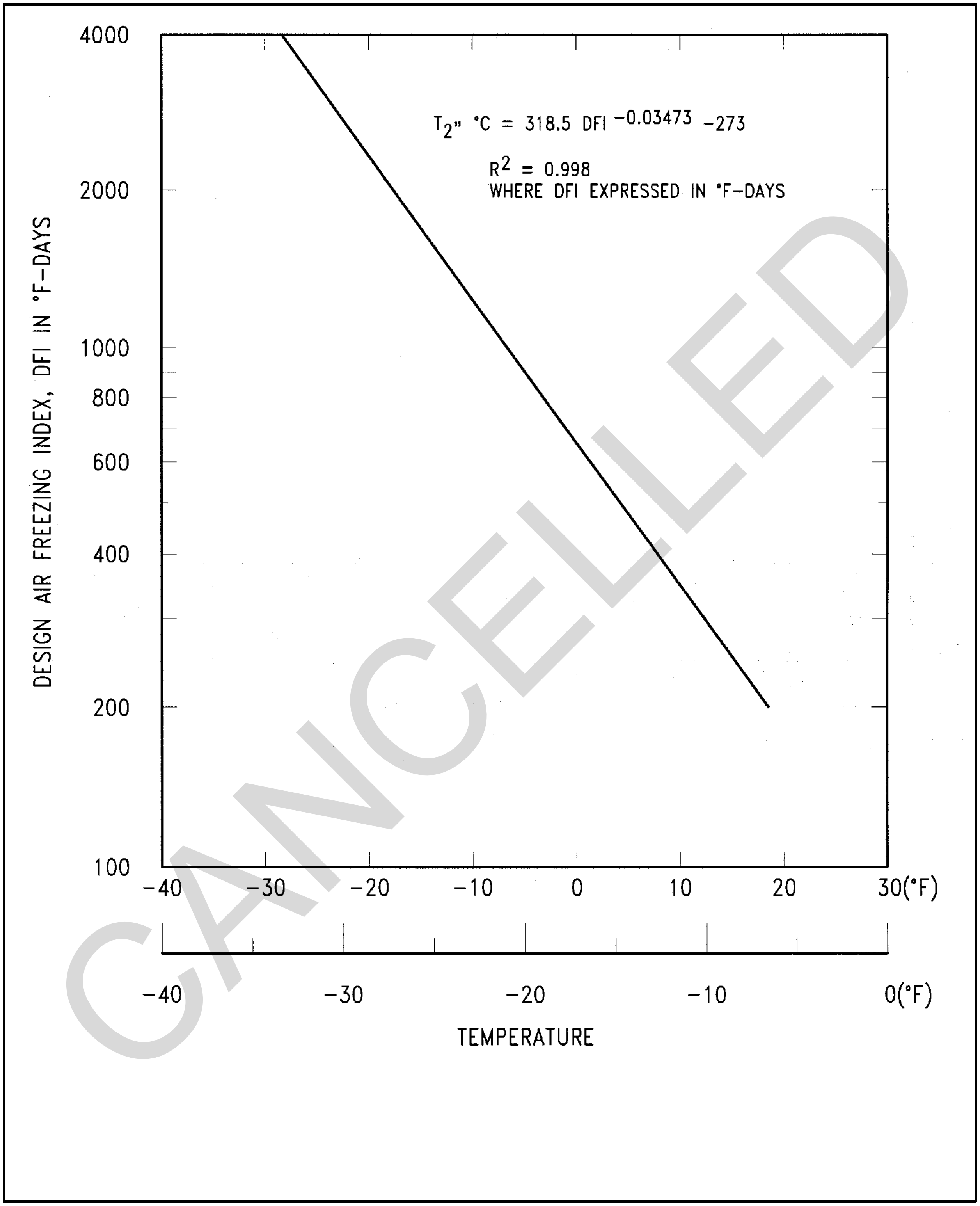

Figure 2-4 Pavement temperature as a function of design air freezing index

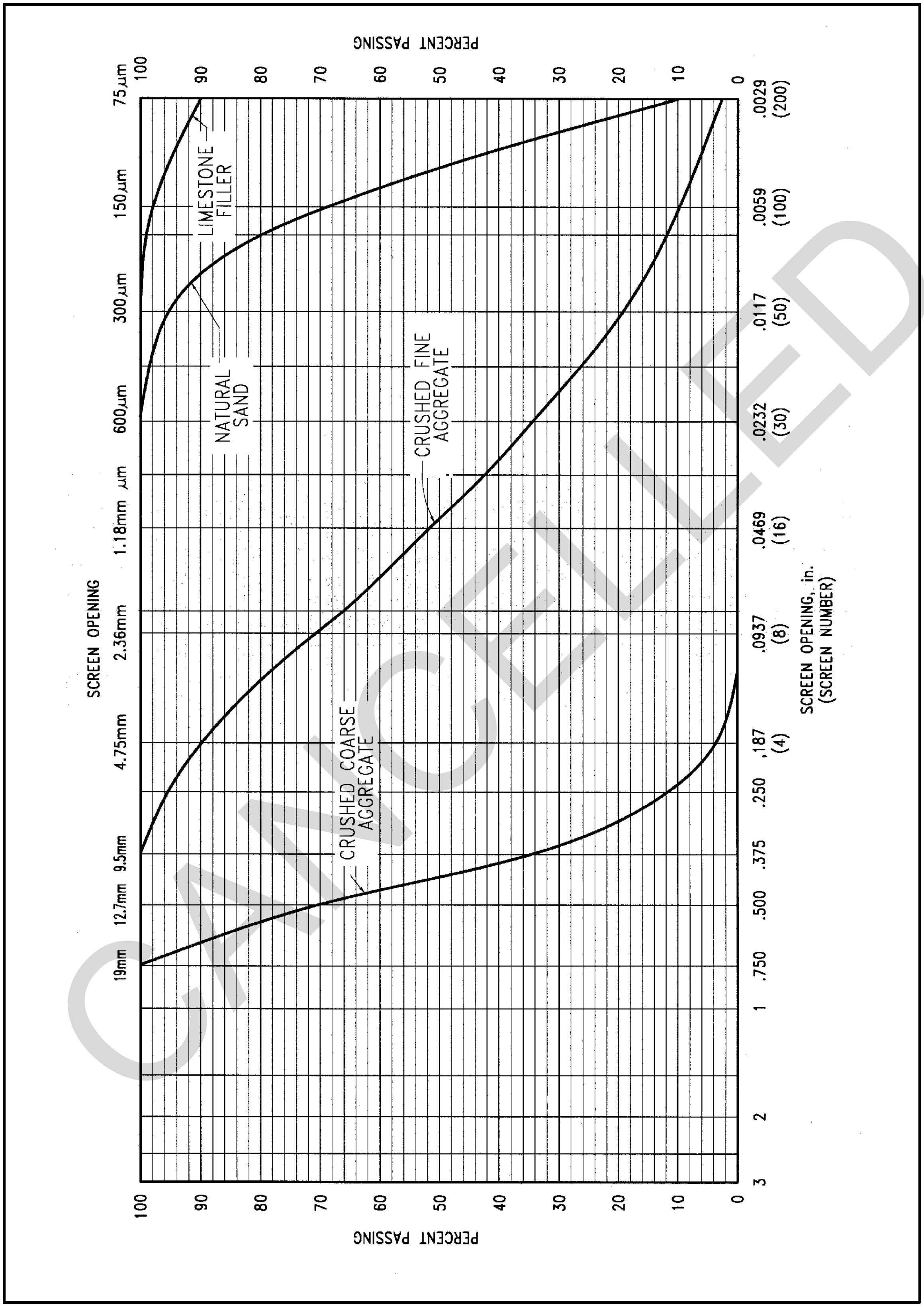

Figure 2-5 Gradation curves for stockpile samples

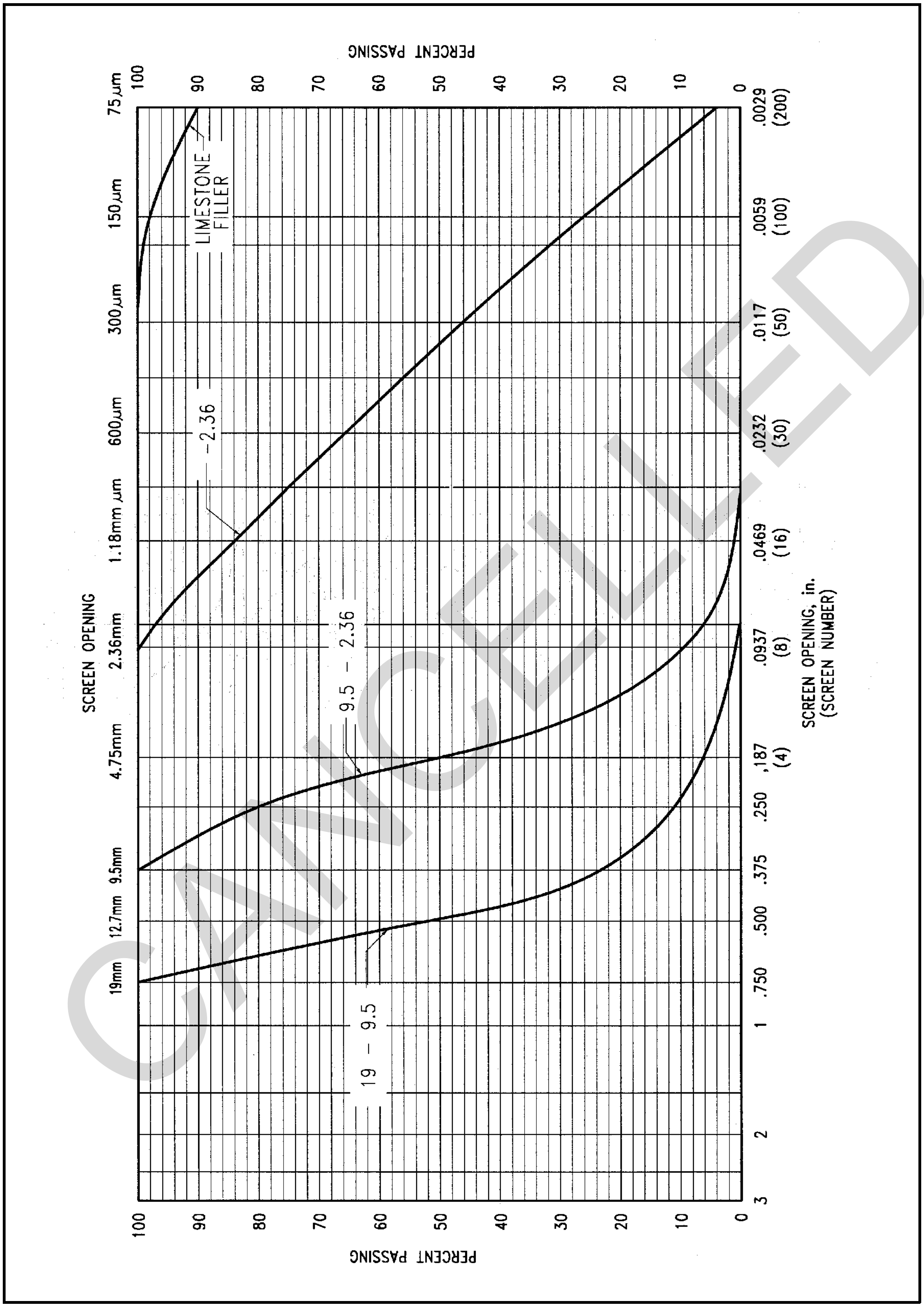

Figure 2-6 Gradation curves for bin samples

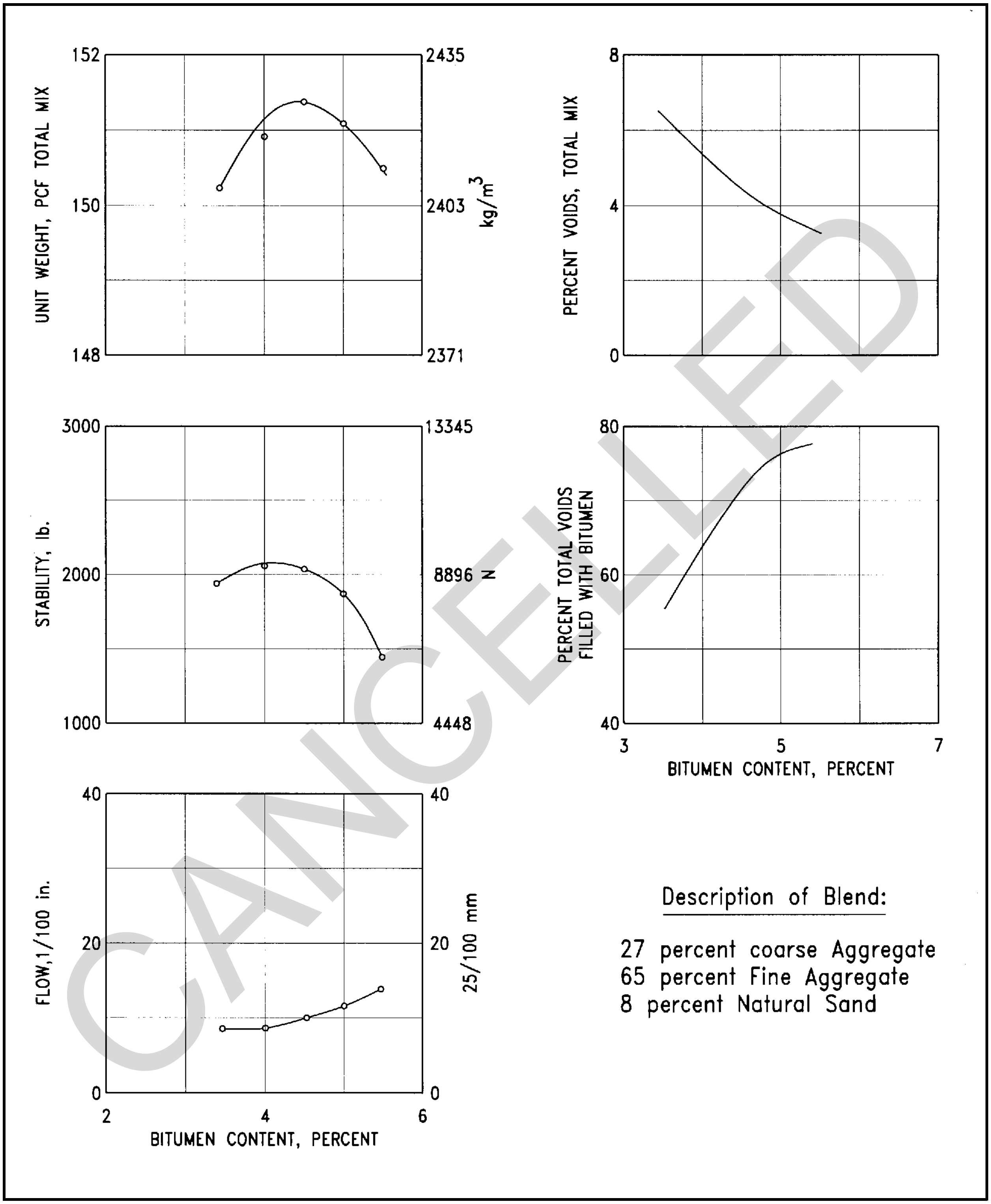

Figure 2-7 Asphalt paving mix design for typical mix

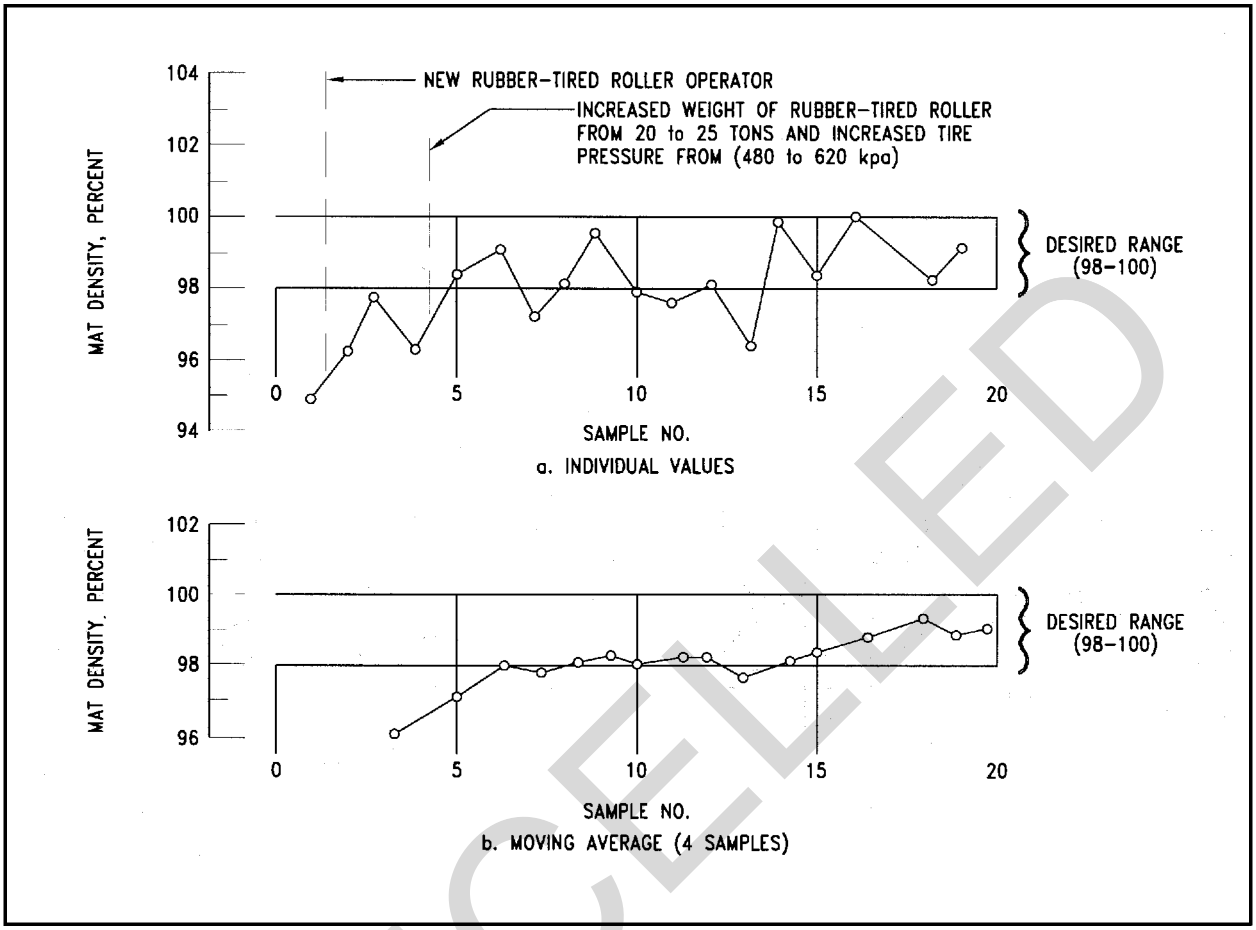

Figure 2-8 Mat density control chart

Probable Causes of Deficiencies in Hot Plant Mix Paving Mixtures / **Types of Deficiencies That May Be Encountered in Producing Hot Plant Mix Paving Mixtures**

Item	Probable Cause	Bitumen content fails to check job-mix formula	Gradation fails to check job-mix formula	Poorly mixed loads	Fat, rich mixtures	Lean or burned mixtures	Mixture temperature fails to check job mix	Smoking loads	Steaming loads	Overweight or underweight loads	Lack of uniformity of mixtures in loads
1	Aggregate scales out of adjustment	X	X		X	X					
2	Bridging of hot aggregate in bin		X							X	X
3	Bitumen scales out of adjustment	X			X	X				X	X
4	Lack of proper weighing by operator	X	X		X	X				X	X
5	Faulty pug mill dump gate	X	X	X	X	X				X	X
6	Bitumen temperature too high			X	X	X	X				X
7	Drum feed not uniform						X	X	X		
8	Improper dryer operation					X	X	X	X		
9	Too little bitumen	X				X					X
10	Too much bitumen	X			X						X
11	Sampling method	X	X		X	X					
12	Excessive moisture content of aggregate								X		X
13	Bin overflow pipes not functioning	X	X								X
14	Leaky bins	X	X		X	X					X
15	Segregation of aggregates in bins		X								X
16	Mixing time not uniform	X		X							X
17	Mineral filler feed not uniform	X	X		X						X
18	Aggregate temperature too high					X	X	X			
19	Temperature mechanism out of adjustment					X	X	X	X	X	X
20	Improper feed of aggregates to dryer	X	X		X	X		X	X		X
21	Overrated dryer capacity						X		X		X
22	Faulty screen operation		X								X
23	Overloaded pug mill			X							X
24	Improper set on pug mill	X	X	X							X
25	Bitumen and aggregate feed out of adjustment	X	X		X	X					X
26	Bitumen pump not functioning properly	X			X	X					
27	Not sufficient hot aggregate in storage bins	X	X								X
28	Aggregate gates not properly set	X	X		X	X					X

Items 6 to 23 are applicable to all types plants. Items 1 to 5 and items 24 to 28 are applicable to batch plants and volumetric plants respectively.

Figure 2-9 Types of hot-mix asphalt deficiencies and probable causes

Types of Pavement Imperfections That May Be Encountered in Laying Hot Plant Mix Paving Mixtures / Probable Causes of Imperfections in Finished Pavements	Excessive primecoat	Improper proportioning	Unsatisfactory batches in load	Poor handwork behind spreader	Excessive segregation in laying	Inadequate rolling	Poor spreader operation	Mixture too hot or burned	Mixture too cold	Rolling mixture when too hot	Rolling mixture when too cold	Poorly graded mixture	Unstable basecourse	Faulty allowance for compaction	Roller standing on hot pavement	Mixture too coarse	Lack of bitumen in mixture	Excess of bitumen in mixture	Inadequate cross rolling	Not cut back to uniform thickness	Excessive moisture in mixture
Bleeding	X	X	X		X							X				X		X			
Brown, dead appearance								X									X				X
Poor surface texture		X	X		X							X				X					
Rough uneven surface		X	X	X	X	X	X		X	X	X		X		X				X		
Uneven joints				X			X		X		X			X						X	
Roller marks						X					X								X		
Shoving		X	X					X	X	X		X						X			X
Waves				X			X		X	X			X		X						
Cracking		X	X		X				X		X	X				X	X				
Honeycomb		X	X	X	X		X		X							X					
Tearing of surface during laying			X				X		X								X				

Figure 2-10 Types of hot-mix asphalt pavement imperfections and probable causes

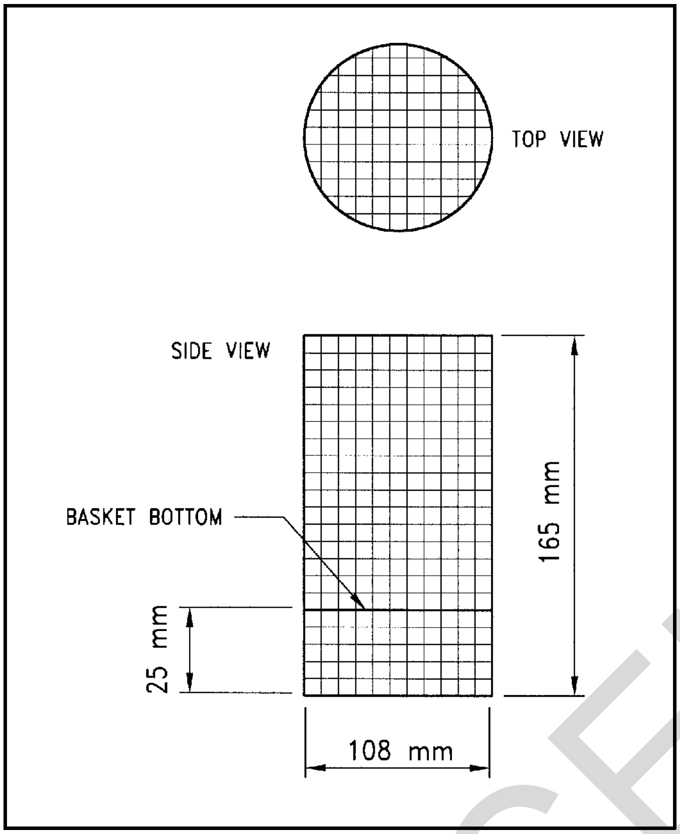

Figure 2-11 Wire basket assembly

CHAPTER 3

SPRAY APPLICATIONS

1. GENERAL. Spray application is a term used to describe many different types of asphalt applications. More maintenance and repair work for flexible pavements is accomplished by spray applications of a asphalt material than by any other technique. When properly constructed, asphalt spray applications are economical as well as long lasting and are beneficial in treating or improving the pavement condition and increasing the life of the pavement. Where additional thickness is needed to increase the structural strength of pavements, spray applications are of little help because they contribute little to the structural strength. The different types of spray applications to be discussed in detail in this chapter are as follows:

— Prime coats.

— Tack coats.

— Fog seals and rejuvenators **(Air Force bases should contact their MAJCOM pavement engineers prior to using these applications on airfield pavements, due to possible decrease in skid resistance.)**.

2. PRIME COAT.

a. General. Asphalt prime coat consists of a low-viscosity liquid asphalt material applied by a pressure distributor to an unbound base course before placement of a hot-mix asphalt pavement. The purposes of the prime coat are to prevent lateral movement of the unbound base during pavement construction; to waterproof during pavement construction; and to form a tight, tough base to which an asphalt pavement will adhere. To accomplish these purposes, the prime material must penetrate into the unbound base and fill the void spaces. A completed unbound base is susceptible to serious damage from rain, wind, and traffic. An adequate prime coat is insurance against this water and traffic damage. Prime coat material should be applied to a dust-free unbound base as soon as the base has been thoroughly compacted and before construction or other traffic loosens surface material in the compacted base. Sufficient time should be allowed to permit prime material to penetrate thoroughly into the compacted base. In instances where construction of an asphalt layer is to follow in less than seven days upon completion of base course compaction, the application of a prime coat may be omitted. When construction of an asphalt layer will not occur for at least seven days, the compacted base will be primed. Whether the compacted base is primed or not, the contractor should take steps to protect the surface from any damage (water, traffic, etc.) until an asphalt layer is placed. Generally, it will take several days for a prime coat to properly cure and withstand construction traffic and cool or wet weather may further increase the time required. Construction traffic on an uncured or improperly aged prime coat can cause more base movement than construction on an unprimed base. Local conditions, local experience, type of base material, and the type of prime coat material available should all be considered when deciding on the application of a prime coat.

b. Materials.

(1) Low-viscosity asphalt material should be used as prime material, but the selection of type and grade must be given special consideration. Some items to consider in selecting the priming material are as follows:

— Air temperature.

— Humidity.

— Void content of base course.

— Curing time of prime material.

— Environmental restrictions.

— Available materials.

(2) The recommended priming materials are emulsified asphalts and cutback (liquid) asphalt. The recommended types and grades are shown in table 3-1.

Table 3-1
Prime Coat Materials

Type	Grade
Cutback	SC-70 SC-250 MC-30 MC-70 MC-250 RC-70 RC-250
Emulsion	SS-1 SS-1h CSS-1 CSS-1h

(3) A prime coat can only work if it penetrates into the base course. Open-textured (high-void content) bases can be primed easily, but a tight surface (low voids) cannot be readily penetrated. In cases of low voids the less viscous cutbacks such as RC-70, MC-30, MC-70, and SC-70 should be considered. If penetration does not occur, an asphalt film will be left on the surface of the base causing slippage of the bituminous surface during and after construction. Caution should also be urged in using RC-70 or RC-250 because the solvent in the cutback may evaporate rapidly or be absorbed by the base-course fines and leave an asphalt film deposited on the surface. Undiluted emulsions can also cause asphalt film problems if the base-course surface is tight.

(4) Weather can influence the choice of the correct priming materials. Since emulsions are dependent on the evaporation of water for curing, low temperature or high humidity can slow or stop the curing process. Cutbacks are not as dependent on weather conditions as emulsions. In cold weather, however, the rapid curing cutbacks (RC's) may perform better than the slower curing cutbacks (MC's and SC's).

(5) Environmental restrictions have begun to limit the types of prime coat materials that are available in some areas of the United States. As a result, some cutback asphalts are not available for priming. Therefore, asphalt emulsion primes are becoming more numerous. Asphalt emulsions must be diluted with water before being applied as a prime, and special handling and storage considerations to prevent freezing, settling, and breaking must be exercised.

c. Application rate. Prime coats are usually applied in quantities of 0.38 to 1.13 liters per square meter (0.10 to 0.25 gallons per square yard) of residual asphalt. The optimum amount of prime is highly dependent on the plasticity index of the base material, the amount of fines in the base, the nature of fines, the tightness of the surface, and the moisture content of the base. Therefore, the optimum amount of prime required should be determined by field trial. Test sections at various application rates are recommended for determining the optimum amount of prime. After 48 hours of curing, if there is free or excess bitumen on the surface or if the base continues to appear shiny, the base is probably overprimed. Generally, most of the prime should be absorbed into the base within 2 to 3 hours. When excessive prime is used, the surplus can be absorbed into the overlying asphalt layers. In turn, the absorption of the excess may contribute to pavement slippage or rutting. Where excessive prime is applied, the excess must be blotted with an application of clean fine sand or mineral dust. The ideal end result is to obtain maximum penetration without leaving free prime on the surface.

d. Placement. Surfaces to be primed which contain appreciable amounts of loose material or are dusty should be lightly broomed. A dusty surface will sometimes cause prime to "freckle," that is, have small areas with no prime and adjacent areas with drops of excess prime. A light application of water just before applying the prime will aid in reducing "freckles" and getting good distribution of the prime. Priming should be uniformly applied with a pressure distributor at the required application rate and at the proper temperature for the asphalt used. Minimum curing time will vary according to the grade and type of asphalt being used, the nature of the base, temperature, and humidity, but generally curing should take place within 48 hours.

e. Control. Since most prime is applied with a pressure distributor, the distributor must be calibrated and checked for the specified application rate before applying the prime. ASTM D 2995 offers a method for determining the application rate of bituminous distributors. In addition, all nozzles should be free and open, the same size, and to the same angle in reference to the spray bar to produce a uniform fan of prime. The height of the spray bar above the surface is important because a bar too high or too low will give an unequal application in the middle of the spray fan and at the ends, causing streaking. The height of the spray bar should be such that a double or triple lap of the spray fan is obtained.

3. TACK COAT.

a. General. A tack coat is a light application of a asphalt material to an existing pavement or asphalt base course immediately prior to placing the next pavement layer or course. The purpose of the tack coat is to provide a bond between the two pavement layers. The tack coat is applied by pressure distributor to cleaned surfaces. The tack coat must be applied in a light and uniform application.

b. Materials.

(1) Emulsions are the most common types of asphalt material used as tack, but cutbacks and asphalt cements may be used in some situations. The correct spraying viscosities (temperatures) need to be obtained for the type of material used. Recommended tack coat materials and spray application temperatures are shown in table 3-2.

(2) The cutbacks and emulsions can be sprayed at relatively low temperatures, but the asphalt cements may require considerable heating to reach a viscosity suitable for spraying.

(3) In cold weather, the cutbacks can be used with less concern than emulsions which contain water. However, environmental restrictions limit the use of cutback materials, making them unavailable at many locations. The use of emulsions for tack coats may require that the emulsion be diluted with water so that a light tack is applied, and its use also requires that special consideration be given to

Table 3-2
Tack Coat Materials and Spray Application Temperatures

Type	Grade	Application Temperature °F
Cutback	RC-70	120-200
	RC-250	165-250
Emulsion	RS-1	70-140
	MS-1	70-160
	HFMS-1	70-160
	SS-1	70-160
	SS-1h	70-160
	CRS-1	125-185
	CSS-1	70-160
	CSS-1h	70-160
Asphalt cement	200-300 pen	265 +
	120-150 pen	270 +
	85-100 pen	280 +
	AC-2.5	270 +
	AC-5	280 +
	AC-10	280 +
	AR-1000	275 +
	AR-2000	285 +
	AR-4000	290 +

weather conditions, storage and handling requirements, and curing time. All tack coats should be cured before placing the new pavement layer.

c. Application rate. Tack coats are usually applied in quantities of 0.23 to 0.68 liters per square meter (0.05 to 0.15 gallons per square yard) of residual asphalt, but the exact quantities should be adjusted to suit field conditions. Light applications are preferred since heavy applications can cause serious pavement slippage and bleeding problems. However, failure to use any tack coat can also cause pavement slippage problems.

d. Placement. Tack coats should be applied to clean, dust free asphalt pavement courses prior to placement of the overlying pavement layer. The tack coat should be applied immediately before placement; therefore, unless an asphalt cement is used, the tack coat must be allowed time to cure. A tack coat may be required on a base course when the prime coat on that surface has been subjected to construction traffic or other traffic. A pressure distributor should be used to apply tack coats at an application temperature which will produce a viscosity between 10 and 60 seconds, Saybolt furol, or between 20 and 120 centistokes, kinematic viscosity. The suggested spray application temperatures in degrees Fahrenheit for tack coat materials are shown in table 3-2. When an even or uniform coating is not obtained, an improved coverage may be possible by making several passes over the freshly applied tack coat with a pneumatic-tired roller. The tack coat should be completely cured (volatiles or water evaporated) before the overlying layer is placed. A properly cured surface will feel tacky. Work should be planned so that no more tack coat than is necessary for one day of operation is placed on the surface. All nonessential traffic should be kept off the tack coat so that dust, mud, or sand will not be tracked onto the surface.

e. Control. To insure that the tack coat is applied as specified, the asphalt distributor should be calibrated and inspected. ASTM D 2995 offers a method for determining the application rate of asphalt distributors. In addition, all nozzles must be free and open, the same size, and at the same angle in reference to the spray bar to produce a uniform spray of tack. Spray bar height above the surface is also important for uniform application. A bar too high or too low will give a variable application in the middle and at the edges. The spray bar should be adjusted to a height that provides a double or triple lap.

4. FOG SEALS.

a. General. A fog seal is a very light spray application of a diluted emulsified asphalt to an existing asphalt pavement surface. The fog seal is used to maintain old pavements, reduce raveling, waterproof, and in general, extend the life of the existing pavement. Fog seals are especially good for treating pavements which carry little or no traffic. However, there are several considerations when using fog seals.

(1) The pavement skid resistance can be reduced.

(2) The pavement air voids or permeability can be reduced.

(3) The pavement should be closed to traffic for 12 to 24 hours to allow for proper cure of the seal material.

b. Materials. In the past, asphalt emulsions and some cutbacks were used for fog seals, but in recent years the materials used are emulsions and rejuvenators. The emulsions most often used are SS-1, SS-1h, CSS-1, and CSS-1h. There are several products marketed as rejuvenators, they are proprietary products (see paragraph Rejuvenation of this chapter).

c. Application rate.

(1) The proper application and dilution rate for fog seal will vary with the absorption characteristics of the existing pavement surface. Field test sections should be placed to determine the best application rate for the existing pavement. The application rate should be adjusted so that the pavement does not become slick or unstable nor have an excess of free material on the surface after curing 12 to 24 hours.

(2) The amount of dilution must be evaluated for each job. Asphalt emulsion can be applied at full strength or can be diluted as much as 1 part emulsion to 10 parts water. Normal application dilution is in the range of 1 to 4 parts water. When highly diluted fog seals are used, a small amount of surface residue is obtained and the skid resistance is slightly reduced.

d. Placement. Only a pressure distributor which has been calibrated to deliver the fog seal at the specified rate should be used to apply the seal material. All surfaces to which the seal is applied must be clean. The fog seal should be applied when the ambient temperature is above 4.5°C (40°F), but warmer temperatures are desired because the material will break and cure faster. The seal material may be applied to a damp pavement if the dilution material is water, but the pavement must not be too wet or the seal will not break properly and will not penetrate into the pavement. Excess seal left on the surface must be blotted with clean sand and broomed.

5. REJUVENATION.

a. General. Rejuvenation is the spray application of a material on an asphalt surface for the purpose of rejuvenating an aged asphalt cement binder. This rejuvenation is intended to extend the life of the asphalt pavement by softening or rejuvenating the surface asphalt toward the properties it had shortly after construction. Rejuvenators are spray applied to the pavement surface and allowed to penetrate into the pavement.

b. Materials. Rejuvenators are not generally specified by ASTM or any other organization. The various rejuvenators available are proprietary products. Fog spray applications of emulsified asphalt cannot be considered to act as rejuvenators.

c. Application rate. The rate of application will vary greatly with the condition of the pavement surface. Dry, oxidized, and open textured pavements will absorb the most material and will be able to absorb the highest amount of rejuvenator. The application rate used should be the amount of material that can be absorbed within 12 to 24 hours of application depending on the trafficking needs of the rejuvenated pavement. Manufacturer's recommendations concerning dilution and other factors must be followed.

d. Placement. Prior to placement of the rejuvenator the pavement surface shall be thoroughly cleaned of all loose material. Rejuvenators are usually placed with an asphalt distributor truck. Manufacturer recommendations concerning application temperature and dilution of the material should be followed. Areas with excess material should be blotted with clean sand and broomed. Rejuvenators can reduce the skid resistance of treated pavement surfaces. Any excess material not removed will reduce skid resistance.

e. Control. The asphalt distributor should be calibrated and checked according to ASTM D 2995. Test sections should be done on small sections of the pavement to be rejuvenated to test various application rates and function of the distribution equipment.

CHAPTER 4

SURFACE TREATMENTS

1. GENERAL. Surface treatments consist of a thin layer of aggregate cemented together with an asphalt (bituminous) material. Surface treatments are widely used because of their low cost and usefulness in light to medium traffic roadways and parking areas. These treatments are normally used to seal or waterproof the pavement, provide wear resistance, and increase skid resistance. All surface treatments are relatively thin coatings of material and do not add structurally to the pavement. **Air Force bases should contact their MAJCOM pavements engineer and Army designer's should contact the U.S. Army Corps of Engineers Transporation Systems Center (TSMCX) prior to using surface treatments on airfield pavements, due to FOD potential.**

2. SINGLE AND DOUBLE BITUMINOUS SURFACE TREATMENTS.

a. General. A single bituminous surface treatment (SBST) consists of an application of bituminous material on a prepared surface followed immediately by a single layer of cover aggregate. Chip seal is a commonly used term for the same process. Double bituminous surface treatment (DBST) is similar to a SBST except that two applications of bitumen and cover aggregate are used. The first application of aggregate uses a coarser aggregate than the second application and usually determines the DBST thickness. The second application of aggregate partially fills the surface voids and keys into the aggregate in the first aggregate course. SBST's and DBST's are used on prepared base courses and on new or old pavements. The DBST's and more additional layers (third or more) are used to provide greater wearing resistance and some structural strength (minimal).

b. Materials.

(1) Binder.

(a) The functions of the asphalt binder are to hold the aggregate in place, bond it to the underlying surface, and seal the underlying surface to prevent the entrance of moisture and air. The binders specified for SBST and DBST are cutback asphalts, emulsified asphalts, and asphalt cements. The types and grades are shown in table 4-1. ASTM D 1369 also provides a list of binder materials.

(b) The type and grade of binder must be carefully selected. Some items to consider are as follows:

— Climatic conditions.

— Curing time of binder.

— Environmental restrictions.

— Available materials.

— Temperature of surface.

— Condition of surface.

— Condition of aggregate.

Table 4-1
Surface Treatment Asphalt Materials

Type	Grade
Cutback	RC-250
	RC-800
	RC-3000
Emulsion	RS-1
	RS-2
	CRS-1
	CRS-2
Asphalt cement	120-150 pen
	200-300 pen
	AC-2.5
	AC-5

(c) Historically, rapid curing cutback asphalts were used for surface treatments. RC-250 was used when cooler temperatures were anticipated, and RC-3000 when very warm temperatures were anticipated. Currently, environmental requirements limit the availability of cutback asphalts, and as a result, emulsified asphalt binders are the most widely used binder.

(d) Emulsions require some special handling and storage considerations to prevent freezing, settling, and premature breaking, but they can be applied with little or no additional heating. In selecting the type of emulsion, the compatibility of the aggregate and emulsion must be considered. As a general rule, anionic emulsions adhere better to limestones and other aggregates composed of predominantly calcium minerals. Cationic emulsions generally adhere better to aggregates high in silica, such as chert and quartz gravels. Cationic and anionic emulsions both adhere well to damp aggregates.

(e) Asphalt cements harden quickly so that the cover aggregate is held in place better than other binders provided the asphalt cement does not chill before the cover aggregate is applied. Chilling of the binder before applying the aggregate is one major disadvantage with asphalt cement binders. To insure good bond, the aggregates are often heated when asphalt cements are used. Another disadvantage with the use of asphalt cements is the high amount of heat required for spraying. Because of the difficulties encountered with asphalt cements, cutbacks or emulsions instead of asphalt cement should be carefully considered.

(2) Aggregates.

(a) The aggregate will have an effect on the degree of wear resistance, riding quality, and skid resistance of the surface treatment. Only clean, dry aggregate fragments, free from dust or dried films of harmful material, should be used. The aggregate should have a single-size (uniform) gradation and it should be composed of hard, angular, polish-resistant material. Flat and elongated aggregate particles and wet or dusty aggregates are not used. Small quantities of moisture up to about 1 percent do not create a problem, especially in warm weather, but dust can prevent the adhesion of the binder to the aggregate. When an emulsion is used as the binder, aggregate with up to 3 percent moisture may be used. ASTM D 1139 offers additional physical requirements for aggregates to be used in surface treatments.

(b) Tables 4-2 and 4-3 give the recommended aggregate gradations for SBST and DBST, respectively. The correlating size number designation from ASTM D 448 is also given. For DBST, gradation Nos. 1 and 2 and gradation Nos. 3 and 4 from table 4-3 will be used in combination.

Table 4-2
Gradations for SBST

Sieve Size	Percent Passing by Weight, Gradation Designation		
	No. 1 (No. 6[1])	No. 2 (No. 7[1])	No. 3 (No. 8[1])
25 mm (1 inch)	100	--	--
19 mm (3/4 inch)	90-100	100	--
12.7 mm (1/2 inch)	20-55	90-100	100
9.5 mm (3/8 inch)	0-15	40-70	85-100
4.75 mm (No. 4)	0-5	0-15	10-30
2.36 mm (No. 8)	–	0-5	0-10
1.18 mm (No. 16)	–	–	0-5

[1] Number size designations from ASTM D 448.

Table 4-3
Gradations for DBST

Sieve Size	Percent Passing by Weight, Gradation Designation			
	No. 1 (No. 6[1]) (First Spreading)	No. 2 (No. 8[1]) (Second Spreading)	No. 3 (No. 7[1]) (First Spreading)	No. 4 (No. 9[1]) (Second Spreading)
25 mm (1 inch)	100	--	--	--
19 mm (3/4 inch)	90-100	--	100	--
12.7 mm (1/2 inch)	20-55	100	90-100	--
9.5 mm (3/8 inch)	0-15	85-100	40-70	100
4.75 mm (No. 4)	0-5	10-30	0-15	85-100
2.36 mm (No. 8)	--	0-10	0-5	10-40
1.18 mm (No. 16)	--	0-5	--	0-10
300 m (No. 50)	--	--	--	0-5

[1] Number size designation from ASTM D 448.

c. Design. The type and amount of aggregate and bitumen to be used for surface treatments can be determined in accordance with ASTM D 1369. This practice provides guidance on typical rates of aggregate and bitumen for the various types of surface treatments. Various other ASTM standards that are applicable for measuring both bituminous and aggregate quantities are given. The standard lists recommended grades of various asphalt and tar materials for use with surface treatments. Similar guidance is also available in the Asphalt Institute publications: ES-11 "Asphalt Surface Treatments-Specifications" and ES-12 "Asphalt Surface Treatments-Construction Techniques."

d. Construction.

(1) Placement. Field construction practices can determine the success or failure of a well-designed surface treatment; therefore, proper equipment, surface preparation, and construction techniques are very important.

(2) Equipment. Among the equipment used in placing a surface treatment, the most important are the asphalt distributor and the aggregate spreader. Aggregate spreaders are used during the construction of bituminous surface treatments to apply the aggregate to the surface being treated. The spreader should be designed and calibrated to apply a predetermined amount of aggregate uniformly over the surface. Some of the aggregate spreaders are self-propelled, while others are propelled by the truck hauling the aggregate. The self-propelled aggregate spreaders are desirable because they allow for a more uniform application of material and a smoother operation. Calibration and proper operation of the distributor and aggregate spreader should be insured.

(3) Surface preparation. Without proper surface preparation the life expectancy of a pavement will be reduced. Therefore, all soft or failed areas must be repaired and all loose material, dirt, and vegetation must be removed prior to placing the surface treatment. A bleeding surface may require either sanding or removal before construction of the surface treatment.

(4) Application.

(a) Special attention must be given to the application rates of both binder and aggregate. Field adjustments to the design application rates may be necessary. Too much binder will cause bleeding or low skid resistance, and too little binder will result in the loss of cover aggregate. Although there should be about 5 to 10 percent excess aggregate, too much aggregate will result in a waste of materials and damage to windshields.

(b) The aggregate must be applied immediately after the binder application in order to obtain a good bond between asphalt and aggregate. Rolling with a rubber-tired roller immediately after applying the aggregate will seat the aggregate in the binder and improve the bond.

(5) Control.

(a) Since the distributor and aggregate spreader are important for the successful application of materials, they must be calibrated and checked to insure that the specified application rate is obtained. ASTM D 2995 offers a method for determining the application rate of asphalt (bituminous) distributors. In addition, all nozzles should be free and open, the same size, and at the same angle with reference to the spray bar to produce a uniform fan of asphalt. The height of the spray bar above the surface is important. A bar too high or too low will produce a variable application in the middle and at the ends, causing streaking. The height of the spray bar should be such that a double or triple lap of the spray fan is obtained. ASTM D 5624 offers a method for determining the application rate of aggregate transversely across the width of the spreader.

(b) A test section is another method to evaluate the construction techniques and the application rates required for surface treatment. At least one test section should be constructed before allowing surface treatment applications on a full scale.

3. SLURRY SEAL.

a. General. A slurry seal is a mixture of asphalt emulsion, well-graded fine aggregate, water, and mineral filler. These materials are combined in the proper proportions to produce a homogeneous, fluid-like slurry. The consistency of the slurry must be such that it can be squeegeed over an existing pavement surface. A thick, sealed surface results after evaporation of the water and curing of the mix. When properly designed, constructed, and cured, the slurry seal should improve the qualities of an existing pavement surface, but the structural strength of the pavement structure is not significantly improved. Slurry seals are used to protect worn, weathered, or cracked pavements from the adverse effects of weather conditions and traffic wear. With proper use of aggregates, the slurry seal can also be used to reduce skid or slipperiness problems. Slurry seals have application to roads and streets, parking lots, and bridge decks. This type of seal coat is best suited for pavements that are not subjected to heavy traffic. Because aircraft can cause a rapid deterioration of the slurry seal, slurry seals should not be applied to airfields.

b. Equipment. Various types of equipment are needed on a slurry seal project, but the basic pieces of equipment required include a truck-mounted continuous-mix slurry machine, spreader box, power broom, front-end loader, distributor, and pneumatic-tired roller. The truck-mounted continuous-mix slurry machine which serves as a portable mixing plant is the most important piece of equipment. It is the only type of mixing equipment recommended for mixing a slurry seal. A slurry seal machine is used to mix aggregate, filler, asphalt emulsion, and water in the correct proportions and to uniformly apply the material to the surface to be sealed. The slurry seal machine generally contains storage for the aggregate, filler, emulsion, and water. Before the machine is used, it must be calibrated and set to deliver the job materials in the correct proportions. The machine manufacturer's instructions usually offer the best guidance for calibrating the slurry machine. However, a calibration method based on a revolution counter is applicable to all machines. By attaching a revolution counter to any shaft that is mechanically interlocked with the emulsion pump, water pump, fines feeder, and aggregate conveyor, the relative quantities of each of these components per revolution can be determined for various gate openings, metering valve openings, or sprocket sizes. The materials are mixed and deposited into a squeegee box, which applies the slurry seal onto the surface at a thickness approximately equal to the maximum aggregate size.

c. Material requirements.

(1) Emulsion. The binder used in a slurry seal is asphalt emulsion. The emulsion is often either slow-set anionic (SS-1 or SS-1h) or slow-set cationic (CSS-1 or CSS-1h). The slow-set emulsions are best suited for slurry seals, but some quick-set emulsions are specifically designed for slurry seal. The use of quick-set emulsions requires that an experienced slurry seal contractor perform the job because of the small amount of time available for handling the slurry seal before it cures. Slow-set cationic emulsions cure faster than slow-set anionic emulsions because the curing process is partly a chemical reaction that expels some of the water from the mix. Anionic emulsions cure primarily by evaporation of the water from the mix; therefore, they are greatly influenced by weather conditions. Low temperatures, high humidity, or rain can slow or stop the curing process. Sometimes an emulsion will break, that is, the asphalt will separate from the water upon contact with certain types of aggregates. If a break occurs, either the emulsion or aggregate type must be changed.

(2) Aggregate.

(a) General. The aggregate as well as the emulsion used in a slurry seal should be given close attention. All aggregates must be clean, and the particles should be crushed to produce an angular shape. Aggregates that contain plastic fines should not be used. These fines absorb excessive amounts of emulsion, leaving inadequate amounts of binder on the remaining aggregate. The fines also promote low-wear characteristics and premature break of the emulsion. Better performance can be expected from slurry seals that are produced using crushed aggregate. Furthermore, natural sands such as dune, river, and beach sands, and other rounded aggregates tend to have poor skid resistance and wear characteristics and therefore should not be used in slurry seal coatings.

(b) Gradations for aggregates. The aggregates should be dense graded so that the particles will lock themselves together. Table 4-4 shows the gradations for use with slurry seals. Gradation type 1 is normally used for filling and sealing cracks in a pavement surface and it will provide a thin wearing surface. Gradation type 2 is probably the most generally used, and is used to fill voids, correct moderate surface irregularities, seal small cracks, and provide a wearing surface for traffic. Aggregate gradation type 3 assures a thicker seal and provides a coarser surface texture. This gradation might be used as the first course in a two-course slurry seal surface treatment.

Table 4-4
Slurry Seal Aggregate Gradations

Sieve Size	Percent Passing		
	Type 1	Type 2	Type 3
9.5 mm (3/8 inch)	–	100	100
4.75 mm (No. 4)	100	90-100	70-90
2.36 mm (No. 8)	90-100	65-90	45-70
1.18 mm (No. 16)	65-90	45-70	28-50
600 m (No. 30)	40-65	30-50	19-34
300 m (No. 50)	25-42	18-30	12-25
150 m (No. 100)	15-30	10-21	7-18
75 m (No. 200)	10-20	5-15	5-15

(3) Mineral filler. When stability or segregation problems occur, mineral filler at a rate of 0.5 to 4.0 percent by weight of the total mixture may be required to overcome the problem. When mineral filler is needed, portland cement or hydrated lime is most often used in slurry seals. The filler is used to improve the mix stability, that is, suspend heavier aggregate particles throughout the slurry seal mixture; to reduce segregation of materials; and to meet gradation requirements. Care should be taken to insure that the fines content, including mineral filler, does not exceed the gradation limits. Excessive fines or mineral filler can cause shrinkage cracking to occur in the seal coat.

(4) Water. Water controls the workability of the slurry seal mixture. The mixture should contain enough water to produce a smooth, creamy, homogeneous fluid like appearance. If too much water is used, the resultant mixture will be soupy, and segregation or bleeding of the mixture will occur. On the other hand, if not enough water is used, the slurry mixture will be stiff and will neither spread smoothly nor perform satisfactorily. Only potable water should be used in a slurry seal mixture.

d. Design. The method of developing a JMF for slurry seals selects the optimum asphalt content based on a desired film thickness of asphalt and the absorption characteristics of the aggregate. The water and mineral filler content requirements are determined by a cone test, and the wear characteristics are determined by the Wet Track Abrasion Test as described in ASTM D 3910. Appendix C contains a summary Design Method and an example problem for Slurry Seals. The method is intended to furnish a starting point for field application. Slight adjustments may be required in the proportions of the mixture to satisfy field conditions; however, a field test section should be constructed using the laboratory-developed JMF.

e. Factors affecting design. Some important factors that should be considered before using a slurry seal are as follows:

(1) The cost of placing a slurry seal is relatively small, but this mixture does not provide additional strength to the pavement and does wear rapidly under a high volume of traffic.

(2) Slurry seal will fill and seal many surface cracks.

(3) Slurry seal can be used to seal a pavement surface to retard oxidation and raveling or to provide a thin (6 millimeter, 1/4-inch) wearing surface.

(4) Skid resistance can be improved if the proper crushed aggregates are used in the mix.

(5) Uncured slurry seal can be adversely affected by changes in weather conditions.

(6) A treated pavement must be closed to traffic to allow the slurry seal to cure (sometimes as long as 24 hours, but usually 6 hours).

(7) Slurry seal is better suited for a pavement subjected to low or moderate traffic because heavy traffic can cause a rapid deterioration of the thin layer.

(8) Only structurally sound pavements are suited for a slurry seal.

(9) Proper design and application are very important for obtaining a satisfactory job.

(10) Generally, slurry seals have a 2- to 5-year life.

(11) A properly placed slurry seal will fill small cracks and coat the surface of the pavement to a depth of 3 to 6 millimeters (1/8 to 1/4 inch).

f. Surface preparation. Without proper surface preparation, the life expectancy of a slurry seal surface is reduced. All loose material (including loose or flaky paint), dirt, and vegetation should be removed. Cracks wider than 3 millimeters (1/8 inch) should be treated before applying the seal coat. After the surface is cleaned, a light tack coat should be applied to improve the bond and to reduce the asphalt absorption of the old surface.

g. Application. Surface texture of the fresh slurry seal will be affected by the condition of the flexible lining of the spreader box, fragments of cured slurry adhering to the edges of the lining or to the squeegee, and the condition of the burlap drag. Worn lining will result in an uneven thickness of the seal coat. Fragments of cured slurry seal or large aggregate particles caught in the lining will produce gouges and streaks. The burlap drag should be washed or replaced as needed to insure that accumulations or crusts of mix do not cause scars or streaks. The mesh basket screen that is hung at the end of the discharge chute should be emptied and cleaned as required. The slurry seal should be checked for lumps or balling which can be caused by inadequate mixing or premature break of the asphalt emulsion. Deviation of the mix from the specified gradation may also result in an unsatisfactory product.

(1) Joints. Whenever possible, joints should be made while the slurry-seal mixture applied in the first pass is still semifluid and workable. If operations preclude fresh working joints, the previously laid pass must be allowed to set and cure sufficiently to support the spreader box without scarring, tearing, or being scraped from the pavement surface.

(2) Hand application. Close attention should be given to spreading of the slurry-seal mixture by hand squeegee. Overworking will sometimes cause partial breaking of the emulsion before the final spreading is completed which results in a non-uniform material that will have poor appearance and durability.

h. Curing. Slurry seals, depending upon the emulsion characteristics in relation to the aggregate with which it is used, may cure primarily by evaporation of water from the surface, by deposition of asphalt on the aggregate which frees the water, or by a combination of both. If curing is from the surface downward, the surface may present a cured appearance but the material below may be uncured. Thorough curing of the slurry seal must be assured before traffic is permitted.

i. Rolling. Rolling is advantageous in reducing voids in the slurry seal, smoothing out surface irregularities, and increasing the resistance to water. Rolling should begin as soon as the slurry seal has cured enough to support the roller without any pickup of the slurry seal mixture. A rubber-tired roller should be used for rolling the slurry seal mixture.

4. FUEL-RESISTANT SEALER.

a. General. Fuel-resistant sealer (FRS) material is a combination of coal-tar emulsion, fine aggregate, water, and occasionally other additives. These materials are mixed in batches and applied to hot-mix asphalt surfaces by hand or mechanical squeegees. The coal-tar emulsion binder provides a fuel-resistant surface and the fine aggregate provides suitable skid resistance. The FRS is placed in thin layers usually around 2 millimeters (1/16 inch) or less. Particle size will effect the minimum thickness that can be applied by squeegee. A FRS will not significantly enhance the structural strength of the pavement structure.

b. Areas of application. FRS should be applied to any hot-mix asphalt surface subjected to fuel drippage or spillage. This includes vehicle maintenance and parking areas.

c. Considerations for use. Some important factors that should be considered before using a FRS.

(1) FRS should only be used where a fuel-resistant surface is required.

(2) FRS's generally do not have as long a service life as surface treatments with asphalt cement binder, but they may last up to 4 years or more depending on traffic and climate conditions.

(3) Parking areas with low vehicle turnover or low usage (therefore lower instances of fuel spillage) rates may be better served with a single or double bituminous surface treatment or a slurry seal.

(4) FRS's will provide a seal to protect the underlying hot-mix asphalt pavement to retard oxidation and weathering.

(5) The pavement must be closed to traffic during the curing of FRS layers (usually 4 to 8 hours).

(6) Uncured FRS can be adversely affected by changes in weather conditions such as rain or freezing temperatures.

(7) Only structurally sound pavements are suited for a FRS.

(8) Proper mixture design and application are very important for obtaining a satisfactory job.

d. Material requirements.

(1) Coal-tar emulsion. The binder material used in a fuel-resistant sealer is a coal tar emulsion. The coal tar emulsion is usually specified as having to meet the requirements of Federal Specification R-P-00355E or ASTM D 5727.

(2) Aggregates. Aggregates shall be either natural or manufactured angular aggregate. The aggregate shall be clean and free of organic and other objectionable material. The aggregate shall meet the gradation requirements as given in table 4-5.

Table 4-5
Fuel Resistant Sealer Minimum Application Rates and Corresponding Aggregate Gradations

Gradation Type	Coarse	Medium	Fine
Minimum Application Rate, L/m^2 (gal/yd^2)	1.35 (0.3)	1.0 (0.22)	0.72 (0.16)
Sieve Size			
2.36 mm (No. 8)	100	100	100
1.18 mm (No. 16)	98-100	100	100
(No. 20)	85-100	98-100	100
600 m (No. 30)	25-90	85-100	98-100
(No. 40)	5-30	30-90	85-100
300 m (No. 50)	2–10	8-35	35-90
(No. 70)	0-4	3-11	10-40
150 m (No. 100)	0-2	0-4	4-12
(No. 140)	--	0-2	0-4
75 m (No. 200)	--	--	0-2

(3) Water. Only potable water shall be used in a FRS mixture. The amount of water required shall be determined from laboratory testing prior to construction. A small amount of additional water may be required under very high temperature pavement conditions.

(4) Additives. Additives sometimes used in FRS's include various types of polymer and silicon materials. These materials may be added to the FRS mixture in the field or added to the coal-tar emulsion during the emulsifying process. The polymer materials most often used are latex combinations of acrylonitrile and butadiene.

e. Design.

(1) General. The design of FRS mixtures has historically been based on the selection of materials (sand, water, and additives) from an allowable range based on a per gallon of coal-tar

emulsion. The current guide specification requires that the final FRS mixture developed be required to meet several test requirements. The tests include curing time, resistance to heat, resistance to water, resistance to kerosene, stiffness, and viscosity.

(2) Application rate. The rate of application of sealer will depend to a great extent on the gradation of the aggregate used. The coarser the gradation, the thicker the application required. This assures that the aggregate is embedded in the sealer and will not wear off under traffic. The rates given are for general guidance and may vary depending upon the final proportions (solids content) of the sealer that is applied.

(3) Requirements. The FRS mixture must meet the requirements as given in table 4-6. A stiffness requirement is given in the current fuel-resistant sealer guide specification. The requirement for stiffness is not applicable for coal tar emulsion sealers. The stiffness test should be required where an alternate binder (i.e. an epoxy system) is used which may not be flexible enough for use as a sealer on a flexible pavement. The amount of sand added to the FRS mixture should not exceed 480 to 720 grams per liter (4 to 6 pounds per gallon) of coal tar emulsion. Sand loads of greater amounts will not normally be fuel resistant and will fail the resistance to kerosene test. Higher sand loadings are usually only possible through the use of polymer additives which increase the viscosity of the FRS mixture and can hold the sand in suspension.

Table 4-6
Physical Properties of Sealer Mixtures

Property	Requirement	Referenced ASTM Test Method
Curing time, firm set	8 hours maximum	D 2939
Resistance to heat	No blistering, sagging or slipping	D 2939
Resistance to water	No blistering, loss of adhesion or tendency to re-emulsify	D 4866
Resistance to kerosene	No penetration or loss of adhesion	D 4866
Viscosity of sealer	Viscosity shall be a minimum of 700 centipoises at 23°C ± 3°C (all constituents added excluding sand)	--

f. Equipment. Various types of hand-held squeegees, brooms, and other non-mechanical equipment are needed on the typical FRS project. Small jobs can sometimes be completed with only small mixers and hand-held squeegees. However, the basic equipment required for mechanical application on a FRS project include a truck-mounted batch-mix machine, squeegee blades, power broom, and front-end loader or fork truck. The truck mounted batch-mix machine is where the FRS mixtures are proportioned and mixed and then taken to the project site and applied to the pavement surface. FRS mixtures are always batch mixed and then applied, unlike slurry seals which are made in a continuous mix operation. The batch-mix machine usually has a manufacturer supplied calibration sheet showing the number of gallons per depth in the tank. The depth is usually monitored with a marked dip stick. The squeegee blades apply the FRS material to the pavement surface. The power broom cleans the pavement surface prior to application. The front end loader can be used for aggregate handling; however, a fork lift is more often needed as bagged and manufactured aggregate is often used.

g. Surface preparation. All loose material should be removed from the pavement surface prior to application of the FRS. Cracks wider than 3 millimeter (1/8 inch) or with vegetation should be cleaned and sealed prior to application of the FRS.

h. Application. After sufficient mixing the FRS mixture should be poured directly on the pavement surface and squeegeed across the pavement surface. In hot weather conditions where the pavement surface gets hot, the application of a fog spray of water prior to application of the FRS material would assist in bonding the FRS to the pavement surface. A minimum of two applications of the FRS material should be used to eliminate the possibility of any continuous, full-depth voids in the FRS. When possible, each additional application should be made perpendicular to the previous one. Whenever possible, consecutive lanes should be placed while the sealer mixture applied in the first lane is still semifluid and workable. If operations preclude fresh working joints, the previously laid pass must be allowed to set and cure sufficiently so it is not scarred, torn, or scraped from the pavement surface during the placement of the adjoining pass.

i. Curing. FRS's cure by evaporation of the water from the sealed pavement surface. Sunlight and warmer temperatures will increase the rate of curing. The time for curing can vary from 2 to 24 hours depending on the thickness of FRS applied and the existing climatic conditions. FRS's should not be applied when freezing temperatures (<0°C, <32°F) are possible within the curing time required.

5. MICRO-SURFACING.

a. General. Micro-surfacing, also known as micro-texturing, macroseal, or macro-pavement, is a latex-modified asphalt emulsion slurry paving system. This system was originally developed in West Germany in the 1970's and has been used in the U.S. since 1980. The total system generally consists of a latex-modified asphalt emulsion, chemical additives, high quality crushed aggregate and mineral filler (usually Type 1 portland cement), and water.

b. Equipment. The methods of mixing and application are similar to those of a slurry seal. Other equipment such as brooms, loaders, and asphalt distributors are the same as for a slurry seal. The equipment required for mixing and application of microsurfacing mixtures are different than these required for slurry seals. Mixing is accomplished in a multi-bladed twin-shaft pug-mill mixer. Application equipment with constant agitation within the slurry box is required to achieve a uniform placement of slurry. Micro-surfacing mixtures are placed with self-propelled mixing and placement vehicles. These vehicles have bins and tanks to carry all the aggregate, filler, asphalt emulsion, water, and additives required to make the mixture. There are two basic types of continuous vehicles with the capability to keep placing with the help of nurse or resupply trucks, and units which place and then leave for resupply. These vehicles have the ability to apply a fog spray of water to the pavement directly in front of the spreader box. The spreader box will contain blades to continually agitate the slurry. On relatively smooth surfaces the rear seal is rubber and acts as a strike-off (screed). On rough surfaces a steel strike-off is normally used to form an intermediate leveling course with another slurry over it. Rut boxes are used to fill ruts in individual traffic lanes. These boxes are V-shaped with the point of the V toward the rear of the box. They have two shafts with multiple blades on each side of the V to continuously agitate the slurry. The box is designed to push the larger aggregate to the center and is equipped with two metal leveling plates and a rubber strike-off.

c. Material requirements.

(1) Emulsion. The binder used in micro-surfacing is a latex-modified asphalt emulsion. The base asphalt emulsion used is normally a cationic slow setting emulsion with a hard base asphalt (CSS-1H) as specified in ASTM D 2397. The latex polymer is combined with the asphalt cement during the emulsifying process, typically at a rate of 3.0 percent by weight of residual material.

(2) Additives. Liquid additives are added during the field mixing process to provide control of the set properties of the micro-surface mixture. The amount of additive used generally increases with decreasing temperatures. This is because the additive acts to cause the emulsion to break or cure faster. These additives are normally obtained from the emulsion manufacturer.

(3) Aggregates.

(a) General. The aggregate used should be a high quality 100 percent crushed aggregate. Aggregates previously used for micro-texturing include granite, flint, slag, limestone, basalt, chert, and gravel. The aggregate shall meet one of the gradation types as given in table 4-7. The gradations used for microsurfacing are the same as those of an asphalt slurry seal, except that Type 1 the finest gradation used for a slurry seal (table 4-4) is not used for microsurfacing.

Table 4-7
Gradation Types for Micro-Surfacing

Sieve Size	Type 2 Percent Passing	Type 3 Percent Passing
9.5 mm (3/8 inch)	100	100
4.75 mm (No. 4)	90-100	70-90
2.36 mm (No. 8)	65-90	45-70
1.18 mm (No. 16)	45-70	28-50
600 m (No. 30)	30-50	19-34
300 m (No. 50)	18-30	12-25
150 m (No. 100)	10-21	7-18
75 m (No. 200)	5-15	5-15

(b) Mineral filler. Mineral filler is added to the mixture to obtain the desired dispersion (reduce segregation) and working characteristics (speed up or slow down the rate of cure of the system) of the micro-surfaced mixture. The amount of mineral filler added shall be determined from laboratory testing and will normally not exceed 3.0 percent of the weight of the aggregate. The mineral filler may be non-air entrained portland cement, hydrated lime, or another approved mineral additives.

(4) Water. The water should be potable, free of soluble salts or any other harmful materials. The amount of water used should be limited to that required to produce a mixture of desired consistency. The amount of water required may increase slightly with increasing temperatures.

d. Design. The Corps of Engineers has not developed a method of mixture design. Instead, procedures developed by the International Slurry Surfacing Association (ISSA) are recommended for use and are detailed here. These procedures can be broken down into three parts. The first is the evaluation of materials to verify they meet requirements as given previously in paragraph *Material requirements* of this chapter. These materials include the aggregates and the polymer-modified asphalt cement. The second part involves testing the effects of mixing and application characteristics, water content, filler, and additives, and determination of optimum asphalt content through the preparation of trial mixes. The third part involves performance related tests on the mixture to ensure good long-term performance.

(1) Mix characteristics. Trial mixes are used to determine if emulsion and aggregate are compatible, if a mineral filler or field control additive is needed, and if used, the concentration, and the range of water that produces homogeneous mixtures. Trial mixes are also prepared to determine the optimum filler content and the effects of mineral filler on wet cohesion. These mixes are prepared with constant asphalt emulsion contents and incremental changes in the amount of mineral filler, usually either hydrated lime or portland cement. Once the desirable mineral filler content has been determined, trial mixes are again prepared, this time holding the mineral filler content constant and making incremental changes in asphalt emulsion content.

(a) Cohesion test (ISSA TB-139). The cohesion test is the method used to classify the set and traffic time of micro-surfacing systems. The cohesion tester is a power steering simulator that measures the torque required to tear apart a 6 or 8 millimeter thick x 60 millimeter in diameter specimen under the action of a 32 millimeter diameter rubber foot loaded to 200 kPa. A system is defined as "quick-set" if it develops a torque value of 12-13 kg-cm within 20 to 30 minutes. A torque of 12-13 kg-cm is considered the cohesion value at which the mixture is set, water resistant and cannot be remixed. A system is defined as "quick traffic" if the mixture develops 20-21 kg-cm torque within 60 minutes. At 20-21 kg-cm, sufficient cohesion has developed to allow rolling traffic. Figure 4-1 provides a method to classify various slurry seals and micro-surfacing systems. All micro-surfacing mixtures are designed as quick set, quick traffic systems. Cohesion test results can also be used to optimize mineral filler by the use of the "Benedict Curve" (see figure 4-2), in which the effect of an incremental addition of mineral filler versus cohesion is plotted. The optimum filler content is the value that gives the highest cohesion value. The shape of the curve will show the sensitivity of the system to changes in mineral filler. This will help in determining the range of mineral filler that will give acceptable laboratory results.

(b) Stripping. Two tests can be used to evaluate the potential for stripping: Wet Stripping Test (ISSA TM 114) and the Boiling Test (ISSA TM 149). The Wet Stripping Test is performed on 60°C (140°F) cured cohesion specimens that are boiled in water for 3 minutes to determine the asphalt adhesion to the aggregate. A coating retention of 90 percent or greater is considered satisfactory, with 75 to 90 percent being marginal and less than 75 percent unsatisfactory. The Boiling Test is similar to the Wet Stripping Test. Both tests can also be used as an early compatibility indicator test.

(2) Determination of optimum asphalt content. There are several procedures used to determine the optimum asphalt cement content. One way is to use ISSA test procedures, and another is to use a modified Marshall procedure. A few states also specify requirements for Hveem stability.

(a) ISSA procedure. The optimum asphalt content is determined from ISSA procedures by graphically combining the results of a wet track abrasion test (WTAT) and a loaded wheel test (LWT). Figure 4-3 (a, b, and c) shows how the optimum asphalt content along with an acceptable range can be determined by graphically combining WTAT and LWT data. The minimum and maximum asphalt content should fall within the range usually provided in the specification. The ISSA recommends that residual asphalt content be within a range of 5.5 to 9.5 percent.

[1] Wet track abrasion test (ASTM D 3910/ISSA TB 100). This test determines the abrasion resistance of micro-surfacing mixture relative to asphalt content and is one of two ISSA tests used for determining optimum asphalt content. This test simulates wet abrasive conditions such as vehicle cornering and braking. A prepared and cured sample of mixture 6 millimeters thick x 280 millimeters in diameter that has been soaked for periods of either 1 hour or 6 days is immersed in a 25°C (77°F) water pan and is wet abraded by a rotating weighted (2.3 kilogram) rubber hose for 5 minutes. The abraded specimen is dried to 60°C (140°F) and weighed. Maximum allowed weight losses for 1-hour and 6-day soaks are 0.54 kilogram/meter^2 and 0.8 kilogram/meter^2, respectively. Asphalt contents that result in these weight losses are considered the minimum asphalt contents. The WTAT on a 6-day soaked sample is generally not required. However, due to the increased severity of

the 6-days soak, it is preferred by some laboratories and user agencies for predicting the performance of the system.

[2] The loaded wheel test (ISSA TM 109). This test is used to determine the maximum asphalt content to avoid asphalt flushing in micro-surfacing systems. This is accomplished by specifying and measuring fine sand that adheres to the sample subjected to simulated wheel loadings. The ISSA recommends a maximum sand adhesion value of 0.54 kilogram/meter^2 for heavy traffic loadings. If the sand adhesion is below this maximum value mixture bleeding should not occur. In this test a 50 millimeter wide x 375 millimeter long specimen of desired thickness (generally 25 percent thicker than the coarsest particle) is fastened to the mounting plate and is compacted with 1000, 57 kilogram cycles at 25°C (77°F). At the end of compaction the specimen is washed, dried at 60°C (140°F) to a constant weight. A measured quantity of sand is then placed on the sample, and the loaded wheel test is repeated for a specified (usually 100) number of cycles. The specimen is then removed and weighed. The increase in weight due to sand adhesion is noted.

(b) Marshall procedure (modified CRD-C 649 or ASTM D1559). The Marshall hot mix asphalt mixture criteria can be used to determine the optimum asphalt content. Since these are cold polymer-modified emulsion systems, the stability and flow test procedures have been modified to allow for air and low temperature drying (at least 3 days of air curing, 18-20 hours of drying in an oven at 60°C (140°F) before compaction at 135°C (275°F)). The mixes are usually compacted with 50 blows per side. Under this procedure several test specimens are prepared for combinations of aggregate and asphalt content. The asphalt contents are selected to provide voids in total mix (VTM) of about 4.5 to 5.5 percent. The compacted test specimens are tested for the bulk specific gravity (ASTM D 2726), stability, and flow values. Finally, the optimum asphalt cement content is determined using results from these tests. For thin micro-surfacing applications, the stability is not considered a primary factor in determining the optimum asphalt cement content. The surface characteristics of some aggregates may require adjustments in the VTM requirement to achieve the desired flow values.

(c) Design limitations.

[1] ISSA design. Torque values are measured in the laboratory under specific conditions (there has been no correlation established with pavement performance in the field). The mixing and wet cohesion test should be performed at various moisture contents, relative humidities, and temperatures to simulate the expected field conditions. In addition, it has been reported that some aggregates that met ISSA torque standards for 60 minutes have failed to meet the torque values for 30 minutes. Some laboratories also use a subjective analysis to determine torque. The sample is examined after the torque is applied, and should it fail, the torque value is determined from a visual examination of the condition of the sample. However, this analyses would appear to negate the objectivity of the cohesion test. This indicates an area where the industry should reexamine their procedures for cohesion test and consider the effect of various aggregates on test results. WTAT was correlated to field performance for only 6 millimeter thickness and 0/4 gradations. Accordingly, values of 0.54 kilogram/meter^2 may not be appropriate for other thicknesses and aggregate gradations. Further tests are needed to verify or establish new values. Also, some limestones meet the WTAT standard for 1-hour soak periods but fail to meet maximum abrasion loss when a sample with a 6-day soak is tested. While WTAT on a 6-day soak specimen is generally used for information only, the industry may wish to review and adjust their current design standards. The reproducibility of the loaded wheel test is questionable. The arm that moves the wheel does not stay horizontal, but rather moves up and down during the test. This changes the pressure on the sample. The arm should be modified to stay horizontal. At the present time, the weights used to apply pressure are bags of lead shot. These bags may shift during the test and can affect the applied pressure. The bags should be replaced by plates that can be attached to the machine. Sample preparation has been shown to affect the LWT results by a factor of as much as two. The test specimen can flush if water levels are not carefully controlled. This

condition will affect the sand adhesion. Current laboratory procedures for sample preparation should be improved so that samples can be more consistently molded. For some aggregates, LWT has shown to permit excessive amounts of binder resulting in unacceptable mixtures. This is true particularly for applications in high shear areas such as intersections. Performance data indicates that mixtures produced with these aggregates using a lower binder content (than would have been permitted by LWT) have performed well in extending the pavement service life. The specific gravity specification is very subjective due to sampling procedure. The entire LWT specimen is weighed wet and dry to obtain specific gravity. After compaction the same test is repeated. The problem is only 50 to 60 percent of the specimen is compacted. Variations in the specific gravities of samples can also skew LWT results.

[2] Marshall design. The applicability of this HMA test for micro-surfacing is questionable. The Marshall series uses large specimens of varying asphalt contents which are dried, reheated to 135°C, and compacted to low void content. Micro-surfacing mixtures neither reach these temperatures nor do they compact to low design voids. Field observation has noted air voids of 10 to 15 percent after 1 to 2 years of placement. There is a need to correlate the voids measured during the design using the Marshall method with the actual field voids. One materials laboratory that has developed a cold Marshall test procedure to estimate field voids is currently correlating the field voids with the voids obtained by the modified HMA procedure. The HMA samples are prepared by compacting in a mold. The question whether the microsurfacing samples should be compacted or screened into the sample mold remains to be answered. Also, for reliable results, the sample has to be cured in a uniformly distributed film throughout the thickness of the lift.

e. Surface preparation. The pavement surface should have all loose material removed prior to application of the micro-surface. Any structurally deficient pavement areas must be repaired. Cracks wider than 3 millimeters (1/8 inch) or with vegetation should be cleaned and sealed prior to application of the micro-surface.

f. Application. A tack coat should be applied to the pavement surface prior to application of the micro-surfacing. Immediately prior to application, the pavement surface should be wetted with a water fogging. This fogging should leave the surface damp but with no free water. The minimum thickness of application should at least exceed the maximum nominal size of the aggregate in the mixture (usually 1-1/4 to 1-1/2 times). This relates to minimum thicknesses of from 10 to 15 millimeters (3/8 to slightly over ½ inch). Where wheel ruts exceed 6 millimeters (1/4 inch) in depth, a separate rut filling layer should be placed prior to the complete overlay. The emulsion is generally heated to within 27 to 49°C (80 to 120°F) prior to mixing. Micro-surfacing applications are generally designed to be opened to traffic within 1 hour after placement. Temperature and humidity are the controlling factors for curing micro-surfacing placement. As the temperature increases and the humidity decreases, the cure time decreases. Construction of a test section is very important for micro-surfacing due to changes in field conditions from lab conditions. Micro-surfacing is a quick-set system. Therefore, changes or variations in field conditions may require moisture, additive, or basic mix design changes to meet field conditions. Where possible, placement should be accomplished utilizing “nurse trucks” to allow for continuous placement. “Nurse trucks” are vehicles that are intended to carry aggregate, emulsion, and water to the application vehicle, whereby, application of the micro-surfacing can be a continuous operation. Whenever placement of the micro-surfacing is stopped, the spreader box must be lifted and cleaned and the transverse joint squared. Paper strips or metal flashing can be used to improve transverse joints. Longitudinal joints should be constructed with a 50 millimeter (2 inch) overlap to assure complete coverage and to reduce rigid development. The use of an operator to control the rate of material flow along with careful control of the placement vehicle’s speed allows for accurate placement of the micro-surfacing.

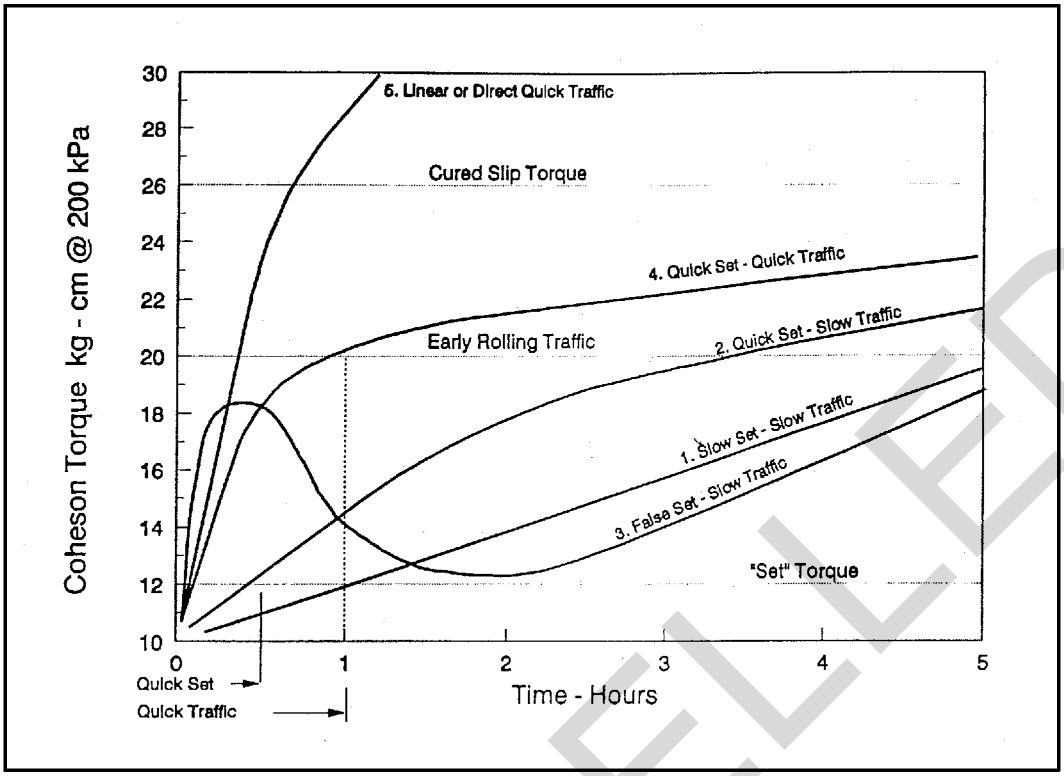

Figure 4-1 Classification of mix systems by cohesion test curves

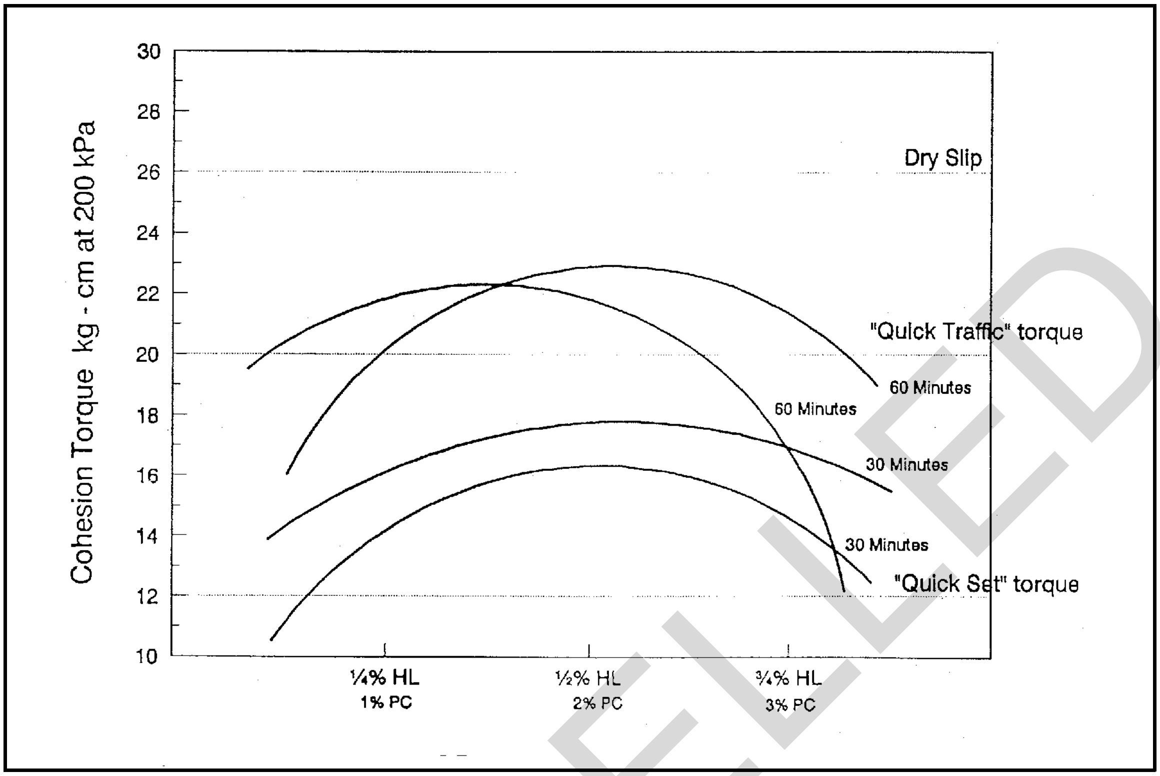

Figure 4-2 Mineral filler content optimization "Benedict Curve"

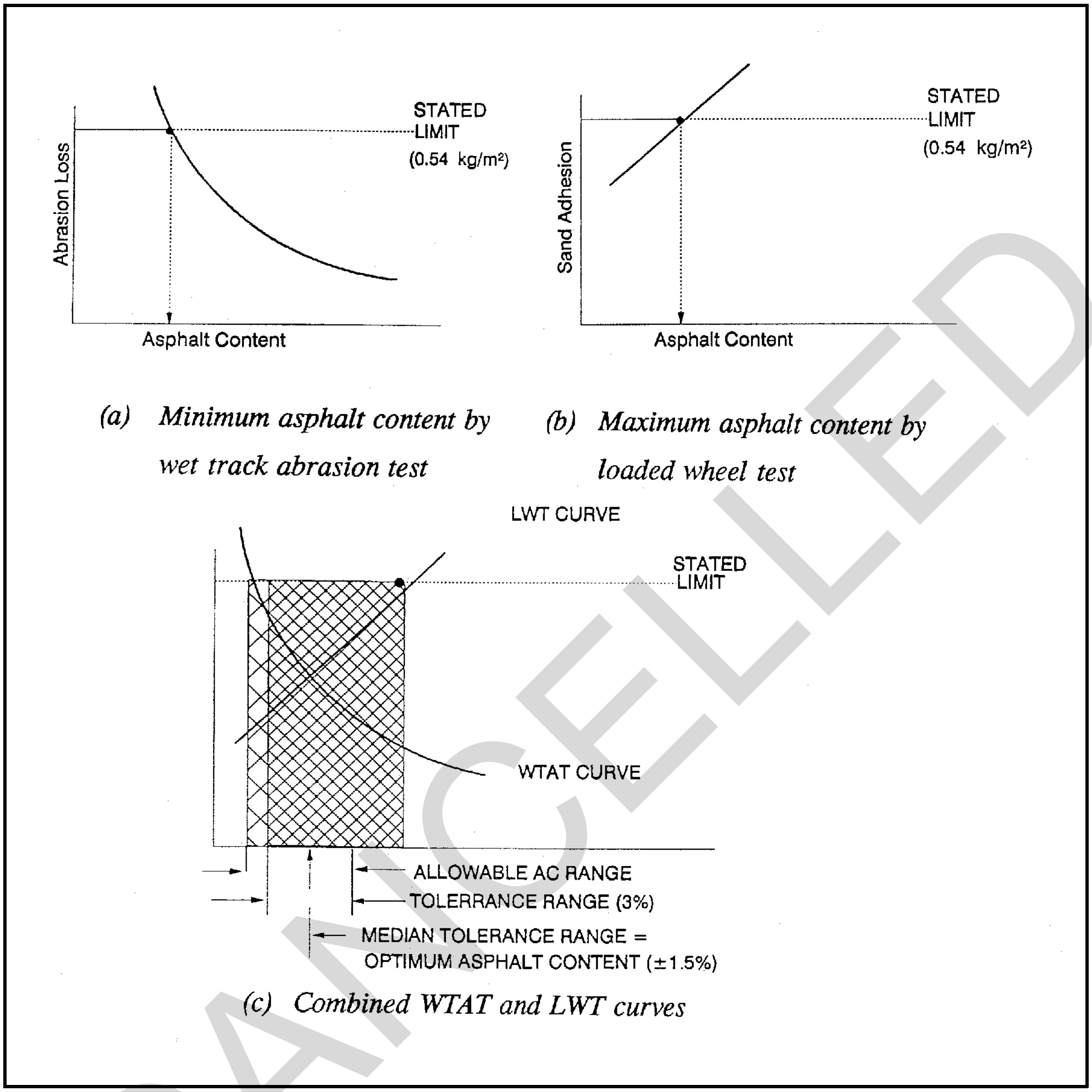

Figure 4-3 Determination of optimum asphalt content

CHAPTER 5

ASPHALT STABILIZATION

1. GENERAL. This chapter contains information for use of asphalt cement for stabilization of soil/aggregate materials and on stabilization of drainage layers. When any subsurface layer receives an asphalt treatment, the treatment will be considered asphalt stabilization. In general, asphalt stabilization is utilized where good base course materials are not readily available and where the existing subgrade materials are sands or silts suitable for stabilization. Technical Manual TM 5-822-4/AFM 88-7, chap. 4 (Future AFJMAN 32-1019) contains detailed information on the design and construction of asphalt stabilized soils.

2. MATERIALS.

a. Soil/aggregate. There are a number of requirements for determining soil suitability for asphalt stabilization. The stabilization of fine-grained soils depends on the plasticity characteristics and amount of material passing the 75 m (No. 200) sieve. Table 5-1 lists a recommended gradation of materials for asphalt stabilization. Soils with high plasticity are not stabilized with asphalt because of difficulty in thoroughly mixing the asphalt into the soil. These soils can only be stabilized if pretreated with lime or cement to decrease the plasticity of the soil.

b. Asphalt. The asphalt used for stabilization may be either emulsified or cutback asphalt. Normally, the emulsions used are slow setting (SS) or possibly some medium setting (MS) emulsions. Rapid set (RS) emulsions are not used. Any type of cutback from rapid (RC) to medium (MC) to slow (SC) cure can be used for asphalt stabilization. The use of emulsions versus cutbacks is dependent on the availability of materials, soil type, climate, and construction practice. The availability of cutbacks may be limited in some areas due to environmental concerns.

Table 5-1
Recommended Gradations for Asphalt-Stabilized Subgrade Materials

Sieve Size	Percent Passing
76.2 mm (3 inch)	100
4.75 mm (No. 4)	50-100
600 m (No. 30)	38-100
75 m (No. 200)	2-30

3. COMPOSITION AND MIXTURE. For stabilized materials, the type of asphalt used can be as important as how much is used. TM 5-822-4/AFM 88-7, chap. 4 (Future AFJMAN 32-1019) contains information on the type and amount of liquid asphalt to use. Design procedures for determining optimum asphalt content are given for both cutback and emulsified asphalts.

4. CONSTRUCTION. Methods and procedures for constructing asphalt stabilized materials are given in TM 5-822-4/AFM 88-7, chap. 4 (Future AFJMAN 32-1019).

5. DRAINAGE LAYERS. Guidance for the design and construction of subsurface drainage features is given in TI 825-01/AFM 32-1124(I)/NAVFAC DM 21.10. Open graded material (OGM) is the drainage

feature that normally requires stabilization for construction stability or for adequate structural strength to serve as a base for a flexible pavement.

a. Design. The amount of asphalt used should only be enough to coat the aggregate and hold it in place and not fill any voids. Normally about 2 to 2-1/2 percent (by weight of total mixture) asphalt is sufficient for stabilization. As a rule, the more open graded the material is, the lower the asphalt content required for stabilization. The asphalt used should be similar to the grade normally used in that location. If possible a higher viscosity (stiffer) asphalt may be used to provide increased stability.

b. Construction. A stabilized OGM should be placed with a paver to minimize segregation and achieve the proper grade and thickness. Usually an asphalt cement is used as the binder and the OGM is run through a hot-mix asphalt plant to achieve proper coating and to allow for placement. Liquid asphalts (emulsions or cutbacks) can be used if conditions warrant. An OGM will not require a large compactive effort. The mixture should only be rolled to seat the aggregate in place.

CHAPTER 6

MISCELLANEOUS MIXTURES

1. SAND-ASPHALT MIXTURES. In regions such as coastal areas where sand of good quality is the only local aggregate available, the sand can be used to produce an economical base or surface course. Sand mixtures meeting these minimum requirements may be considered for paving roads and streets where light loads are anticipated and where considerable savings may be realized by using locally available sand. Mineral filler is often added to increase the density and stability of the mixture, but mineral filler is sometimes omitted in designing sand-asphalt mixtures for asphalt-stabilized base courses. Asphalt cement, cutback asphalt, or emulsified asphalt may be used for binder. Cold-laid asphalt mixtures may be mixed at a central plant, mixed with a travel plant, or mixed in place. Hot-mix asphalt is mixed at a central plant. Sand mixes are fine textured, dense, and relatively impermeable. The stability and durability of the sand mixes depend on the quality and grading of the fine aggregate, the amount and grade of asphalt binder, and the degree of control exercised in construction operations. The sand should be sufficiently well-graded to meet the specified aggregate requirements for the type of course to be constructed and should be free from excessive amounts of foreign matter. In many cases, the proper gradation may be obtained by selecting and blending locally available sands.

a. Advantages and disadvantages. Sand-asphalt mixes can be produced with locally available materials at a relatively low cost. The use of sand mixes is limited due to the relative lack of strength and durability.

b. Uses. Sand mixes will not be used as surface or intermediate courses for airfield and heliport pavements designed for high-pressure tires or for pavements designed for solid-rubber tires, steel wheels, or tracked vehicles. High pressure truck tires and ATV tires should not be allowed on sand asphalt mixes. Sand mixes may be considered for asphalt-stabilized base courses for all types of traffic areas and for any course in nontraffic areas. Sand mixes may be considered for surface and intermediate courses with pavements subjected to low-pressure tires (690 kPa, 100 psi or less) and low traffic volumes. In this case, trial mixes should be made and tested in the laboratory. This type of mix has been used to provide temporary travel paths for construction vehicles over completed asphalt concrete pavements. The maximum sized aggregate particle should be no more than 9.5 millimeters (3/8 inch) to prevent the traffic from making indentations on the underlying asphalt concrete pavement.

2. SHEET ASPHALT. Sheet asphalt is a refined type of hot sand-asphalt pavement in which the grading, quality of sand, amount of mineral filler, and asphalt cement content are carefully controlled. The percentage of asphalt required is generally higher than that used for sand asphalt. Sheet asphalt provides a smooth, impermeable, homogeneous surface course that gives best service when traffic is spread evenly over the pavement. Normally, sheet asphalt is used for surface courses only and is constructed 38 to 50 millimeters (1-1/2 to 2 inches) thick over an intermediate course.

3. STONE-FILLED SHEET ASPHALT. Stone-filled sheet asphalt normally consists of up to 35 percent coarse aggregate, well-graded sand, mineral filler, and asphalt cement prepared in the same manner as sheet asphalt. The coarse aggregate should pass the 16 millimeter (5/8-inch) sieve. The stone-filled sheet asphalt mixture is a type of sheet asphalt mixture and has the same general characteristics. The percentage of coarse aggregate will vary proportionally when the specific gravities of the fine aggregate and coarse aggregate portions are not uniform. Stone-filled sheet asphalt pavement is used generally as a surface course constructed 38 to 50 millimeters (1-1/2 to 2 inches) thick and is sometimes called “Topeka Mix.” The uses of this mixture should be limited to those given for SAND-ASPHALT MIXTURES.

a. Advantages and disadvantages. The addition of stone increases the strength of the sand mixture significantly. However, the addition of stone may increase the cost and in some cases produce a loose aggregate problem resulting in broken windshields or foreign object damage.

b. Uses. Stone-filled sheet asphalt pavements have the same uses as sand-asphalt mixtures.

4. PENETRATION MACADAM.

a. General. A penetration macadam surface course is constructed beginning with a layer of rolled coarse aggregate followed by a pressure application of asphalt cement. Next, the surface voids in the coarse aggregate layer are filled with fine aggregate to lock in the coarse aggregate followed by an additional application of asphalt binder which is then covered with fine aggregate and rolled. A minimum amount of equipment is required for construction, and for this reason the pavement is particularly adapted for jobs in remote localities involving small yardage. Macadam surfacing is not generally considered equal in quality to asphalt pavements produced by central paving plants. The surface course is not as dense as plant-mixed asphalt pavements, and the possibility of loosely bound surface aggregates prohibits the use of penetration macadams on airfield and heliport pavements. Penetration-type surfaces may be considered for roads and streets not subjected to traffic by tracked vehicles. The use of penetration macadam construction has greatly diminished over the years because of new and better developments in equipment and construction techniques for other pavement types.

b. Materials.

(1) Asphalt materials. The binder specified for penetration macadam is an asphalt cement. The asphalt may be either an 85 to 100 or a 120 to 150 penetration-graded or an AC-5 or AC-10 viscosity-graded asphalt cement.

(2) Aggregates.

(a) Only clean, uncoated, dust-free aggregate should be used in macadam construction. The aggregate should be composed of hard, angular stone with a one-size (uniform) gradation. The gradation should also be strong enough to resist crushing under the construction rolling and should be polish-resistant under traffic. Flat and elongated aggregate particles and wet or dusty aggregate are undesirable. Wet or dusty material can result in poor adhesion and stripping.

(b) Tables 6-1 and 6-2 give the recommended gradations for 50 millimeter (2 inch-) and 64 millimeter- (2-1/2 inch-) thick macadam, respectively.

c. Design. Tables 6-3 and 6-4 present the general application rates for placing one application of coarse, two of key, one of fine aggregate, and three applications of bitumen. Table 6-3 is for 50 millimeter (2-inch)-thick macadam, and table 6-4 is for 64 millimeter (2-1/2-inch)-thick macadam.

d. Placement.

(1) Special attention must be given to each course of aggregate and binder to insure that the desired application rates are applied, that the rolling is sufficient, and that the desired grade and smoothness are obtained.

(2) For better control of application rates, an aggregate spreader and an asphalt distributor should be used. The spreader and distributor must be calibrated and checked for the specified application rate. ASTM D 2995 offers a method of determining the application rate of asphalt

Table 6-1
Gradation for 50 millimeter- (2-inch)- Thick Macadam Wearing Course

Sieve Size	Percent Passing by Weight Coarse Aggregate	Key Aggregate	Fine Aggregate
50 mm (2 inch)	100	--	--
38 mm (1-1/2 inch)	90-100	--	--
25 mm (1 inch)	20-55	--	--
19 mm (3/4 inch)	0-15	100	--
12.7 mm (1/2 inch)	--	90-100	100
9.5 mm (3/8 inch)	0-5	40-70	86-100
4.75 mm (No. 4)	--	0-15	10-30
2.36 mm (No. 8)	--	0-5	0-10
1.18 mm (No. 16)	--	--	0-5

Table 6-2
Gradation for 64-millimeter- (2-1/2-inch)- Thick Asphalt Macadam Wearing Course

Sieve Size	Percent Passing by Weight Coarse Aggregate	Key Aggregate	Fine Aggregate
64 mm (2-1/2 inch)	100	--	--
50 mm (2 inch)	90-100	--	--
38 mm (1-1/2 inch)	35-70	--	--
25 mm (1 inch)	0-15	100	--
19 mm (3/4 inch)	--	90-100	--
12.7 mm (1/2 inch)	0-5	--	100
9.5 mm (3/8 inch)	--	20-55	86-100
4.75 mm (No. 4)	--	0-15	10-30
2.36 mm (No. 8)	--	0-5	0-5

Table 6-3
Application Rates for 50-millimeter- (2-inch)- Thick Course

Placing Operations	Asphalt Material liters/sq m (gal/sq yd)	Aggregate, kg/sq m (lb/sq yd)
First spreading	--	90-95 (165-175)
First application	4.98-5.89 (1.10-1.30)	--
Second spreading	8-13.5 (15-25)	--
Second application	1.36-2.26 (0.30-0.50)	--
Third spreading	6.5-11 (12-20)	--
Third application	1.13-2.04 (0.25-0.45)	--
Fourth spreading	5.5-11 (10-20)	–

Table 6-4
Application Rates for 64-millimeter (2-1/2-inch-) Thick Course

Placing Operations	Asphalt Material liters/sq m (gal/sq yd)	Aggregate, kg/sq m (lb/sq yd)
First spreading	--	111-117 (205-215)
First application	6.34-7.24 (1.40-1.60)	--
Second spreading	11-16 (20-30)	--
Second application	1.81-2.72 (0.40-0.60)	--
Third spreading	8-13.5 (15-25)	--
Third application	1.36-2.26 (0.30-0.50)	--
Fourth spreading	11-16 (20-30)	–

distributors. In addition, the Asphalt Institute's Manual Series No. 13 offers guidance for calibrating and checking application equipment.

(3) Rolling is necessary to seat the aggregate, but the first or main course of coarse aggregate should not be closed by rolling. Rolling should be continued only long enough to seat the coarse aggregate, and the aggregate should be left open enough to permit ready penetration of the first application of asphalt and entrance and interlocking of the key aggregate. Immediately following the first application of asphalt the key aggregate should be uniformly spread and rolled. The key aggregate will be applied in two applications, each preceded by an application of asphalt. The final course of aggregate is the fine aggregate which immediately follows the third application of asphalt.

5. ROCK-ASPHALT. Rock-asphalt pavement is composed of crushed, natural asphalt-impregnated limestone or sandstone, or a combination of these, used alone or mixed with additional asphalt or flux oil. Rock-asphalt pavement is laid cold in the same manner as cold-laid asphalt mixture. Rock asphalt will only be used in surface courses for roads and will not be constructed over 38 and 50 millimeters (1-1/2 and 2 inches) thick for blended and fluxed rock asphalt, respectively. Kentucky, Alabama, Texas,

New Mexico, Oklahoma, and Utah have natural rock-asphalt deposits where paving material is produced commercially. The character and quantity of the aggregate and asphalt in the material varies among the different deposits and sometimes varies within the same deposit. Rock asphalt pavement is prepared by blending into the natural asphalt a crushed impregnated limestone or sand-stone or a combination of the two in proper proportions to produce a properly graded mixture with a specified asphalt content. The natural rock asphalt must be enriched (that is, more asphalt must be added to the mixture) if the material contains insufficient asphalt in its natural state to produce a satisfactory mixture. Hot mixes are sometimes produced by heating crushed limestone impregnated with relatively hard asphalt, alone or with added sand, and mixing with additional asphalt cement in a conventional plant.

a. Advantages and disadvantages. The advantages and disadvantages are the same as those for plant-mix cold-laid asphalt mixtures. In addition the use of rock-asphalt pavement reduces cost because this mixture already contains binder material.

b. Uses. Rock-asphalt pavements are used for roads and streets not subjected to traffic by tracked vehicles. Rock asphalts are sometimes used as the aggregate in slurry seals, but only predominantly sandstone rock asphalts should be used in slurry since some limestone rock asphalts polish under traffic and thus produce a slick pavement surface.

6. PLANT-MIX COLD-LAID ASPHALT PAVEMENTS.

a. General. Cold-mix asphalt pavements can be used as a low-cost surface for low-volume roads or as a base course for high-volume roads and airfields. While cold mixes do not provide pavements with the same quality of hot mixes, cold mixes do perform satisfactorily for the purposes intended. Cold mixes can be stored for several months or more and are very useful for minor patching. Because fuel is not needed to heat cold mixes, these pavements can generally be constructed at lower costs than hot mixes. Some disadvantages of using cold mixes are that a lower density is usually obtained in cold mixes than in the construction of hot mixes and that a curing period is needed to allow water or volatiles to evaporate so that a satisfactory shear strength is obtained.

b. Design.

(1) Preliminary work. The first step in designing a paving mixture is to make a survey to insure that the materials needed are available in suitable quantities and their use is economically feasible in the pavement construction. Sufficient samples of material should be obtained during the survey to accomplish the tests described later. Materials normally required for the paving mix are coarse aggregate, fine aggregate, mineral filler, and bitumen.

(2) Sampling. Test reports reflecting the results of sampling and testing of the aggregates and bituminous materials will be prepared. A gradation analysis must be conducted on the aggregates to determine whether the aggregates can be blended to meet the contract gradation specifications. Representative samples of materials must be furnished for laboratory testing. Large samples must be divided into sizes usable for testing in the laboratory, in a way that will represent field conditions. Sufficient quantities of materials will be obtained at the time of sampling to meet the ASTM requirements and for laboratory pavement design tests subsequently described. Normally, aggregates that will produce 90 kilograms (200 pounds) of the desired gradation and 19 liters (5 gallons) of bitumen will be sufficient for these tests.

c. Materials.

(1) Tests on aggregates.

(a) Aggregates for use in an asphalt mixture should be clean, hard, and durable. Angular aggregates provide more stable pavements than do rounded aggregates. Most of the tests of aggregates required in the design of hot-mix, hot-laid asphalt mixtures are also applicable to the cold-laid type. Table 6-5 lists the aggregate gradation requirements. These gradations correspond to those recommended in this text for hot-mix, hot-laid asphalt mixtures. The gradations given in table 6-5 correspond to those given in table 2-1 for hot-mix asphalt.

Table 6-5
Aggregate Gradations for Plant-Mix Cold-Laid Asphalt Pavements

	Percent Passing Sieve by Weight	
Sieve Size	12.7 Millimeter (1/2-inch) Maximum	9.5 Millimeter (3/8-inch) Maximum
12.7 mm (1/2 inch)	100	--
9.5 mm (3/8 inch)	86 ± 9	100
4.75 mm (No. 4)	66 ± 9	85 ± 9
2.36 mm (No. 8)	53 ± 9	71 ± 9
1.18 mm (No. 16)	41 ± 9	57 ± 9
600 m (No. 30)	31 ± 9	43 ± 9
300 m (No. 50)	21 ± 8	31 ± 8
150 m (No. 100)	13 ± 6	19 ± 6
75 m (No. 200)	4.5 ± 1.5	6 ± 3

(b) Generally, aggregates for paving mixes must be combined from two or more stockpiles. The decision of whether to add a mineral filler sometimes required depends on the amount of filler naturally present in the aggregate. Mathematical equations are available for making such combinations, but are not presented in this manual because they are lengthy and trial-and-error procedures are normally easier. The method of combining stockpile sample gradations is described in paragraphs *Proportioning of stockpile samples* and *Proportioning of bin samples* under *HOT-MIX ASPHALT MIXTURES*. The gradation of the aggregate must fall within the limits of the gradations chosen from table 6-1 for the project specifications and shall present a smooth curve when plotted with sieve size versus percent passing.

(2) Tests on asphalt cement.

(a) The specific gravity of the asphalt cement must be known to determine the percent by volume of bituminous materials in the mix. Because only the residual asphalt will be used in calculating the percent binder, the amount of residual asphalt cement in cut-back asphalts and asphalt emulsions will be determined as specified in ASTM D 402 and ASTM D 244 for cut-back and emulsified asphalts, respectively. The specific gravity of the residual asphalt shall be determined as described in ASTM D 70.

(b) Plant-mix cold-laid pavements may be made with asphalt cement and liquefier, cut-back asphalts or emulsified asphalts. A cut-back asphalt can be produced, usually for small or remote projects, by using kerosene to liquify an asphalt cement. The type of asphalt cement used to make this liquid binder can be easily varied to meet various climate conditions. The cut-back binder produced can have a relatively long shelf life, depending on the amount of cut-back material or kerosene that is added.

Cut-back asphalts can be contained in a single tank, and only the standard pipelines and spray bar are necessary. Additional equipment is necessary for handling the kerosene and asphalt cement, when this type of binder is produced. Asphalt emulsions are advantageous in that damp aggregate can be used in the mixing process; whereas, dry aggregates are required for the other binder materials. Mixes made with asphalt emulsions cannot be stockpiled unless the emulsion has been specifically formulated for stockpiling purposes. The choice of asphalt material type depends primarily on economics and the type of equipment to be used. Table 6-6 is provided as a guide to the selection of the proper type and grade of asphalt cement. The table provides information on asphalt for mixes to be used immediately and on asphalt for mixes to be stockpiled for later use.

Table 6-6
Selection of Asphalt

Asphalt Parameter	Cold (less than 16°C, 60°F)	Conditions Climatic Moderate 16-27°C, (60-80°F)	During Construction or Storage Hot (above 27°C, 80°F)
Penetration grade	85-100	85-100	120-150
Viscosity grade	AC-20	AC-20	AC-10
Kerosene, gallon per ton mix	2.0 (4.5[1])	1.7 (3.7[1])	1.5 (3.0[1])
Cut-back asphalts	RC-70 - RC-250	RC-250 - RC-800	RC-800 - RC-3,000
Emulsified asphalts[2]	MS-2h SS-1h	MS-2 - MS-2h SS-1 - SS-1h	MS-2 SS-1

Note: RC = rapid curing; MS = medium set; SS = slow set.
[1] Amount of kerosene to be added when mixture is to be stockpiled for future use.
[2] Emulsified asphalts are available that are specifically formulated for stockpile use.

d. Design. Several equations based on the surface area of the aggregate are available for calculating the optimum amount of asphalt cement in the mix. Although these equations give an approximation of the binder content, they do not properly account for porosity of the aggregate or the compaction characteristics of the mix and, therefore, can be misleading. The following procedure is recommended for determining the amount of asphalt cement to be used in the paving mix for plant-mix cold-laid pavements. This design procedure is similar to the procedure used for designing plant-mix hot-laid mixes for roads and streets. The laboratory equipment and test procedures shall be determined by CRD-C 649 and CRD-C 650.

(1) Asphalt contents for specimens. The quantity of asphalt cement required for a particular aggregate is the most important factor in the design of a paving mixture. An estimate of the optimum amount of asphalt cement for the aggregate to be tested should be made in order to start the laboratory tests. Laboratory tests normally are conducted for a minimum of five asphalt cement contents: two above, two below, and one at the estimated optimum content. Incremental changes of 1 percent may be used for preliminary work, but increments of 0.5 percent are generally used where the approximate optimum asphalt cement content is known and for final designs.

(2) Proportioning of aggregates. As a preliminary step in mixture design and manufacture, it is necessary to determine the approximate proportions of the different available stockpiled materials required to produce the desired gradation of aggregate. The above-mentioned step is necessary to determine whether a suitable blend can be produced and, if so, the approximate proportion of aggregates to be fed from the cold feeders into the dryer. Sieve analyses are conducted on material from each of the stockpiles. The aggregates are combined as described in chap 2. After a suitable

blend has been prepared from the available materials, then samples of these materials can be processed for used for use in the laboratory design tests as specified in CRD-C 649.

(3) Determination of optimum asphalt cement content. The optimum asphalt cement content will be taken as the average of the asphalt contents corresponding to the mix properties in table 6-7. The optimum asphalt cement content will be the amount of asphalt cement that will be incorporated into the mix. The percent of cut-back asphalts and emulsified asphalts will be corrected to give a residual asphalt content equal to the optimum asphalt content determined by the tests. Because all of the volatiles do not evaporate, the amount of bitumen to be added as determined by this mix design procedure should be decreased slightly. When the asphalt cement and kerosene type mix is to be used, the desired amount of kerosene will be added to the actual paving mix in addition to the optimum asphalt content determined from the laboratory design.

Table 6-7
Selection of Optimum Asphalt Content

Mix Property	Value for Determining Optimum Asphalt Content
Unit weight of mix, pcf	Peak of curve
Voids total mix, percent	4 ± 1
Voids filled with asphalt, percent	75 ± 5

(4) Plant control. Plant control is discussed in chap 2.

(5) Plant operation. The plant operation varies with the type of asphalt material used in the mix. For mixes using asphalt cement and kerosene, the kerosene and asphalt cement must be introduced onto the aggregate at different times. Drying of the aggregate is not necessary with asphalt emulsions, but for cut-back binders the aggregates should be heated to between 380° and 107°C (100° and 225°F). Aggregates should not be hotter than 93°C (200°F) when mixed with cut-back asphalts or asphalt cement and kerosene. The asphalt materials should be in the temperature ranges given in table 6-8 when introduced into the pugmill.

(6) Plant laboratory. Use of a plant laboratory will insure that the aggregate is of the proper gradation and that the mix contains the prescribed percentage of asphalt material. The plant laboratory should contain the following major equipment:

— Hand- or power-driven mechanical sieve shaker. The sieve shaker shall have a capacity of not less than eight full-height 20 millimeter (8-inch)-diameter sieves.

— Full-height 200 millimeter (8-inch)-diameter sieve for each of the following sieve openings: 12.7 millimeter (1/2 inch), 9.5 millimeter (3/8 inch), 4.75 millimeter (No. 4), 2.36 millimeter (No. 8), 1.18 millimeter (No. 16), 600 m (No. 30), 300 m (No. 50), 150 m (No. 100), and 75 m (No. 200). The sieves shall have square openings and shall conform to requirements of ASTM E 11.

— Extractor suitable for obtaining bitumen content within close tolerances.

— Balance having a capacity of 2 kilograms and sensitive to 0.1 gram.

— Marshall equipment for compacting and testing samples to verify mixture design.

Table 6-8
Mixing Temperatures for Asphalt Materials

Bituminous Material Type	Grade	Temperature Range, °F
Emulsified asphalts	MS-2	100-160
	MS-2h	100-160
	SS-1	75-130
	SS-1h	75-130
Cut-back asphalts	RC-70	100-135
	RC-250	135-175
	RC-800	170-205
	MC-70	100-135
	MC-250	135-175
	MC-800	170-205

Note: MC = medium curing; RC = rapid curing; MS = medium set; and SS = slow set.

(7) Adjusting mix proportions. Mix proportions shall be adjusted whenever tests indicate that specified tolerances are not being met. Fully automated plants should produce consistent mixtures, provided they are correctly calibrated and in good working condition. Improper weighing or faulty scales may be detected readily and corrective measures taken by maintaining a close check or load weights. The total weight of each load of mixture produced shall not vary more than plus or minus 2 percent from the total of the batch weights dumped into the truck. Figure 2-15 presents other probable causes of paving-mixture deficiencies due to improper plant operations.

e. Preparation of construction specifications.

(1) Specifications. Cold-laid asphalt mixtures will be produced according to provisions of guide specifications except when small quantities of mix, less than 100 metric tons, may be necessary for limited use in repairs. In these cases, the procedures specified in the guide specification would not be economical. When such an exception is deemed necessary, locally available cold-laid bituminous mix produced according to local state highway department specifications may be used when approved by the Division Engineer. When the quality exceeds 100 metric tons for Army projects, approval from the USACE Transportation Systems Center (CENWO-ED-TX) will be required. A copy of the specification or proper reference thereto and information regarding traffic conditions and facilities to be paved will accompany the request for approval.

(2) Placing. Although closer control of layer thickness and better prevention of segregation of the mix can be achieved with a mechanical spreader, a motor grader is sometimes desirable for spreading plant-mix cold-laid pavements. Aeration of the mix to remove some of the volatile material is often necessary to bring the mix to the proper condition for compaction. A motor grader can aerate the mix by balding it back and forth across the roadbed.

(3) Compaction of mixture. At the time of compaction, the asphalt material in the mixture must provide a proper amount of cohesion, so that the desired density can be reached. Cohesion of the mixture will be controlled by the type of asphalt material, volatile content, and temperature of the mixture. Low cohesion will cause the mix to be unstable under the roller, while high cohesion will cause

the mix to be too stiff to be compacted. The mixture should be compacted as soon as it will support the roller without undue displacement.

7. ASPHALT ROAD MIX. Asphalt road mixes are normally mixed in place by the use of travel plants or common types of road-building equipment, such as blade graders, disk harrows, drags, and pressure distributors. The binders used in road-mix construction may be either cut-back asphalts or emulsified asphalts. The percentage of asphalt required is generally the same as for cold-laid asphalt mixes and depends upon the type and gradation of the aggregate used. Aggregates used in road mixes may be existing subgrade materials, loosened existing subgrade materials blended with imported materials, or properly processed imported materials placed on the existing base or subgrade. When the amount of material passing the 75   m (No. 200) sieve exceeds 20 percent, stabilization with asphalt is difficult. A wide range of aggregates may be used, and the gradation requirements are less strict than those for hot or cold plant-mixed types. The bitumen is normally applied by a pressure distributor to the processed aggregate on the base or subgrade and then thoroughly mixed with the aggregate. A travel-type mixing plant combines the aggregates with an asphalt material and continuously discharges the mixture at the rear of the machine as the plant travels along the strip being paved. The use of a travel plant permits more accurate proportioning of the bitumen and aggregate and generally produces a more uniform and higher quality mixture than a mixed-in-place method. Further, because more viscous types of cut-back asphalt may be used, the curing time is reduced. Curing is usually required to reduce the volatiles in the cut-back asphalt or water in the asphalt emulsion prior to spreading and compacting, because excessive amounts of volatiles and water affect the compatibility of the mixture and the stability of the finished pavement. Manipulation with blades or other road machines may speed up curing.

a. Advantages and disadvantages. Much less equipment is required for construction using asphalt road mix than is required using asphalt concrete, thus resulting in cost savings. The use of locally available materials also results in significant cost savings. Asphalt road mix, however, does not have the strength or durability of hot-mix asphalt. The road-mix type of pavement provides an economical means of obtaining a satisfactory surface for roads and streets when the required amount of pavement is small, when the natural soil is suitable as aggregate, or when satisfactory aggregates are nearby. Seal coats with aggregate cover should be applied as a part of road-mix construction, since road mixes are often open graded or of relatively low density and are therefore susceptible to oxidation and abrasion.

b. Uses. When properly designed and constructed on a suitable existing subgrade or using locally available aggregates, the quality of road-mix construction approaches that of cold-laid plant mix. Road mix is used for intermediate or surface courses, but because of the less accurate control, it is considered inferior to plant mixtures. Road mix is not suitable for use above the base course for airfields. Road mix may be used as a wearing course for temporary roads and streets, or as the first step in stage construction for permanent roads and streets when these are to be supplemented by plant-mix surfaces as the demands of traffic increase and warrant the increased thickness. Seal coats reduce infiltration of air and water and thus improve the durability of road-mix pavements.

CHAPTER 7

RECYCLING

1. INTRODUCTION.

a. General. The recycling of pavement materials has proven to be an economical and feasible process to rehabilitate worn-out pavements. **The use of recycled mixtures for surface courses is not recommended by either the Army or the Air Force. If an exception to this policy is required, the Air Force base should contact their MAJCOM pavements engineer and the Army designer should contact the USACE Transportation Systems Center (TSMCX).** Recycling should always be considered when repairing or rehabilitating existing pavement. The use of recycled materials in pavement maintenance and rehabilitation has increased for the following reasons:

(1) Environment. The reconstruction of old pavements without recycling often consists of removing, stockpiling, or disposing of all pavement materials. Recycling of these pavement materials reuses an available material resource and eliminates the disposal problem.

(2) Material cost. In the last several decades it has been recognized that there is not an unlimited supply of natural materials. The amount of asphalt and high-quality aggregate available for construction is limited. This fact, along with economic realities have caused a substantial increase in the cost of pavement materials and have encouraged the use of recycled materials. Increasing costs of fuel and equipment have encouraged recycling, especially as haul distances become longer.

(3) Technology and equipment. Increased interest in recycling pavements has brought about the development of technology and equipment for recycling that can generate an overall reduction in cost when compared to using new materials. There still exist technical limitations that prevent the complete recycling of existing pavements into new pavements.

b. Recycling methods. Asphalt pavement recycling methods can be divided into the following three categories: surface recycling, cold-mix recycling, and hot-mix recycling. Table 7-1 lists the advantages and disadvantages of the various methods. Many types of distresses can be corrected by one of the pavement recycling methods identified in table 7-2.

(1) Surface recycling. Hot in-place recycling, rejuvenating, and cold milling are methods of surface recycling that are used to increase skid resistance, decrease permeability to air and water, and improve properties of the asphalt binder. Depending on the process used, surface recycling may modify the top 5 to 40 millimeters (1/4 to 1-1/2 inches) of pavement. However, surface recycling does not increase the structural strength of the pavement. The existing condition of the pavement surface will control in the decision whether or not to recycle. The costs involved in the hot in-place recycling of a pavement to a depth of 25 millimeters (1 inch) will approach the cost of a 25 millimeter (1 inch) overlay. The existing pavement surface condition will need to be considered when judging the benefits of the additional 1 inch of overlay versus the benefits obtained from hot in-place recycling.

(2) Cold-mix recycling. Cold-mix recycling is a process which reclaims most or all of the existing asphalt pavement by breaking it to a maximum particle size of 25 to 40 millimeters (1 to 1-1/2 inches), mixing it with virgin materials, if needed, and reusing the mixture as a pavement material. Cold recycling material can be used to surface secondary roads, if a seal coat is applied, and as a base course for high-quality pavements.

7-1 Advantages and Disadvantages of Asphalt and Portland Cement Concrete Pavement Recycling

Table 7-1
Advantages and Disadvantages of Asphalt and Portland Cement Concrete Pavement Recycling

Pavement Recycling Method	Advantages	Disadvantages
1. Surface recycling Hot in-place recycling	1. Minimizes traffic disruption 2. Requires less new materials 3. Retards reflective cracking with thin overlay 4. Smooths out minor roughness 5. Quality control on job is difficult to obtain	1. Tendency to violate pollution standards 2. Difficult to control quality of overlay mix 3. Should be used only on structurally sound pavements 4. Burning of old asphalt may occur
Cold milling	1. Improves rideability of pavement 2. Can be used with asphalt concrete and portland cement concrete pavements 3. Improves skid resistance of overlay 4. Provides a good temporary road surface if money is not available for immediate overlay 5. Reduces thickness of overlay required 6. Minimizes traffic disruption	1. Possible foreign object damage problem 2. Should be used only on structurally sound pavements
Rejuvenator	1. Minimizes traffic disruption 2. Quick and easy to apply 3. Least expensive of any option	1. Temporarily reduces skid resistance 2. Should be used only on structurally sound pavements 3. Cannot be used on pavement with rich asphalt content
2. Cold-mix recycling	1. Uses old pavement 2. Decreases reflective cracking 3. Improves structural soundness of pavement 4. Improves frost susceptibility 5. Allows for subgrade repairs if necessary	1. Traffic disruption 2. Requires an overlay 3. May not be cost-effective
3. Hot-mix recycling	1. Uses old pavement 2. Requires less new materials 3. As good as new pavement 4. Maintains present drainage patterns and structures 5. Decreases reflective cracking 6. Allows for subgrade repairs if necessary	1. Traffic disruption 2. May not be cost-effective

Table 7-2
Method of Repair Guide for Asphalt Pavement Rehabilitation

Pavement Distress[a]	Severity Level[b]	Surface Recycling: Rejuvenators	Surface Recycling: Hot in-place Recycling	Cold-Milling	Cold-Mix Recycling	Hot-Mix Recycling	Seal Cracks	Remove and Replace	Surface Seal	Overlay
Alligator or fatigue cracking	L	X					X		X	
	M		X		X	X				X
	H					X		X		X
Bleeding			X	X		X				X
Block cracking	L	X					X		X	
	M		X			X	X	X		X
	H					X		X		X
Corrugation	L									
	M				X	X		X		X
	H				X	X		X		X
Depression	L		X					X		
	M		X		X	X		X		X
	H				X	X		X		X
Jet blast erosion								X	X	
Joint reflection cracking from PCC (longitudinal and transverse)	L						X			
	M					X	X			X
	H						X			
Longitudinal and transverse cracking (non-PCC joint reflective)	L	X								X
	M	X			X	X	X	X	X	X
	H						X			
Oil spillage				X						
Patching and utility cut patch	L									
	M			X				X	X	
	H									
Polished aggregate			X	X						X
Raveling and weathering	L	X							X	
	M	X	X			X			X	X
	H									X

(Continued)

[a] Detail description given in Technical Manual TM 5-826-6/Air Force Regulation AFR 93-5, Procedures for U.S. Army and U.S. Air Force "Airfield Pavement Condition Surveys," July 1989.
[b] L = Low, M = Medium, H = High; refer to AFR 93-5 for description.

Table 7-2 (Concluded)

Pavement Distress	Severity Level	Surface Recycling: Rejuvenators	Surface Recycling: Hot in-place Recycling	Cold-Milling	Cold-Mix Recycling	Hot-Mix Recycling	Seal Cracks	Remove and Replace	Surface Seal	Overlay
Rutting	L									
	M		X			X				X
	H					X				X
Shoving of asphalt pavement by PCC slabs	L									
	M			X				X		
	H									
Slippage cracking					X		X			
Swell	L									
	M			X				X		
	H									

(3) Hot-mix recycling. Hot-mix recycling is a process which involves removing the existing asphalt mixture, crushing it if necessary, and mixing it in a hot-mix plant with new aggregate, asphalt, and recycling agent, when required. The hot-mix recycled asphalt mixtures can be designed for use in all types of pavements. Crushed portland cement concrete has also been used as aggregate for hot recycled mixtures.

c. Potential problems. Recycling asphalt concrete pavements generally requires more time and effort for a proper material design. Also, asphalt mixtures with highly variable material properties become very difficult to recycle. Pavement areas containing one or more overlays with varying mix designs make it difficult to establish baseline properties for a subsequent recycling design. When recycling such a pavement, separate material designs are required for each pavement area containing unique pavement materials.

2. SURFACE RECYCLING.

a. General. When a pavement is structurally sound and rehabilitation is needed to correct a surface problem, surface recycling should be considered. The three surface recycling processes discussed in the following paragraphs are hot in-place recycling, rejuvenating, and cold milling. Hot in-place recycling can be divided into either single or multiple pass methods. The basic procedures for surface recycling are shown on the flow chart in figure 7-1.

b. Equipment. The major pieces of equipment required for the various types of surface recycling techniques include: brooms, trucks, front-end loaders, graders, asphalt distributors, self-contained heating units, heater-scarifiers, hot-milling machines, pavers, trucks, and/or cold-milling machines.

c. Hot in-place recycling.

(1) General. Hot in-place recycling of the pavement surface prior to overlay can minimize some existing pavement surface problems such as bonding of overlays if the existing pavement surface has become polished over a period of years from the action of traffic. In this case, the surface can be scarified or hot milled to promote a good bond between this existing polished surface and the overlay. Hot in-place recycling also breaks up the existing crack pattern and reduces the amount of reflective cracks that will appear in the overlay. The hot in-place recycling procedure is often used to maintain secondary roads to provide a tight waterproof surface. In most instances, this process is followed by an asphalt concrete overlay. The quality of mixes obtained by hot in-place recycling is difficult to control. The quality of the mixture depends on the depth of recycling, time of heating, amount of rejuvenator added, and amounts of compaction. When no overlay is applied in conjunction with the recycling material, it is necessary that the heated material be rolled immediately to ensure that a satisfactory density is obtained. Multiple-pass methods which treat to a total depth of about 25 millimeters (1 inch) can cause an excess of coarse aggregate on the surface. This coarse aggregate makes the material difficult to compact and results in a surface that tends to ravel. The multiple-pass method without an overlay should only be used to improve the surface of mixtures on secondary roads. An overlay in conjunction with multiple-pass method is recommended. The overlay may be added prior to compaction of the recycled material and both layers compacted simultaneously, or the recycled material may be compacted prior to addition of the overlay. To ensure better bond and better overall density, it is recommended that the overlay be placed immediately after recycling the surface and the entire depth of material compacted. Although this recycling and overlay approach has been used on airfields, generally other alternatives should be selected. The asphalt sampled from the recycled and rejuvenated material should show an improvement in properties over the existing asphalt properties. The desired properties of the recovered asphalt binder will depend upon the local climatic conditions and the existing properties of the asphalt binder. Generally, the penetration and viscosity values should range from 30 to 70 and 1,000 to 3,000 poises, respectively. The amount of binder material added should not cause the voids in

the compacted mixture to become overfilled and thus create an unstable mixture. To determine when a mixture is unstable, samples of the mixture should be obtained and compacted at 121 degrees C (250 degrees F) using the standard compaction effort for the job. When the voids of the compacted samples are less than 3 percent, the mixture should be considered unstable, and the amount of rejuvenator should be reduced. Pollution caused by smoke from the heating of the asphalt surface may be a problem. But the amount of smoke can usually be controlled within an acceptable range on most asphalt mixtures. Heating of pavements that have numerous sealed cracks may present a problem since the sealer material usually causes an increase in the amount of smoke during the heating operation.

(2) Single-pass method.

(a) General. Single-pass recycling methods were first developed in Europe and have recently started to gain wide usage in the United States. The single-pass method will involve one of two procedures outlined in table 7-3. The first procedure, called remix, involves the combining of a new asphalt mixture with the reclaimed (scarified or hot-milled) asphalt mixture prior to placement on the pavement surface. The second procedure, called repave, involves overlaying the recycling material with new asphalt mix prior to rolling or cooling of the recycled material. The single-pass method usually involves several pieces of equipment, including heaters, sacrificers, hot milling heads, spray bars, or pavers in various combinations or as separate pieces of equipment. The single-pass recycling method usually involves larger and more complex pieces of equipment than are used in the multiple-pass procedure.

(b) Heating. Prior to displacing or loosening the pavement, the pavement surface is heated. The heating units are generally a refractory type and typically use liquid propane as the fuel to heat the inside of the heater unit. In this way there is never a direct flame placed on the pavement surface. Despite this lack of contact between flame and asphalt, it is not unusual for the surface asphalt to be burned. The severity of this problem is increased by excess asphalt or oils on the pavement surface. The amount of heat applied to the pavement is controlled by the amount of propane burned, the height or distance of the heater from the pavement, and the speed of the heater traveling over the pavement surface. Many methods employ two heating units for increased productivity. The first heating unit preheats the pavement; the second machine follows closely to provide additional heat to bring the pavement to the desired temperature. The heating vehicles can be either towed or self propelled.

(c) Material displacement. The single-pass methods all use hot-milling to remove approximately 25 to 40 millimeters (1 to 1-1/2 inches) of the existing asphalt concrete pavement with one pass. For greater depth of recycling two separate machines each with hot-milling heads are used. These machines usually contain pavement heating elements, tanks and spray apparatus for adding rejuvenator, or possibly new asphalt cement, some sort of mixing screws or a pugmill for mixing conveyors, and storage apparatus for new asphalt concrete, and a paving screed at the end in addition to the hot milling drum.

(d) Recycled mixture. The rejuvenator or new asphalt cement is usually either added during milling or during the succeeding mixing operation. The mixing can be accomplished by a series of augers perpendicular to the direction of travel or by a traveling pugmill. The new asphalt concrete, if it is required, is usually added to the recycled mix during this mixing. Some equipment can apply new asphalt concrete on top of the recycled mixture.

(e) Placement. The recycled mixtures are usually placed with a screed, often attached at the end of a recycling train. After placement, the mix is compacted with rollers to achieve the desired density. Single-pass methods can provide a relatively small amount of corrections from the existing grade.

Table 7-3
Hot In-Place Recycling Method Sequence

					Placing Recycled Mix		Placing New Mix	
Method	Heating	Planning/ Scarifying	Milling	Adding Rejuvenator	Intermediate Course	Surface Course	Surface Course	Compact
Single pass								
Remix	1	2	2	3	4	4		5
Repave	1	2	2	3	4		5	6
Multiple pass	1	2	2	3	4		6	5, 7

(3) Multiple-pass method.

(a) General. The multiple-pass recycling technique applies the recycled material and the wearing surface in separate operations. The recycled material is used only as an intermediate or leveling course whereas a new asphalt mixture is used as the wearing course. The multiple-pass method usually involves less complicated equipment. The original heater-planer equipment fits into this type of method. The multiple-pass method involves the use of equipment that heats the pavement, scarifies or mills the heated asphalt material, adds rejuvenator as required, and places the recycled asphalt material. This normally involves several separate pieces of equipment including heaters, sacrificers, hot milling machines, and pavers. The recycled material is placed and compacted before cooling and is used as an intermediate or leveling course. A hot-mix asphalt wearing surface is later applied to the recycled surface within a predetermined period of time. The asphalt surfacing is required to protect the recycled surface from the effects of traffic.

(b) Heating. The heating methods and procedures used are the same as those used for single-pass recycling method.

(c) Material displacement. The material can be removed with either scarifying teeth or a mill. The majority of the multiple pass methods use scarifying teeth to loosen or displace the pavement surface. The scarifying teeth are usually located at the end of the heating vehicles. In most methods, the second vehicle would not only heat the pavement but also scarify, level, and screed the pavement. The scarifying teeth are normally spring-loaded and “give” when a solid obstacle is encountered. These springs also help prevent any fracturing of the aggregate during scarification. When a preheating unit is used, the scarifying teeth can be set to penetrate up to 30 millimeters (1-1/4 inch) to obtain an effective overall depth of 25 millimeters (1 inch). The depth of scarification required will control the speed of the recycling operation.

(d) Recycled mixture. As with single-pass methods, the rejuvenator is added somewhere during the scarifying, mixing, or leveling (screening) processes. The mixing in this method is usually accomplished by auguring/mixing drums located behind the scarifying teeth.

(e) Placement. The recycled mix is usually leveled and placed by auger drums and a screed. The recycled mix is then compacted with rollers to the required density. This recycling method cannot normally change grades; however, it can smooth some bumps, depressions, and minor ruts.

d. Rejuvenating. The application of a chemical rejuvenator provides the penetration of chemicals into the asphalt pavement which act to soften the binder. Rejuvenators can be based on either asphalt or coal-tar binder materials. Rejuvenators can be sprayed directly on the surface of an asphalt pavement or they can be used in conjunction with many types of recycling processes.

(1) Properties of rejuvenators. Some of the properties of rejuvenators are described below.

(a) The application of a rejuvenator to an asphalt pavement partially restores its original asphalt properties. However, for a rejuvenator to be successful, it must penetrate the pavement surface and soften the asphalt binder. Most rejuvenators penetrate 5 millimeter (1/4 inch) or more into the surface of a pavement, depending on the type of rejuvenator, the weather conditions, and the permeability of the pavement surface.

(b) When a rejuvenator is applied to a pavement in which the asphalt binder is oxidized, it will retard the loss of surface fines and reduce the formation of additional cracks. Application of a rejuvenator will also tend to reduce the skid resistance of the pavement, in some cases, for up to 1 year. While this reduction in skid resistance should not be a significant factor for parking aprons and taxiways, it may be significant for runways or other areas where high aircraft speeds are likely to occur. **Extreme caution** must be exercised when applying rejuvenators to areas subject to high-speed traffic.

(c) A rejuvenator should not be applied to pavement having an excess of binder on the surface such as that found in a slurry seal, porous friction course, or surface treatment. When excessive binder is on the surface, the rejuvenator will soften the binder and cause the surface to become tacky and slick.

(d) The amount of air voids in the asphalt mixture being rejuvenated should be at least 5 percent to ensure proper penetration of the rejuvenator into the pavement. If the voids are less than 5 percent, the rejuvenator may fill the voids and thus cause an unstable mix.

(e) Care must be used in selecting a rejuvenator. Some rejuvenators perform satisfactorily, but many do not. The rejuvenator selected for use should have a proven record of satisfactory performance. However, if performance data on a particular rejuvenator are not available, the rejuvenator should be applied to a test area on the pavement and evaluated over some period of time to determine its potential performance.

(f) It is desirable to improve the existing properties of the asphalt cement in the top 5 millimeter (1/4-inch) or more of the pavement so that the asphalt cement approaches its original properties. Test results have shown that the viscosity test is more effective in determining a change in asphalt properties than the penetration test. While the application of a small amount of rejuvenator will be reflected by the viscosity test, the penetration test may indicate very little or no change in asphalt property.

(g) Rejuvenators should be applied in hot weather, above 21 degrees C (70 degrees F), so that the rejuvenator will penetrate more deeply into the asphalt pavement and will cure sooner.

(2) Application of rejuvenators. When applying a rejuvenator, the following must be considered.

(a) The asphalt distributor is the key piece of equipment used to apply asphalt rejuvenators. It is essential that the distributor is in proper operating condition when rejuvenators are applied to ensure that the rate of application is uniform. An inspection of the distributor should ensure that:

[1] The distributor has a circulating tank so that the rejuvenator can be thoroughly mixed prior to spraying.

[2] The motor is in proper running condition so that it does not misfire when accelerating and cause varying rates of rejuvenator to be applied.

[3] The size of the spray nozzles is selected so that a smooth consistent spray is obtained over the range of desired application rates.

[4] All spray nozzles are the same size and are set at the same angle with the spray bar.

[5] The spray bar is at the correct height to provide either a double or triple overlap.

[6] The application rate is checked to verify proper calibration.

(b) Before the rejuvenator is applied to the pavement, several test sections should be constructed and the rejuvenator should be applied to the sections at various rates to determine the proper application rate. Generally, the application rate should not exceed that which will allow the rejuvenator to penetrate the pavement within 24 hours.

(c) The amount of rejuvenator needed to properly modify the asphalt binder may not be the same amount needed to penetrate the asphalt pavement. The determinations made from the test sections should dictate the amount of rejuvenator that can penetrate the asphalt pavement, and this amount should never be exceeded. The optimum benefit will be obtained by applying the maximum rate that will penetrate the pavement.

(d) When a rejuvenator is applied to the pavement, clean dry sand should be available to blot areas that received too much rejuvenator. The sand should be evenly spread over these areas, broomed into a pile, and removed. Rolling the pavement surface 1 or 2 days after rejuvenator has been applied may help to knead and close hairline cracks.

e. Cold milling.

(1) Cold milling process. The cold milling process can be used to mill a bituminous or portland cement concrete pavement to a desired grade or depth. The milling machine normally mills up to 50 millimeters (2 inches) of pavement in one pass but can remove up to 100 millimeters (4 inches) ore more in one pass. The machines can use sensors that follow a stringline grade reference and slope control to directly control the finished grade. A problem with dust may occur, but this problem is usually controlled by spraying a small amount of water onto the pavement in front of the machine. The milling machine can be used during all weather conditions to produce a smoother grade.

(2) Cutting teeth. The cutting teeth on the milling machine are a high maintenance item and must be replaced often. The teeth may last 1 or 2 days, depending on hardness of the material being milled and the number of operation hours per day. The cutting teeth can be adjusted to provide a range of surface textures from smooth to very rough. When all the teeth are in position, the finished surface texture is relatively smooth. By removing some of the teeth, the surface texture can be made rougher. When the milled surface is used for a riding surface, a rougher surface texture provides better skid resistance; however, the rougher surface also causes more tire wear and rider discomfort.

(3) Milled surface. Occasionally, when a pavement surface has been milled, the surface is used as the riding surface for a period of time. For instance, when a pavement does not have adequate skid resistance but no immediate funds are available to overlay this pavement, one alternative is to mill the surface to give it a rough surface texture and provide adequate skid resistance until it can be overlaid or otherwise repaired. An excessive amount of material should not be removed because the pavement structure could be weakened. It is recommended that the pavement be overlaid as soon as possible after the milling. It is recommended that the milled pavement be swept with a power broom to remove all fines. Otherwise, these fines can collect and be imbedded in the milled grooves making them difficult to remove later. Raveling after the milling process may become a problem with asphalt concrete pavements. On airfields, raveling may cause foreign object damage (FOD) to the aircraft. To prevent FOD, an overlay should be applied immediately after the milling operation.

(4) Milled material. The material obtained from milling operations can be used in pavement construction. The milled material can be stockpiled, but care must be exercised not to stockpile it too high, especially in hot weather, since the asphalt concrete material will have a tendency to bond, thus making it difficult to use. In most cases, the material should not be stockpiled over 3 meters (10 feet). The milled material can be used for producing recycled cold mix, recycled hot mix, and other mixes. Occasionally, this milled material can be used to surface secondary roads that otherwise would not be surfaced. In this case, some additional binder material, such as asphalt emulsion or rejuvenator, is usually added to rejuvenate the old asphalt or improve binding qualities. This milled material, mixed with

asphalt emulsion, can also be used as a base course for high-quality pavements. The material can be mixed in place or removed and plant-mixed to produce a satisfactory base course. For high-quality airfield pavements, this base course should be overlaid with the minimum amount of asphalt concrete mixture required by design. The hot mix and cold mix prepared from materials obtained by milling are discussed later in this chapter.

(5) Gradation. The gradation of the milled material obtained from the milling operation is important when the material is to be used to produce recycled cold or hot mixes.

(a) When the material is to be used in a recycled cold mix, the maximum size of the milled conglomeration of aggregate and asphalt, should not exceed 38 millimeters (1-1/2 inches). However, a small amount of material larger than 38 millimeters (1-1/2 inches) is acceptable if it can be removed by screening prior to mixing. Generally, the milled material, without additional virgin aggregates, is used to produce recycled cold mix.

(b) When the milled material is to be used in recycled hot mix, the gradation of the milled material after extraction of the asphalt cement is important. Very little breakdown of the aggregate should occur during the milling operation. It is important that the maximum size of the material as milled does not exceed 38 to 50 millimeters (1-1/2 to 2 inches) to ensure that it will break up and satisfactorily mix with the new materials in the production of recycled hot mix. Some filler material passing the 75 m (No. 200) sieve will be manufactured during the milling operation. Depending on the aggregate type, 1 to 3 percent additional filler may be manufactured. One of the problems in designing a recycled mixture is not to exceed the maximum amount of filler allowed. Generally, new aggregates that are to be added to a recycled mixture are required to have little or no filler. Therefore, washing of new aggregate is often required to remove the filler prior to producing the recycled mixture.

(6) Base course. When the asphalt pavement material is to be removed down to the base course, care should be taken to prevent damage to the base course. Any damage to the base course should be corrected prior to placing the recycled mixture. Generally, approximately 1.5 centimeters (1/2 inch) of asphalt mixture should be left in place to prevent damage to the base course by the milling equipment or by rain.

3. RECYCLED COLD-MIX ASPHALT.

a. General. When a pavement has deteriorated to a point that the thickness of a conventional overlay required to satisfactorily provide a solution to the problem is not economical or is prohibited by existing grades, the use of recycled cold mix should be considered. A recycled cold mix involves the reuse of the existing pavement structure by reprocessing it and adding an asphalt binder to it without the use of heat. Recycled cold mix in conjunction with a hot mix overlay can often be used to repair an existing pavement at lower cost than with a conventional overlay. The basic process is shown on the flow chart in figure 7-2.

b. Equipment. The equipment required for pavement removal and crushing is either conventional equipment for ripping or scarifying and crushing or a cold-milling machine. For mixing and placing, a rotary mixer and grader, a mix-in-place travel plant, or a central plant and a conventional paver are required. The required equipment includes a distributor, trucks, brooms, rollers, and front-end loaders.

c. Pavement design. The structural design of pavements using recycled cold-mix asphalt should be the same as that for the asphalt-stabilized materials as provided in TM 5-825-2/AFJMAN 32-1014. The recycled cold-mix should provide a structure whose performance is equal to that of the asphalt-stabilized material. Mixture design for recycled cold-mix asphalt concrete is important to ensure proper material proportions and to obtain maximum field density. When no new aggregates are to be added to the reclaimed materials, the mix design should be performed on the reclaimed materials as recovered. The maximum-size particles of the reclaimed asphalt concrete should not exceed the requirement which is usually 3.5 centimeters (1-1/2 inches). When new aggregates are to be added, the design should be performed on the desired mix of reclaimed aggregate and new aggregate.

d. Mix design. Development of the mix design accomplished two objectives: it determines the amount of new binder and rejuvenator, modifier, or recycling agent required to obtain a durable and stable mixture, and it determines the amount of moisture needed to provide maximum density.

(1) Additives. A rejuvenator, modifier, or recycling agent can be used in place of new asphalt cement in some instances to improve the old asphalt cement properties. A thorough blending of these materials and oxidized asphalt cement does not immediately occur when mixing the recycled cold mix. In fact, the additive initially coats the old asphalt mixture pieces and with time, probably months, will penetrate the old asphalt binder and produce an improved binder. During the first few months, the recycled cold mix may be unstable because of the film of additive around the oxidized asphalt and aggregate. After the additive penetrates the old asphalt and the binder material becomes more homogeneous, the recycled cold mix should perform satisfactorily. Because of the initial instability and increased costs created by additives, asphalt emulsions are usually used by themselves in recycled cold mixes when the desired asphalt properties can be achieved.

(2) Asphalt content. A guide for the selection of the type of asphalt emulsion to be used is given in ASTM D 3628. The amount of new asphalt binder needed in the recycled cold mix should be determined by conducting a conventional hot-mix design on the recovered aggregate. The laboratory density obtained in the hot-mix design is approximately equal to the maximum density that will be obtained in the field under traffic. The amount of asphalt added should be varied by 0.5 percent increments from 0 percent to the high side of optimum asphalt content. The samples should be compacted by the required effort, either 50 blows for low-pressure tires or 75 blows for high-pressure tires, and determinations should be made for density, stability, flow, voids total mixture, and voids filled with asphalt. These determinations should be plotted and curves drawn to select the optimum asphalt content. The optimum additional asphalt will often be between 0 and 1 percent. When the optimum additional asphalt to be selected is 0 percent, no additional asphalt should be added since it may cause the mixture to become unstable. When no asphalt is needed, only water should be added to lubricate the mixture so that the needed density can be obtained in the field. There are several other design methods in use by other state agencies and private organizations. The mix design method of the Asphalt Institute is similar to others in that it is based mainly on aggregate properties and gradation. In comparison to these methods, the Corps of Engineers procedure should normally require the highest percentage of asphalt cement or the most conservative design.

(3) Compacted samples. After the optimum asphalt content has been determined, samples should be made at the optimum asphalt content with varied water contents. These samples should then be compacted at room temperature using the same compaction effort as that used to determine optimum asphalt content. Next, the dry density for each of the compacted samples should be determined, a moisture/ density curve should be plotted, and the moisture content that provides maximum dry density should be selected as the optimum moisture content. A design example is given in Appendix B.

e. Removal of in-place material. The material to be used in the recycled cold mix can be removed or loosened from the in-place pavement by a number of methods. The reclaimed material for central plant cold-mix recycling can be removed by cold milling or ripping and crushing the existing asphalt concrete pavement. For In-place recycling the same methods can be used or the pavement can be pulverized and mixed in place. The three more common methods are identified below.

(1) Cold milling. When a cold-milling machine is used, the existing asphalt pavement can be removed to any desired depth. Generally, the particle size of the removed material is satisfactory for recycling, and no further crushing is necessary.

(2) Ripping. The last procedure for loosening the pavement involves using a ripper tooth or sacrificer to loosen the asphalt mixture. When a ripper tooth is used, the asphalt mixture is removed full depth since there is no way to control the depth of material loosened. When the asphalt concrete is removed by ripping, it must be further broken down by crushing in place with a pulverizer or other equipment or be carried to a crusher. When this method is used, a significant amount of base repair will be required. While the old pavement is being removed, consideration should be given to drainage of the area to prevent unnecessary delays caused by rain. The exposed surface should be sloped to promote good drainage, and outlets or other means should be provided to prevent the ponding of water.

(3) Pulverizing. Another procedure for loosening the pavement is to pulverize it in place, generally with a rotary mixer. This piece of equipment can reduce the pavement into nearly individual aggregate size particles. Additional passes can be used to reduce the particle sizes down to the individual aggregates as required. This procedure can be very effective except on thicker asphalt sections where ripping or scarifying the surface may be most effective.

f. Construction. After the asphalt mixture has been broken down to the desired particle size, it can be mixed with asphalt or other additives and water at a central plant or in place. Any procedure should be acceptable as long as the contractor can demonstrate that material meeting the specification requirements can be produced. Construction should not continue during rainfall or when rain is expected. The ambient temperature should be at least 10°C (50°F) and freezing temperatures should not be expected for at least 5 days. Generally the warmer the weather the better will be the final properties of the cold recycled mixture.

(1) Mixing. The in-place mixture produced by a rotary mixer or a traveling plant is less expensive than the mixture produced at a central plant, but control of the quality is not as good. To meet the specification requirements, the contractor must be able to control the amount of additional asphalt, additives, and water as well as the mixing time.

(a) Central plants. Central plants generally consist of a mixer, asphalt cement and additives storage, a water supply, and a system of cold feeds for RAP and new aggregates (if required). The mixer may be either a batch, drum, or continuous type with suitable equipment for feeding the asphalt, additives, water, and aggregate as required. Continuous mix plants are most commonly used for cold-mix recycling. Existing hot-mix asphalt plants can usually be adapted to produce cold-mix recycled material. Mixing times for cold-mix recycling are usually shorter than those for hot-mix. Mixing time and procedures should achieve a uniform dispersion of the binder and complete coating of fine aggregate. The coarse aggregate may not be completely coated; however, additional coating and mixing will occur during transit and placement. These blades not only loosen or pulverize the pavement to the required particle size but they also mix the asphalt and water into the reclaimed material. The rotary mixers may have their own spray apparatus in the chamber or the asphalt and water may be applied ahead of it by a distributor. Even when all materials are added during the initial break up pass, additional passes are usually made to assure desired sizing and complete mixing. Travel plant mixers are usually self-propelled pugmill plants that mix the loosened and sized reclaimed material with asphalt and water at a prescribed rate. They may discharge the mix into a windrow or the mixture may be placed with a screed that is attached to the back of the travel plant mixer.

(b) In-place mixing. In-place mixing may be accomplished by graders, rotary (pulverize) mixers, or travel plant mixers. Mixing with graders is requires that the pavement be properly sized and loosened to the required depth prior to mixing. Water and asphalt are usually added with a distributor truck. The grader mixer by working the materials back and forth and the action of the blade blends the materials together. Depending on conditions the water may be mixed prior to the addition of the asphalt. After the required mixing and aeration have occurred the grader can be used to grade and level the mixture prior to compaction. Rotary mixers are usually self propelled and have a chamber that contains 1 or 2 transverse shafts with cutting blades.

(2) Placement. The recycled mixtures produced at central plants or by travel plant mixers are usually placed by a paver to achieve a more uniform appearance, structure, and density. Mixtures produced by graders and rotary mixers are normally windrowed and placed with graders. Widowing prior to placement allows for aeration, when it is required. Moisture from emulsified asphalts and water used for compaction must be allowed to escape. Therefore the recycled mixtures should be placed in uncompacted layers of at least 50 millimeters (2 inches) and not more than 100 millimeters (4 inches). The upper limit may be increased to 150 millimeters (6 inches) if an open graded mixture is used.

(3) Curing. Cold-mix recycled mixtures gain strength and stability with time, as they cure. Factors that effect the cure time are; type of emulsified asphalt, mix water content, gradation, ambient and mixture temperatures, wind velocity, and humidity. When multiple lifts are required, the cure time between them should be from 2 to 5 days depending on the amount of moisture and porosity of the mixture.

(4) Compaction. Compaction should begin as soon as the emulsified asphalt has broken or when the mixture has been properly aerated. Compaction is usually accomplished by either or a combination of both rubber-tire, steel-drum and vibratory rollers. The type and size used will depend on the type of mixture and the thickness that it has been placed. Since it is difficult to establish a laboratory density for comparison with field density, the theoretical maximum density (TMD) should be used to establish field density requirements. The theoretical maximum density is that density at which there would be zero air voids in the mixture. At least 86 percent of the theoretical maximum density should be obtained in the field to ensure that the voids in the field mixture are not excessive.

(5) Field density measurements. The field density should be determined from cores removed from the in-place pavement. With some mixes it will be difficult to obtain undamaged cores prior to curing the cold mix for a few days. When cores cannot be obtained within 24 hours of paving, other methods of obtaining samples should be considered. For example, ice placed on the sample locations for 1 to 2 hours prior to coring samples will cool the material and reduce damage caused by heat developed during the coring operation. Another approach is to use a concrete saw to cut small cubes from the pavement. Nuclear density gages can be used to obtain an indication of density, but actual samples should be taken to determine acceptability for the density of the in-place mixture.

4. RECYCLED HOT-MIX ASPHALT.

a. General. Recycled hot-mix asphalt should be considered as an alternative anytime pavement reconstruction is planned. Recycling will create a greater savings in material cost and total job cost than the use of new hot-mix that for an asphalt for reconstruction projects. The performance of recycled hot mix should be considered near equivalent to that expected with conventional hot mix. Recycled hot mix can be used to construct asphalt base, intermediate, and surface courses (Surface courses require prior approval.). Figure 7-3 provides an outline of the hot-recycling process.

b. Equipment. The equipment required for pavement removal and crushing will include either conventional equipment for ripping and crushing or a cold-milling machine. A batch or drum plant, either designed or modified to mix recycled materials is also required. Placement is with a conventional paver, and trucks, front-end loader, and asphalt distributor are also required.

c. Recycling hot-mix procedures. Recycling hot mix consists of removing the existing pavement; crushing the reclaimed mix, if necessary; mixing the reclaimed mix with virgin aggregate, virgin asphalt, and recycling agent; and placing the recycled mix by the same procedures as those used for a conventional mix (figure 7-3).

d. Removal and sizing. The asphalt pavement should be removed by a cold-milling machine or with a ripper tooth and crushed. The cold-milling machine is a self-propelled, power-operated planing machine capable of removing, in one pass, a layer of bituminous material up to 4 meters (12 feet) wide and 50 to 100 millimeters (2 to 4 inches) deep. The equipment should be capable of establishing grade control by referencing from existing pavement or from independent grade control and should have a positive means of controlling transverse slope elevations. The equipment should have an effective means of preventing dust from the operation from escaping into the air. The milled material should pass through a 50 millimeter (2-inch) sieve. The teeth on the cutting drum must be in satisfactory condition at all times to prevent shearing off chunks of the asphalt concrete and creating oversize particles or a rough surface. If oversize particles are present, they should be removed by screening.

e. Virgin aggregates. Virgin aggregates are added to the recycled hot mix for a number of reasons.

(1) Gradation. The gradation of the aggregate in the existing mix can be improved by adding virgin aggregates. Many times existing pavements do not contain the desired aggregate gradation, and if they do contain a satisfactory gradation, it may be changed during the milling or crushing operation. Therefore, the addition of new aggregate allows the gradation of the recycled mix to be modified to an acceptable range.

(2) Pollution control. Without the addition of new aggregate, air pollution during mix production for most plants would exceed the allowable levels. With the addition of new aggregate, an aggregate shield can be used in the plant's mixing drum to prevent the flame from having direct contact with the reclaimed asphalt pavement (RAP). Such direct contact between the heating flame and RAP would cause the asphalt in the reclaimed asphalt pavement to burn, which is the main source of air pollution in hot recycling.

(3) Aggregate quality. Many times the quality of the aggregates in an existing mix is not acceptable even though the gradation is satisfactory. One cause of poor quality in an aggregate blend is the use of an excessive amount of natural rounded sand. Rounded sand is a poor aggregate for asphalt concrete, but because of its abundance and low cost, it is often used in excess in asphalt concrete mixtures. The addition of a new high-quality aggregate can reduce the percentage of rounded sand in the mixture and thus improve the overall quality of the mix. The amount of natural sand added to a recycled mixture should not exceed 15 percent of the new aggregate for airfields.

(4) Excess filler material. Many existing asphalt pavements have been constructed with the amount of filler material passing the 75 m (No. 200) sieve near or above the maximum allowed by specifications. The amount of filler in the reclaimed mixture most often varies between 8 and 12 percent, whereas the maximum amount of filler allowed is 6 percent. During the milling or crushing operation, approximately 1 to 3 percent additional filler will be manufactured. Thus, in order to control the amount of filler, the new aggregates must be limited to very little or no filler. The virgin aggregates may have to be washed to minimize the amount of filler material. In addition, the percent of virgin aggregate in the recycled mixture may have to be adjusted to help control the filler content.

(5) Asphalt binder. The asphalt binder in the existing pavement is usually oxidized and requires some modification during recycling to produce an acceptable asphalt binder and resulting mixture. If no new aggregate is added to the mix, the addition of asphalt or recycling agent needed to produce satisfactory asphalt cement properties may result in a mixture that is too rich. The asphalt cement

content of the existing pavement mixture is generally near the optimum asphalt content; hence, the addition of more asphalt cement or recycling agent may result in an excessive asphalt content. If the existing asphalt binder is not modified with a low viscosity asphalt or recycling agent, a brittle mixture with a short service life will be produced.

f. Mixture design. The mix design is conducted to determine the percentages of reclaimed asphalt mixture, each new aggregate, recycling agent, and asphalt cement to be used in the mixture. The amount of reclaimed mixture used in a recycled mixture is usually based on the amount of reclaimed materials available, the desired physical properties of the recycled mix, requirements of the aggregate gradation, economical considerations, and the type of asphalt plant. A drum mixer can prepare recycled asphalt mixtures using up to a maximum of 70 percent reclaimed mixture. However, in order to ensure that the quality of the mix is controlled, the amount of reclaimed asphalt concrete used in the production of recycled hot mix should not normally exceed approximately 40 percent. When a modified batch plant is used to produce the recycled mixture, the maximum amount of reclaimed materials that can be added to the mixture generally varies between 50 and 60 percent because at least 40 to 50 percent new superheated aggregate is needed to obtain sufficient heat transfer to the reclaimed asphalt pavement material. In general practice the amount of reclaimed asphalt pavement used ranges from 10 to 40 percent of the total weight of the recycled mixture. The selection and evaluation criteria for the new and old aggregate are the same as those for new hot mixes.

(1) Percentage of aggregate. The first step in the mixture design is to determine the percentage of each new aggregate and reclaimed asphalt concrete that should be used. The amount of reclaimed asphalt concrete that can be practically recycled was discussed in the preceding paragraph. The gradation of the aggregate extracted from the reclaimed asphalt and the gradations of the new aggregates are then determined. The percentage of each aggregate to be used in the recycled mixture is then selected so that the blended gradation of all aggregates used, including the aggregate in the reclaimed asphalt concrete, meets the specification requirements.

(2) Type of binder. The second step is to determine the type of binder or recycling agent to be used in the mixture. A recycling agent is usually required to modify the oxidized asphalt binder. When the penetration of the old asphalt binder is more than 10 and the amount of reclaimed asphalt concrete used in the recycled mixture is below 40 percent, the existing asphalt binder can usually be modified with an asphalt cement such as an AC-2.5 (ASTM D 3381). In this case, no recycling agent would be needed. When the amount of reclaimed asphalt concrete used in the mixture exceeds 40 percent, or when the penetration of the existing asphalt binder is less than 10, a recycling agent is generally needed. The use of a recycling agent is not normally recommended for hot-mix recycling.

(3) Preparation. The third mix design step consists of preparing recycling mixtures at various asphalt contents with 0, 0.5, and 1.0 percent or more of new asphalt cement. The following data should be plotted for each asphalt content being evaluated: (1) density versus additional asphalt content, (2) stability versus additional asphalt content, (3) flow versus additional asphalt content, (4) voids in the total mix versus additional asphalt content, and (5) voids filled with asphalt versus additional asphalt content. These graphs, with the exception of stability, take the same shape as those developed when conducting a mix design for conventional hot-mix asphalt concrete. The plot of stability versus additional asphalt content generally indicates the highest stability at 0 percent additional asphalt and a reduction in stability as the asphalt content is increased. The optimum asphalt content should be determined by averaging the asphalt contents at the peak of the density curve, middle of the voids in the total mixture requirements, and middle of the voids filled with asphalt requirements. The requirements for voids in the total mix, voids filled with asphalt, stability, and flow are the same as those for conventional hot-mix asphalt concrete. Mixtures at optimum asphalt content for each recycling agent content should be prepared and the asphalt recovered from these mixtures. The penetration of the recovered asphalt should be a minimum of 60 percent of the desired original asphalt penetration for the area in which the

mixture is to be used. Penetration is used because of the relative ease of use in a field laboratory. Viscosity or performance graded binder properties can also be used, provided the necessary testing is accomplished to produce an asphalt mixture with binder properties approaching those of new in-place hot-mix asphalt pavement. The amount of recycling agent should be selected so that the recovered asphalt penetration meets the desired limits. It is important that the penetration of the recovered asphalt be measured during plant production and that adjustments be made if necessary to ensure proper asphalt consistency. Paragraph B-2 in appendix B gives a design example of a hot-mix design for a recycled asphalt pavement. The JMF supplied by the contractor should contain all the information given for hot-mix asphalt in Chapter 2. This information should also include the properties of the asphalt and aggregate in the RAP.

g. Production of recycling hot-mix. Most recycled asphalt concrete is produced with a drum mixer designed or modified to produce recycled mixtures. Modified batch plants have also been used successfully to produce recycled hot mix.

(1) Drum mixer. When a drum mixer is used for recycling, the new aggregate is added at the high side of the drum near the flame. The aggregate absorbs much of the heat from the burner and acts as a shield to protect the reclaimed asphalt concrete, new asphalt binder, and recycling agent. The reclaimed asphalt concrete is added to the drum near the midpoint followed by the recycling agent and new asphalt. The flights inside the drum should be in good condition so that the veil of new aggregate will properly protect the asphalt materials from heat damage. The final recycled mixture is generally heated to between 125 and 145 degrees C (260 and 290 degrees F) to produce a mixture that can be compacted to meet density requirements. Air pollution is sometimes a problem, but generally the mix design can be modified by lowering the percent of reclaimed asphalt pavement to bring the emissions within an acceptable range.

(2) Batch plant. Batch plants have been modified for the production of recycled mixtures. The modification consists of adding a feeder and conveyor to carry the reclaimed asphalt pavement directly to the weigh bucket. The new aggregate that passes through the dryer is usually superheated to between 260 and 315 degrees C (500 and 600 degrees F) so that when the materials are blended, the resulting temperature is suitable for mixing and compaction. An increase in the amount of reclaimed asphalt concrete used in the mix would require an increase in the new aggregate temperature. Also, additional moisture in the new aggregate or reclaimed asphalt pavement stockpiles will require additional heat. Therefore, to save energy both stockpiles should be kept as dry as possible.

(3) Stockpiling. Prior to production of recycled asphalt concrete, the stockpile of reclaimed materials should be inspected to ensure that no significant segregation of material exists. Many pavements have been patched during their lives, causing variation in the type of materials at various locations in the pavements. Therefore, the materials should be removed from the pavement and stockpiled in such a way as to ensure proper mixing of these localized material with the other reclaimed materials. When the asphalt pavement is removed in two lifts, the properties of the material in the top lift will probably vary from the properties of the materials in the bottom lift. In this case, the materials should be stockpiled separately, or some acceptable procedure for blending these materials must be used.

(4) Cold feeds. In order to remove all material larger than 50 millimeters (2 inches), a screen should be placed over the bin or cold feeder from which the reclaimed materials will be fed to the plant. When conglomerations of asphalt and aggregate exceed this size, they will not break down enough in the asphalt plant to produce a homogeneous mixture. Consequently, these oversize pieces may cause problems with pulling and tearing of the mat during lay-down operation.

(5) Control testing. During production of recycled asphalt concrete, a number of tests must be conducted to ensure that a satisfactory product is produced. The tests used to evaluate recycled

mixtures are the same tests used to evaluate conventional hot mix. These tests evaluate material properties such as Marshall stability, flow, laboratory density, voids in the total mixture, voids filled with asphalt, aggregate gradation, asphalt content, temperature, and field density. Penetration for the recovered asphalt cement is another property that is needed to evaluate recycled mixtures during production.

h. Placement of recycled hot mix. There should be no difference between the placement of recycled hot mix and the placement of conventional hot mix.

i. Excess reclaimed asphalt pavement. Unless there is a specific reason for Government to keep it, all excess reclaimed asphalt pavement should be transferred to the contractor. A credit should be given to the Government for its value.

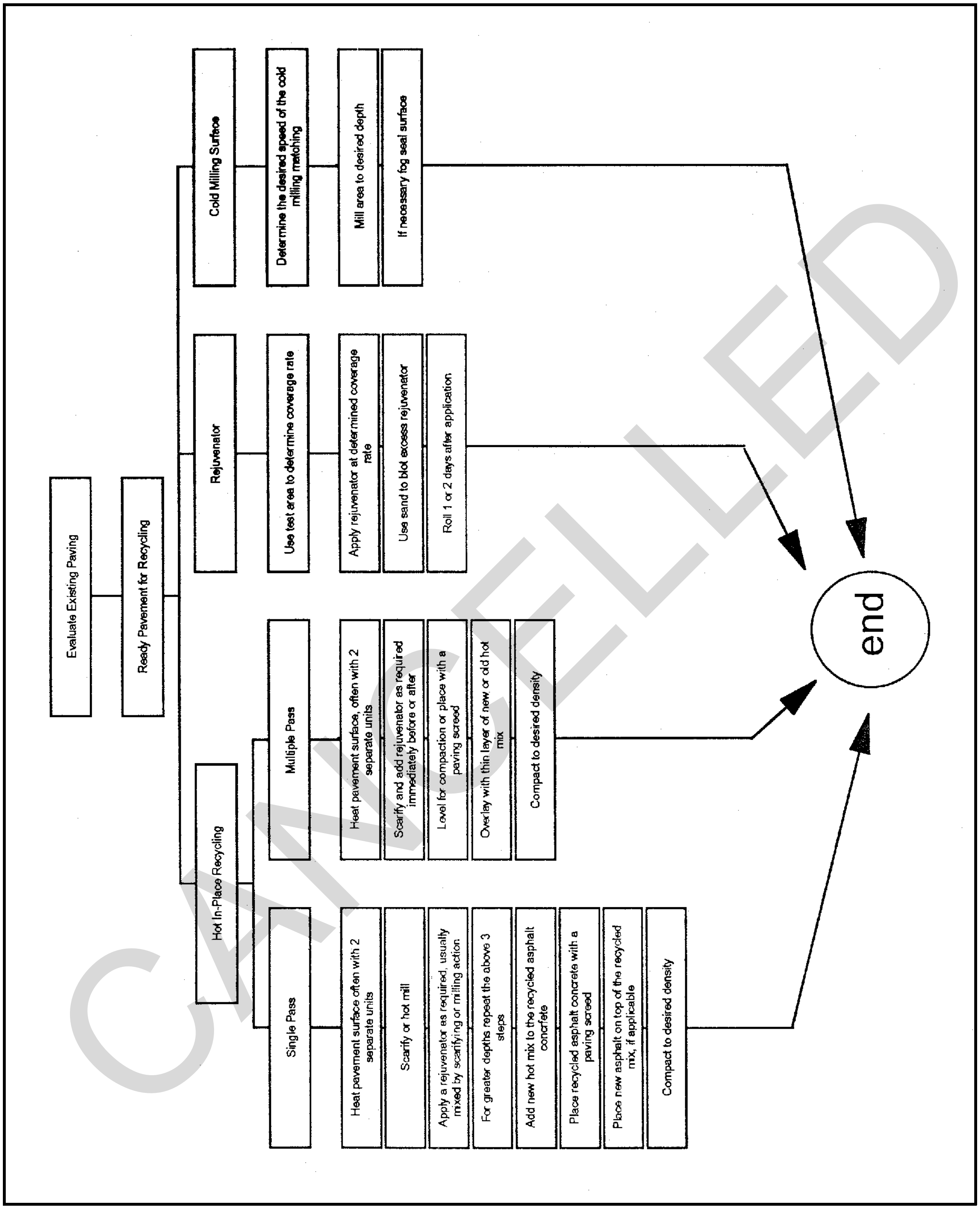

Figure 7-1 Surface recycling flow chart

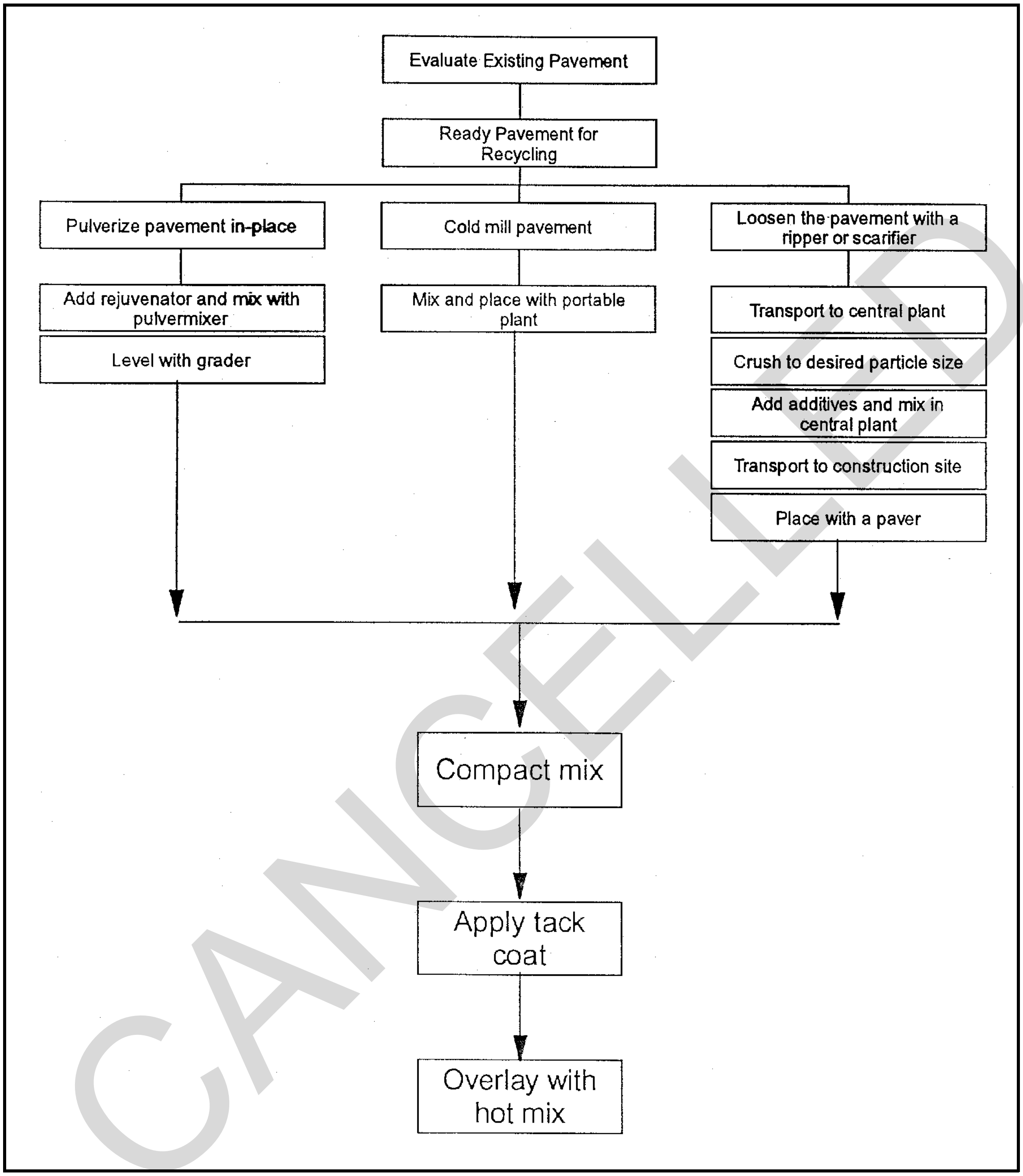

Figure 7-2 Cold-mix recycling flow process

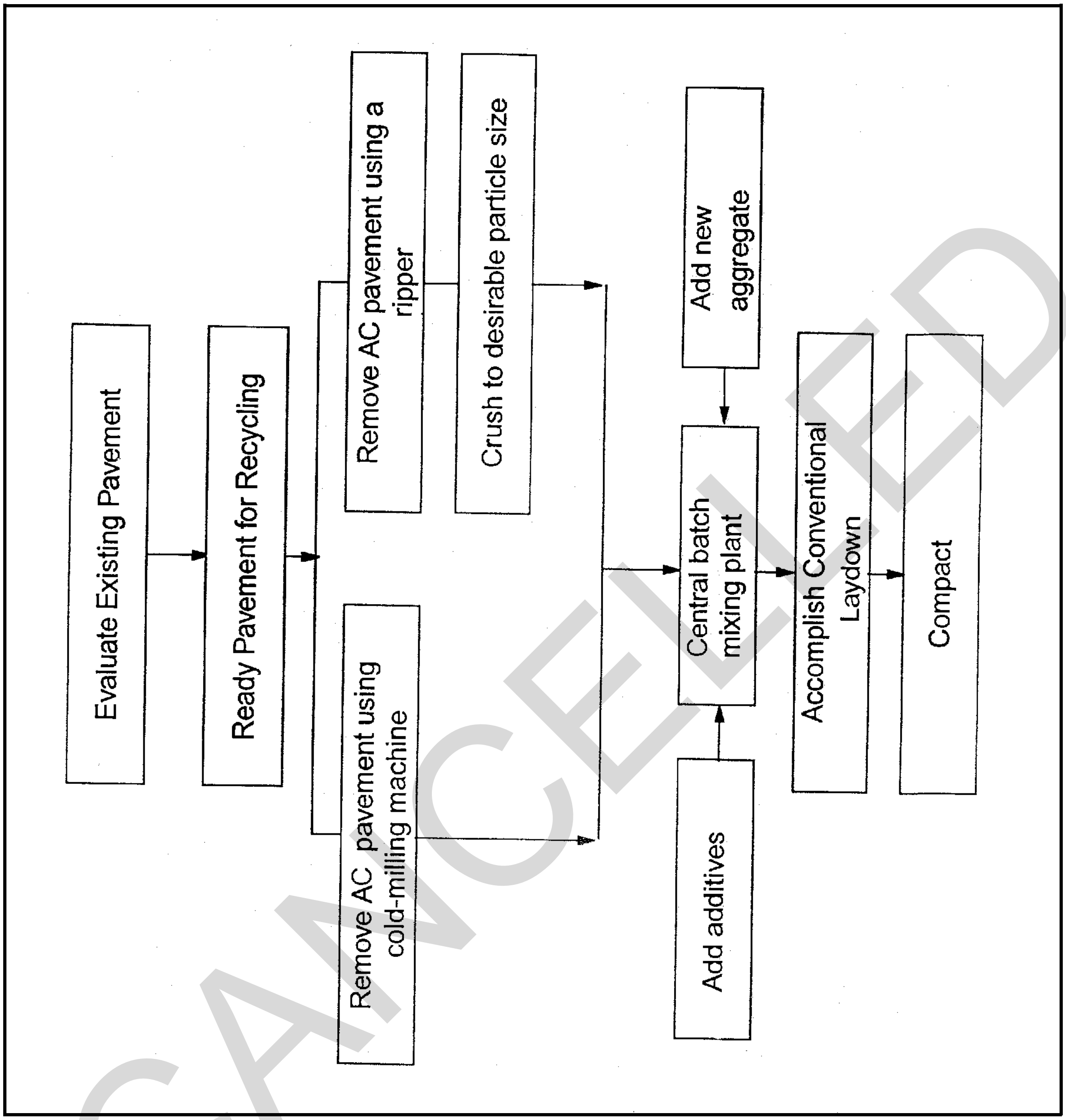

Figure 7-3 Hot recycling process

CHAPTER 8

RESIN MODIFIED PAVEMENT (RMP)

1. GENERAL. Resin modified pavement (RMP) is a tough and durable surfacing material that combines the flexible characteristics of hot-mix asphalt with the fuel, abrasion, and wear resistance of portland cement concrete (PCC). The RMP is best described as a cross between AC and PCC and can be categorized somewhere between these two most common types of paving materials. The RMP process is basically an open-graded asphalt concrete mixture containing 25 to 35 percent voids which are filled with a resin modified portland cement grout. The open-graded asphalt mixture and resin modified cement grout are produced and placed separately. The production of the materials and the mixture requirements for both the open-graded asphalt mixture and the cement grout differ slightly from conventional procedures. The open-graded asphalt mixture is designed to be the support layer and to determine the thickness of the RMP, which is generally 50 millimeters (2 inches). The open-graded mixture is placed with standard AC paving equipment but is not compacted. After placing, the open-graded asphalt material is simply smoothed over with a small steel-wheel roller, generally a 3-metric ton maximum. Compaction of the open-graded AC material will adversely decrease the voids and hinder grout penetration. After the asphalt mixture has cooled, the cement grout is poured onto the open-graded asphalt material and squeegeed over the surface. The cement grout is then vibrated into the voids with the small steel-wheel roller to ensure full penetration of the grout. This process of grout application and vibration continues until all voids are filled with grout, which essentially completes the construction process. RMP was developed in France in the 1960's as a fuel and abrasion resistant surfacing material. The RMP, or Salviacim process, as it is known in Europe, was developed by the French construction company Jean Lefebvre as a cost-effective alternative to PCC. The RMP process has been used on various types of pavements including warehouse floors, tank hardstands and roads, and aircraft parking aprons. This surfacing material is best suited for pavements that are subjected to abrasive traffic, heavy static point loads, heavy fuel spillage, and channelized traffic. The RMP has been successfully constructed in numerous countries including France, Great Britain, South Africa, Japan, Australia, Saudi Arabia and the United States. Based on this international experience and the results of evaluations conducted by U.S. Army Engineer Waterways Experiment (WES), the RMP process has been recommended as an alternative pavement surfacing material by the U.S. Army, the U.S. Air Force, and the Federal Aviation Administration (FAA). The Corps of Engineers has established the initial policies concerning the use and potential areas of application. The Corps has also developed a material and construction specification for the RMP process.

2. MATERIALS.

a. Open graded asphalt mixture.

(1) Aggregates. The required physical properties and gradation required for aggregates in the open-graded asphalt portion of RMP are given in tables 8-1 and 8-2, respectively.

(2) Asphalt cement. The asphalt cement used shall be of the same grade as normally used in the area. When possible, the hardest asphalt cement available should be specified to assist in providing a stable surface for the subsequent grouting operations. The asphalt cement will have to meet the requirements of ASTM D 946, ASTM D 3381, or AASHTO MP-1.

b. Cement slurry grout.

(1) Aggregate. The cement slurry grout requires a silica sand meeting the gradation given in table 8-3. Silica sand is specified because of its soundness and durability. The silica sand should meet

Table 8-1
Aggregate Physical Properties

Test	Specification Requirements
Specific gravity (ASTM C 127)	--
L.A. Abrasion (ASTM C 131)	< 40 percent
Percent Fractured faces	
+ 4.75 millimeter (No. 4)	> 70 percent
- 4.75 millimeter (No. 4)	> 70 percent
Percent flat and elongated (ASTM D 4791)	< 8 percent

Table 8-2
Recommended Gradation for Open Graded Asphalt Mixture

Sieve Size	Specified Limits, Percent Passing
19 mm (3/4 inch)	100
12.7 mm (1/2 inch)	54 - 76
9.5 mm (3/8 inch)	38 - 60
4.75 mm (No. 4)	10 - 26
2.36 mm (No. 8)	8 - 16
600 m (No. 30)	4 - 10
75 m (No. 200)	1 - 3

Table 8-3
Aggregate Gradation for Slurry Grout

Sieve Size	Percentage by Weight Passing Sieves
1.18 mm (No. 16)	100
600 m (No. 30)	95 - 100
75 m (No. 200)	0 - 2

the requirements for wear and soundness specified for the aggregate in the open graded asphalt concrete. Deviations from these aggregate requirements have resulted in significant construct ability problems in the past.

(2) Filler. Some filler or material passing the 75 meter (No. 200) sieve will normally be present in the aggregate used in the cement grout. When additional filler is required it should be a class F (ASTM C 618) fly ash with a limit on the calcium oxide content of 5 percent by weight maximum. The fly ash should have a minimum of 95 percent by weight of material passing the 75 meter (No. 200) sieve.

(3) Cement. The portland cement used should conform to ASTM C 150. The portland cement used can be either type I, II, III, or IV. Type I is the cement most widely used for RMP applications. The other types can be used where moderate to high sulfate- resistance or high early-strength are required.

(4) Cross polymer resin additive. The cross polymer resin additive used is Prosalvia L7 (PL7) and it is a proprietary product. PL7 is generally composed of five parts water, two parts cross polymer resin of styrene and butadiene, and one part water reducing agent. The PL7 is used as a plasticizing and strengthening agent.

3. MIXTURE DESIGN.

a. Open graded asphalt mixture. The optimum asphalt content for the open-graded asphalt mixture is determined through a modified Marshall mix design procedure. Marshall laboratory samples 152.4 millimeters (6 inches) in diameter by 63.5 millimeters (2-1/2-inches) in height are produced using the determined JMF aggregate gradation and a series of asphalt contents ranging below and above an estimated optimum asphalt content value. The estimated optimum asphalt content is determined using a procedure developed in France and based on aggregate properties. The procedure is outlined below:

$$\textit{Optimum asphalt content} = 3.25(\alpha)\left(\sqrt[5]{\Sigma}\right)$$

where

$\alpha = \dfrac{2.65}{\gamma_G}$ where γ_G = apparent specific gravity of the combined aggregates

Σ = conventional specific surface area

= 0.21G + 5.4S + 7.2s + 135f

G = percentage of material retained on the 4.75 millimeter (No. 4) sieve

S = percentage of material passing the 4.75 millimeter (No. 4) sieve and retained on the 600 m (No. 30) sieve

s = percentage of material passing the 600 m (No. 30) sieve and retained on the 75 m (No. 200) sieve

f = percentage of material passing 75 m (No. 200) sieve

If, for example, the estimated optimum asphalt content calculated for a given aggregate gradation was 4.2 percent, then the asphalt contents used for the subsequent laboratory Marshall sample evaluation could be 3.8, 4.0, 4.2, 4.4, and 4.6 percent. The 152.4 millimeter (6-inch) diameter Marshall samples are compacted in the laboratory using a 4.536 kilogram (10-pound) hand hammer with a 152.4 millimeter (6-inch) diameter impact plate. The samples are compacted at 121°C (250°F) using 25 blows on one side of the sample. Three samples are produced for each of the five asphalt contents used, and the resulting average voids data of percentage of voids total mix and voids filled are used to finalize the selection of an optimum asphalt content. As a general rule, as the percent of asphalt increases, the voids total mix will fluctuate over a relatively small range. Also, the voids filled will increase slowly until the percentage starts to show a significant increase indicating that further increases in asphalt content are working more to fill the void spaces rather than coating the aggregate particles. This is an undesirable condition since an excess amount of asphalt cement in the RMP void structure will hinder the slurry grout penetration upon application. The asphalt content selected should be below the point where voids filled shows a significant increase and where the voids total mix are within the 25 to

35 percent range of values. The voids total mix of laboratory specimens and ungrouted field cores can be calculated using the following formula:

$$VTM = \left[1 - \frac{WTair}{Volume}\,\frac{(1)}{SG_T} \times 100\right]$$

where

VTM = voids total mix

Wtair = dry weight of specimen

Volume = ð/4 D^2H (measured)

D = diameter

H = height

SG_T = theoretical specific gravity

b. Cement grout. The slurry grout job mix formula can be developed using the range of properties given in table 8-4. Using these proportions, the following procedure is used. The slurry group samples are prepared in the laboratory by first dry mixing the cement, sand, and fly ash in a blender until they are thoroughly mixed. The appropriate amount of water is then added, and the grout mixture is blended for 5 minutes. After this 5 minute mixing period, the PL7 resin additive is added and mixed with the grout for an additional 3 minutes. Immediately after the 3 minute mixing period, the grout is poured into the Marsh flow cone and tested for viscosity. A Marsh cone has dimensions of 155 millimeters (6.2 inches) base inside diameter, tapering 315 millimeters (12.6 inches) to a tip inside diameter of 10 millimeters (0.4 inch). The 10 millimeter diameter neck should have a length of 60 millimeters (2.4 inches). The viscosity, in seconds, is measured for each sample and three different batches of each blend are tested to obtain an average viscosity value. The requirements for viscosity of the grout are given in table 8-5. The individual components of the grout may be adjusted within the prescribed tolerances listed in table 8-4 to obtain a desired grout viscosity.

Approximately 10 to 13 kilograms (22 to 28 pounds) of mixed slurry grout will fill in 0.8 square meters (1 square yard) for each 25 millimeters (1 inch) of thickness of open graded asphalt mixture with 25 to 35 percent voids total mix.

Table 8-4
Resin Modified Cement Slurry Grout Mixture Proportions

Material	Percent by Weight
Silica sand	16 - 20
Fly ash	16 - 20
Water	22 - 26
Type I cement	34 - 40
Cross polymer resin	2.5 - 3.5

Table 8-5
Slurry Grout Viscosity

Time Elapsed After Mixing	Viscosity
After 0 minutes	7 to 9 seconds
After 15 minutes	8 to 10 seconds
After 30 minutes	9 to 11 seconds

4. EQUIPMENT.

a. General. The equipment used to place, transport, and mix the open-graded asphalt mixture is generally the same as used to place dense-graded asphalt mixture, except for smaller steel wheel rollers. This equipment includes sweepers, distributors, pavers, asphalt concrete plants, and transport trucks. The equipment used to place the cement slurry grout consists of transit trucks, vibratory steel wheel rollers, and hand tools.

b. Rollers. The rollers used to place the open graded asphalt concrete and the cement slurry grout are small (3 metric tons (3 tons) maximum) vibratory rollers. These rollers are used in the static mode only while placing the open-graded asphalt mixture, and in the vibratory mode while placing the cement grout. When placing the grout, there should be more than one vibratory roller available at the job site in case of breakdowns.

c. Hand tools. Hand squeegees are used to spread the cement grout over the pavement surface during application and to remove excess grout from the pavement surface once the grout application is completed. Hand brooms are used to smooth the texture of the joints during grout application and can be used to roughen the texture of the entire grouted pavement surface immediately after the grout application.

5. PLACEMENT.

a. Open-graded asphalt mixture. The open-graded mix is mixed, transported, and placed by the same methods and procedures used to place dense-graded asphalt mixture. A light tack coat of any suitable asphaltic material is first applied on the existing asphalt concrete on which the RMP is to be placed. After placing with a standard asphalt paver, the mixture is not compacted but is rolled to seat or smooth the surface. This is accomplished with a small (3-metric ton (3 ton) maximum) tandem steel wheel roller. A vibratory roller of this size may be used provided it is run in the static mode. One to three passes of the roller is usually sufficient for seating. A similar size roller is also used as a finishing roller to remove roller marks.

b. Cement slurry grout.

(1) Mixing and transport. The slurry grout can be mixed in a batch plant, portable mixer, or in a ready-mix truck. The cross polymer resin is added to the mixture after all other ingredients have been thoroughly mixed. Generally, the cross polymer resin should be added to the grout mixture at the batch plant if the haul distance is less than 30 minutes. If the haul distance is greater than 30 minutes, the cross polymer resin should be added to the grout mixture at the jobsite. When using ready-mix trucks for transporting slurry grout, the grout mixture shall be thoroughly mixed at the jobsite immediately before application for a minimum of 10 minutes. Thorough mixing is best accomplished by rotating the

mixing drum at the maximum allowable revolutions per minute. The final control on the acceptability of the mixing process is the mixing of a consistent grout which will meet the viscosity requirements.

(2) Placement.

(a) Application of grout. The surface temperature of the bituminous mixture shall be less than 38 degrees C (100 degrees F) before applying grout. On hot days, this will require the use of a fog spray of water to reduce the temperature. Excessive amounts of water that cause ponding shall not be used. Each batch of grout should be tested at the jobsite immediately before placement and shall be used in the finished product only if it meets the viscosity requirements listed in table 8-5. The cement grout is poured over the bituminous mixture from the ready-mix truck by means of a pivoting delivery chute and then spread around with the hand squeegees. The application of the cement grout should be sufficient to fill the internal voids of the open-graded bituminous mixture. The grouting operation should begin at the lowest side of the sloped cross-section and proceed from the low side to the high side. It should be noted that slopes up to 2 percent are considered the practical limit for RMP. Sections with slopes up to 5 percent have been placed but excess hand work and grout overruns can be expected at slopes greater than 2 percent. The slurry grout should be placed in successive paving lanes with a maximum width of 6 meters (20 feet). The use of 50 millimeter (2-inch) by 100 millimeter (4-inch) strips of lumber as wooden battens separating each of the grouting lanes and the RMP from adjacent pavements will facilitate an orderly grouting operation. Secure the wooden battens to the surface of the bituminous mixture before grout application to help prevent excessive grout runoff and to prevent overworking the grouting crew. The direction of the grouting operation should be the same as used to pave the open-graded bituminous mixture. The small (3-metric ton (3 ton) maximum) tandem steel wheel roller (vibratory mode) passing over the grout covered bituminous mixture shall be used to promote full penetration of the slurry grout into the void spaces. Once the open-graded layer is fully saturated with grout, all excess grout is removed by squeegeeing. This process will expose the rough surface of the open-graded material and improve skid resistance.

(b) Joints. The formation of all joints between successive lanes of RMP should be made in such a manner as to ensure a continuous bond between the paving lanes. The wooden battens should be removed as soon as the grout has been applied to the surrounding area and the area underneath them vibrated or reworked with additional grout and hand brooms to assure full penetration and smoothness in these joint areas. There are no time restrictions for placing successive lanes of grout in order to create proper joints. All RMP joints should have the same texture, density, and smoothness as other sections of the course. The joints between the RMP and any surrounding pavement surfaced with portland cement concrete should be saw cut to one-half of the RMP thickness and filled with a joint sealant material approved by the contracting officer.

(3) Curing. Proper curing of a new RMP surface is accomplished with a light coating of a white-pigmented, membrane-forming curing compound. The curing compound should be applied to the finished pavement surface while the surface is still damp but without excessive moisture on the surface, normally within 2 hours of the completed slurry grout application. The curing compound shall be applied by means of an approved pressurized spraying machine. Application of the curing compound shall be made in one or two coats with a total application rate of 4.5 square meters per liter (200 square feet per gallon).

(4) Covering pavement surface.

(a) Prior to grouting. The contractor should protect the ungrouted pavement and its appurtenances against contamination from mud, dirt, wind blown debris, water born material, or any other contamination which could enter the void spaces of the open-graded asphalt mixture before grout application. Protection against contamination shall be accomplished by keeping the construction site clean and free of such contaminants and by covering the ungrouted pavement with a protective material such as rolled polyethylene sheeting. The sheeting may be mounted on either the paver or a separate movable bridge from which it can be unrolled without dragging over the pavement surface.

(b) After grouting. The contractor should protect the pavement and its appurtenances against both public traffic and traffic caused by the contractor's employees and agents for a period of 28 days. In order that the pavements be properly protected against the effects of rain before the pavement is sufficiently hardened, the contractor will be required to have available at all time materials for the protection of the edges and surfaces of the unhardened RMP. The protective materials and method of application shall be the same as previously described in paragraph PRIOR TO GROUTING. When rain appears imminent, all paving operations shall stop, and all available personnel should cover the surface of the hardened RMP with protective covering.

APPENDIX A

REFERENCES

GOVERNMENT PUBLICATIONS

Department of Defense

Departments of the Army, the Air Force, and the Navy

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Engineer Technical Letter (ETL)	Engineering and Design Drainage Layers for Pavements
TM 5-803-4	Planning of Army Aviation Facilities
TI 825-01/AFM 32-1124(I)/ NAVFAC DM 21.10	Pavement Design for Airfields
TM 5-822-4/AFM 88-7, Chap. 4 (Future AFJMAN 32-1019)	Soil Stabilization for Pavements
TM 5-824-1/AFJMAN 32-8008V1	General Provisions for Airfield Design
TM 5-825-2/AFJMAN 32-1014	Flexible Pavement Design for Airfields
TM 5-822-2/AFM 88-7, Chap. 4 (Future AFJMAN 32-1018)	General Provisions in Geometric Design for Roads, Streets, Walks, and Open Storage Areas
NAVFAC DM 21	Airfield Pavements

U.S. Army Corps of Engineers Handbook for Cement and Concrete (CRD)

C150	Portland Cement
CC 618	Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete
CRD-C 649	Standard Test Method for Unit Weight Marshall Stability, and Flow of Bituminous Mixtures
CRD-C 650	Standard Method for Density and Percent Voids of Compacted Bituminous Paving Mixtures

NONGOVERNMENT PUBLICATIONS

American Association of State Highway and Transportation Officials, (AASHTO), 444 North Capitol Street, N. W., Suite 249, Washington, DC. 20001

T 88	Particle Size Analysis of Soils
MP1	Performance Graded Asphalt Binder
PP6	Grading or Verifying the Performance Grade of an Asphalt Binder

American Society for Testing and Materials (ASTM), 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959

C 29	Unit Weight and Voids in Aggregate
C 88	Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate
C 117	Materials Finer than 75- m (No. 200) Sieve in Mineral Aggregates by Washing
C 127	Specific Gravity and Absorption of Coarse Aggregate
C 128	Specific Gravity and Absorption of Fine Aggregate
C 131	Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine
C 136	Sieve Analysis of Fine and Coarse Aggregates
C 150	Portland Cement
C 188	Density of Hydraulic Cement
C 618	Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete
C1252	Uncompacted Void Content of Fine Aggregate (as influenced by particle shape, surface texture, and grading)
D 70	Specific Gravity of Semi- Solid Bituminous Materials
D 244	Emulsified Asphalts
D 402	Distillation of Cut-back Asphaltic (Bituminous) Products
D 422	Particle-Size Analysis of Soils
D 448	Sizes of Aggregate for Road and Bridge Construction
D 490	Tar

D 854	Specific Gravity of Soils
D 946	Penetration-Graded Asphalt Cement for Use in Pavement Construction
D 977	Emulsified Asphalt
D 979	Sampling Bituminous Paving Mixtures
D 1139	Aggregate for Single or Multiple Bituminous Surface Treatments
D 1369	Quantities of Materials for Bituminous Surface Treatments
D 1559	Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus
D 2026	Cutback Asphalt (Slow-Curing Type)
D 2027	Cutback Asphalt (Medium-Curing Type)
D 2028	Cutback Asphalt (Rapid-Curing Type)
D 2041	Theoretical Maximum Specific Gravity of Bituminous Paving Mixtures
D 2170	Kinematic Viscosity of Asphalts (Bitumens)
D 2171	Viscosity of Asphalts by Vacuum Capillary Viscometer
D 2172	Quantities Extraction of Bitumen from Bituminous Paving Mixtures
D 2397	Cationic Emulsified Asphalt
D 2726	Bulk Specific Gravity of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens
D 2993	Acrylonitrile-Butadiene Rubberized Tar
D 2995	Determining Application Rate of Bituminous Distributors
D 3381	Viscosity-Graded Asphalt Cement for Use in Pavement Construction
D 3628	Selection and Use of Emulsified Asphalt
D 3910	Design, Testing, and Construction of Slurry Seal

D 4125	Asphalt Content of Bituminous Mixtures by the Nuclear Method
D 4791	Flat Particles, Elongated Particles, or Flat and Elongated Particles in Coarse Aggregate
D 4867	Effect of Moisture on Asphalt Concrete Paving Mixtures
D 5148	Centrifuge Kerosene Equivalent
D 5360	Design and Construction of Bituminous Surface Treatments
D 5444	Mechanical Size Analysis of Extracted Aggregate
D 5624	Determining the Transverse-Aggregate Spread Rate for Surface Treatment Applications
D 5727	Emulsified Refined Coal Tar (Mineral Colloid Type)
D5892	Type IV Polymer-Modified Asphalt Cement for Use in Pavement Construction
E 11	Wire-Cloth Sieves for Testing Purposes
PS 090	Asphalt Content of Hot-Mix Asphalt by the Ignition Method

Asphalt Institute, Asphalt Institute Building, College Park, MD 20740

Manual Series No. 13	Asphalt Surface Treatments and Asphalt Penetration Macadam
Manual Series No. 2 (MS-2)	Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types

Proceedings, Association of Asphalt Paving Technologists

Vol 41	A 4-Year Survey of Low Temperature Transverse Pavement Cracking on Three Ontario Test Roads

International Slurry Surfacing Association (ISSA)

TB-100	Wet Track Abrasion
TB-109	Loaded Wheel
TB-114	Wet Stripping
TB-139	Cohesion

TB-149	Boiling
A 143	Recommended Performance Guidelines for Micro-Surfacing

Federal Highway Administration (FHWA), 400 Seventh Street, SW, Washington, DC 20590

Publication No. FHWA-SA-94-051

National Asphalt Pavement Association (NAPA)

IS 118	Guidelines for Materials, Production, and Placement of Stone Matrix Asphalt (SMA)

APPENDIX B

EXAMPLES OF COLD-MIX AND HOT-MIX

RECYCLING PROBLEMS

B-1. COLD-MIX RECYCLING PROBLEM. The middle 16 meters (50 feet) of an airfield taxiway is to be removed to a full depth (7.5 to 1.25 centimeters, 3 to 5 inches), replaced with a recycled cold mix, and overlaid with 7.5 centimeters (3 inches) of new hot mix. The design mix must be developed for the recycled cold mix.

a. Step 1. Obtain samples of the in-place pavement (use jackhammer or other acceptable means).

b. Step 2. Run an extraction on the old asphalt pavement to determine the following:

(1) Asphalt content. Use the determination of the existing asphalt content as a guide to calculate how much, if any, additional asphalt binder will be needed.

(2) Asphalt penetration. After recovering the asphalt cement perform a penetration test to determine if the existing asphalt has become so hard and brittle that it needs rejuvenating. If possible, avoid using a rejuvenator with recycled cold mixes. Until the rejuvenator penetrates the old asphalt, the mix is unstable and could remain unstable for as long as 2 months. Generally, a slow-set asphalt emulsion is preferred for cold-mix recycling.

c. Step 3. Vary the amount of asphalt emulsion added from 0 to 2.5 percent, residual asphalt, in 0.5 percent increments. This range will generally be large enough to bracket the optimum amount of emulsion to be added. Prepare a set of three samples at each percentage of asphalt emulsion, and compact at 75-blow compaction effort at a temperature of 121 degrees C (250 degrees F).

d. Step 4. Test the samples obtained in step 3 for stability, flow, unit weight, percent voids total mix, and percent voids filled with asphalt. Record the test results in plots similar to those shown in figure B-1. The plots in figure B-1 are used to determine the optimum asphalt emulsion to be added.

e. Step 5. Using figure B-1 and the procedure outlined in TM 5-822-8/ AFM 88-6, Chap. 8 (Future AFJMAN 32-1028), and TM 5-825-2/AFJMAN 32-1014, select the preliminary optimum asphalt emulsion to be added from table B-1.

f. Step 6. Determine the optimum water content by preparing a set of samples of various water contents at the previously determined asphalt content (0.6 percent added asphalt emulsion held constant) using the 75-blow compaction effort at the approximate temperature at which the reclaimed asphalt concrete will be during construction.

g. Step 7. Using the data obtained in step 6, plot the dry density versus the water content, as shown in figure B-2. Pick the peak of the curve to obtain the optimum water content. For the example, the optimum water content is 2 percent.

h. Step 8. Adjust mix during laydown operations as needed.

Table B-1
Determination of Optimum Asphalt Content

Selection Point	Asphalt Emulsion Added
Peak of stability curve	0.5 percent
Peak of unit-weight curve	1.0 percent
4 percent voids in total mix	1.0 percent
75 percent total voids filled with asphalt	0.0 percent
Average	0.6 percent

B-2. HOT-MIX RECYCLING PROBLEM. The middle 24 meters (75 feet) of a runway is to be removed full depth (7.5 centimeters, 3 inches) and replaced with a recycled asphalt mixture containing 50 percent reclaimed asphalt pavement. Develop the design mix.

a. Step 1. Obtain samples of the in-place pavement (use jackhammer or other acceptable means) along with samples of the new aggregates to be used and the new asphalt and recycled agent, if needed.

b. Step 2. Run sieve analyses on all aggregates including aggregate extracted from sample of the in-place asphalt mixture. If an adequate history upon which to evaluate the new aggregate is not available, use the standard tests as outlined in TM 5-822-8/AFM 88-6, Chap. 8 (Future AFJMAN 32-1028), and TM 5-825-2/AFJMAN 32-1014. The history of the performance of the old aggregate should suffice for its evaluation. The aggregate gradations for this example are shown in table B-2.

Table B-2
Aggregate Gradations

	Percent Passing			
Sieve Size	Reclaimed Asphalt Pavement	New Coarse Aggregate	New Fine Aggregate	New Natural Sand
19 mm (3/4 inch)	100	100	100	100
12.7 mm (1/2 inch)	95	95	100	100
9.5 mm (3/8 inch)	83	75	100	100
4.75 mm (No. 4)	63	12	100	98
2.36 mm (No. 8)	52	2	79	95
1.18 mm (No. 16)	40	0	57	89
600 m (No. 30)	29	0	42	77
300 m (No. 50)	21	0	30	48
150 m (No. 100)	12	0	18	12
75 m (No. 200)	6.0	0	8.0	4.5

c. Step 3. Determine the percentage of each aggregate to be used so that the gradation requirements for the blend are satisfied. The gradation requirements for this example job are outlined in table B-3. The gradation requirements for recycled hot mix are the same as those for new mixtures. Through trial and error, it was determined that a blend using 50 percent reclaimed asphalt materials, 24 percent coarse aggregate, 19 percent fine aggregate, and 7 percent natural sand would satisfy the gradation requirements (table B-3).

Table B-3
Gradation of Recycled Mixture

	Percent Passing	
Sieve Size	Specifications	Recycled Mixture
19 mm (3/4 inch)	100	100
12.7 mm (1/2 inch)	82 - 96	95
9.5 mm (3/8 inch)	75 - 89	86
4.75 mm (No. 4)	59 - 73	60
2.36 mm (No. 8)	46 - 60	48
1.18 mm (No. 16)	34 - 48	37
600 m (No. 30)	24 - 38	28
300 m (No. 50)	15 - 27	20
150 m (No. 10)	8 - 18	10
75 m (No. 200)	3 - 6	4.8

d. Step 4. Conduct a penetration test on the recovered asphalt cement. A penetration test on the asphalt recovered from the in-place asphalt mixture indicated an asphalt penetration of 10. The target penetration for this example (mild climate) is about 50. Because of the low penetration, it will be necessary to use a low-viscosity asphalt cement, AC-2.5, and possibly an asphalt recycling agent.

e. Step 5. Prepare three samples at each selected asphalt content with no recycling agent and three samples at each selected asphalt content, including an additional 0.5 percent recycling agent. The added asphalt content should be varied from 2.5 to 4.0 percent for the samples with no recycling agent and from 1.5 to 3.0 percent for the samples with 0.5 percent recycling agent. Figure B-3 shows the properties of the mixtures with various added asphalt contents and 0.5 percent recycling agent. Figure B-4 shows the properties of the mixtures at various asphalt contents with no recycling agent.

f. Step 6. Select the optimum asphalt content for the mixture with no recycling agent and for the mixture with 0.5 percent recycling agent. The optimum asphalt content and mixture properties for the two mixtures, as well as the penetration of the asphalt cement recovered from these two mixtures, are listed in table B-4.

g. Step 7. Select a preliminary mix design to provide penetration of recovered asphalt cement to be approximately 50 by interpolating between penetration values of 40 and 90 as determined in step 6. The change in penetration with a change in recycling agent is not linear, but for the preliminary mixture design a linear interpretation is sufficient. The properties at optimum asphalt and recycling agent contents are presented in table B-5.

Table B-4
Asphalt Mixture Properties at Optimum Asphalt Content

Property	Mixture with no Recycle Agent	Mixture with 0.5 Percent Recycle Agent
Optimum asphalt content, percent (by mass of total mix)	4.0	3.0
Density, kg/m^3 (pcf)	2,404 (150.1)	2,363 (147.5)
Stability, N (lb)	9,786 (2,200)	8,007 (1,800)
Flow, 0.25 mm (0.01 inch)	16	16
Voids total mix, percent	3.9	4.5
Voids filled with asphalt, percent	75	72
Penetration of recovered asphalt binder, 0.1 mm	40	90

Table B-5
Mixture Properties at Optimum Asphalt and Optimum Recycling Agent Content

Property	Mixture
Optimum recycling agent, content, percent	0.1
Optimum added asphalt content, percent	3.8
Density, grams/centimeter^3 (pcf)	2,397 (149.6)
Stability, N (lb)	9,119 (2050)
Flow, 0.25 millimeter (0.01 inch)	16
Voids total mix, percent	4.0
Voids filled with asphalt, percent	74
Penetration of recovered asphalt binder, 0.1 millimeter	50

h. Step 8. At start-up of plant operations, the mixture may have to be modified to suit field conditions. The properties of the asphalt binder can be adjusted without changing other mix properties significantly by increasing the amount of recycling agent slightly and decreasing the amount of asphalt cement by the same amount or vice versa. Failure to modify mix design to meet field conditions may result in an unsatisfactory mix.

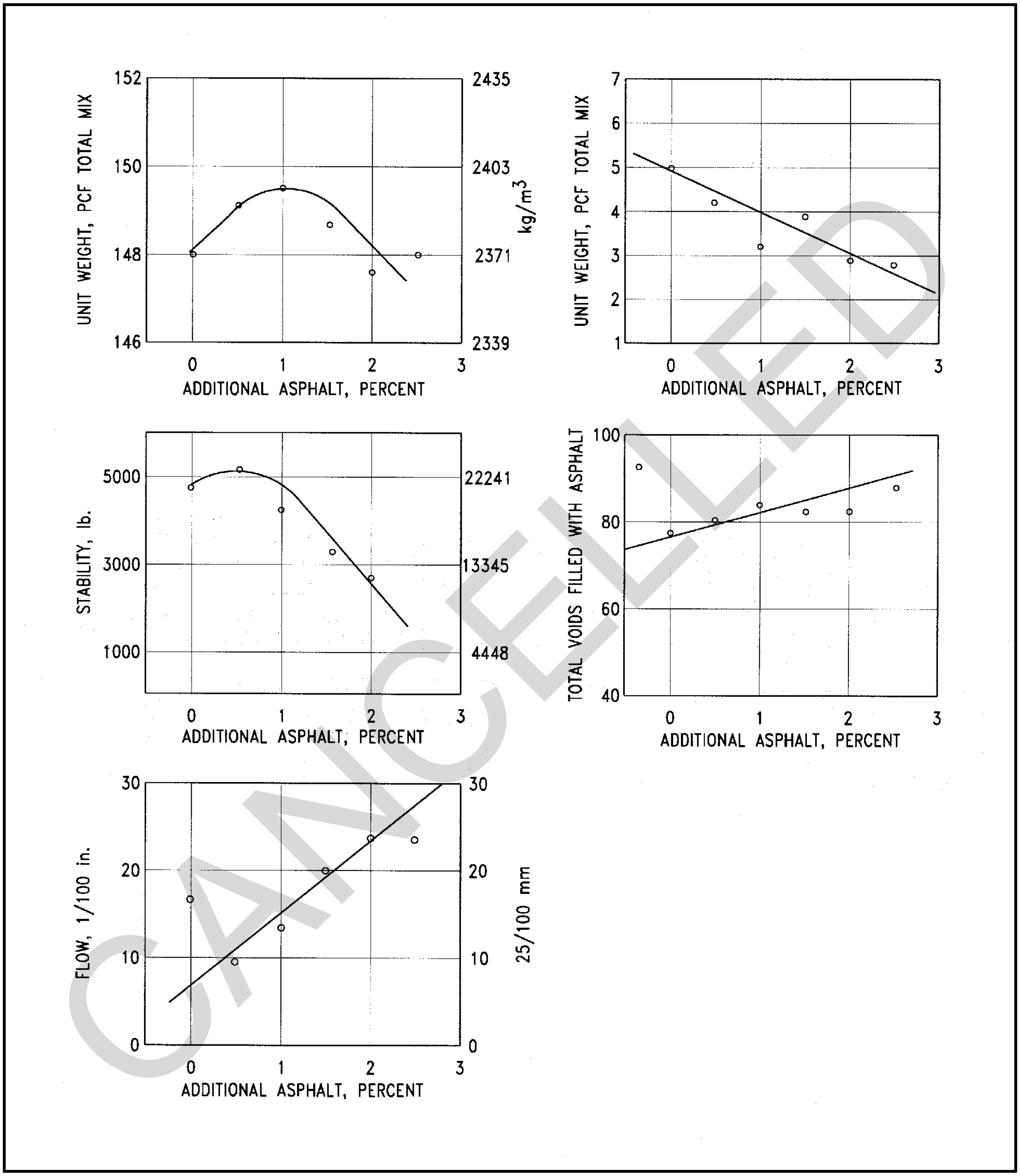

Figure B-1 Recycled cold-mix design using asphalt emulsion

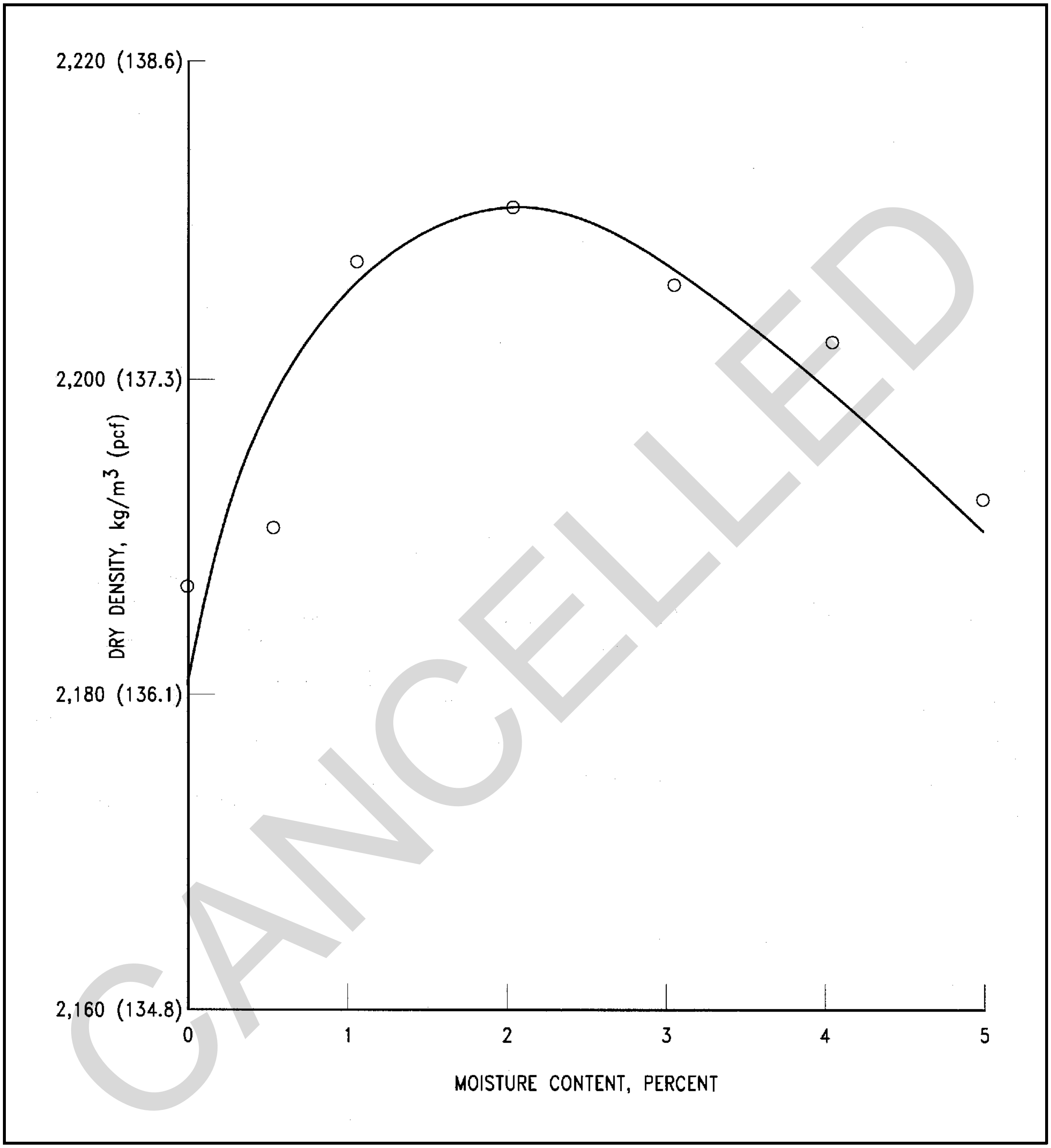

Figure B-2 Determination of optimum moisture for cold-mix design

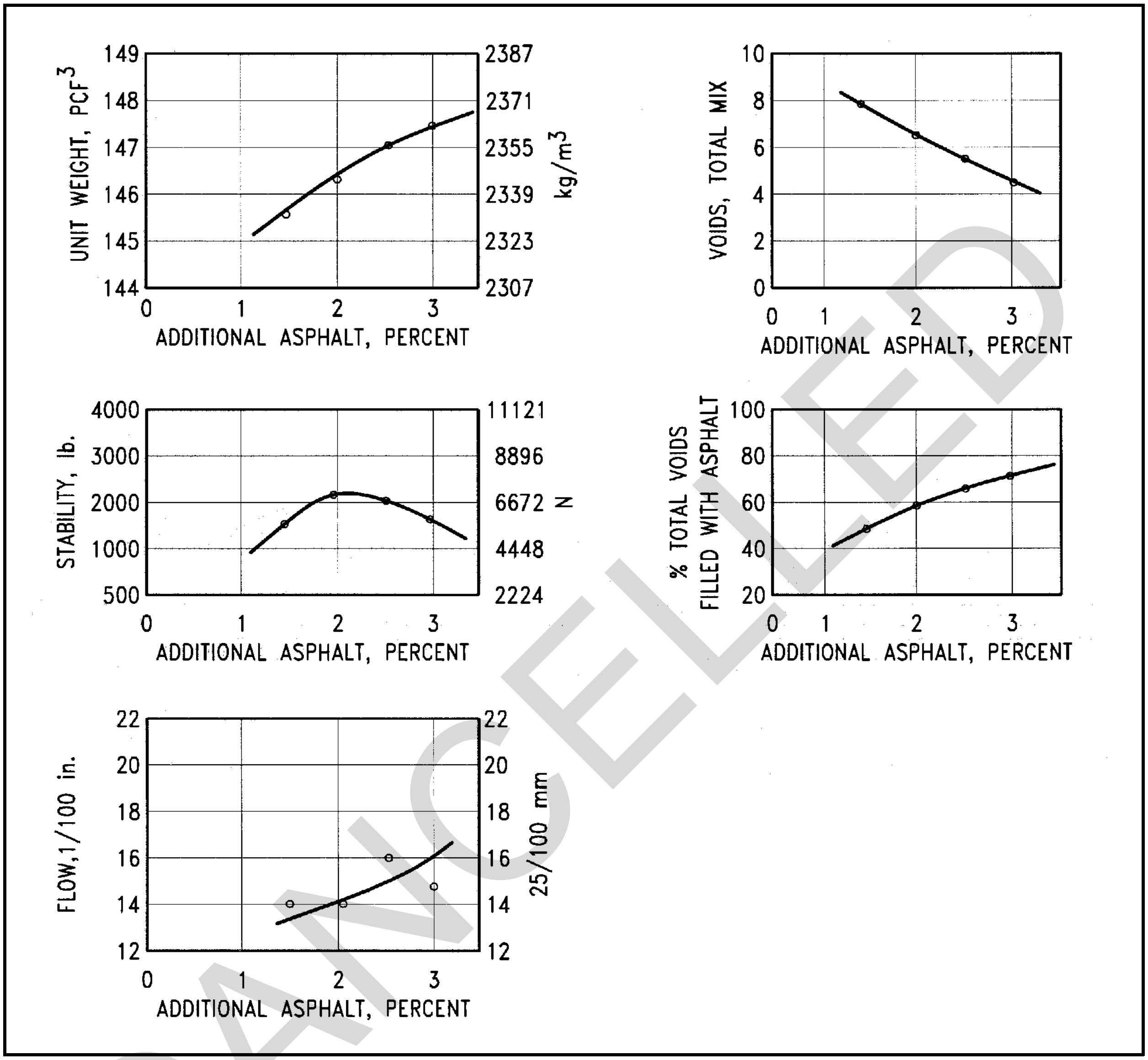

Figure B-3 Recycled hot-mix asphalt mix design for recycled hot mix; AC-2.5 asphalt cement and 0.5 percent recycling agent

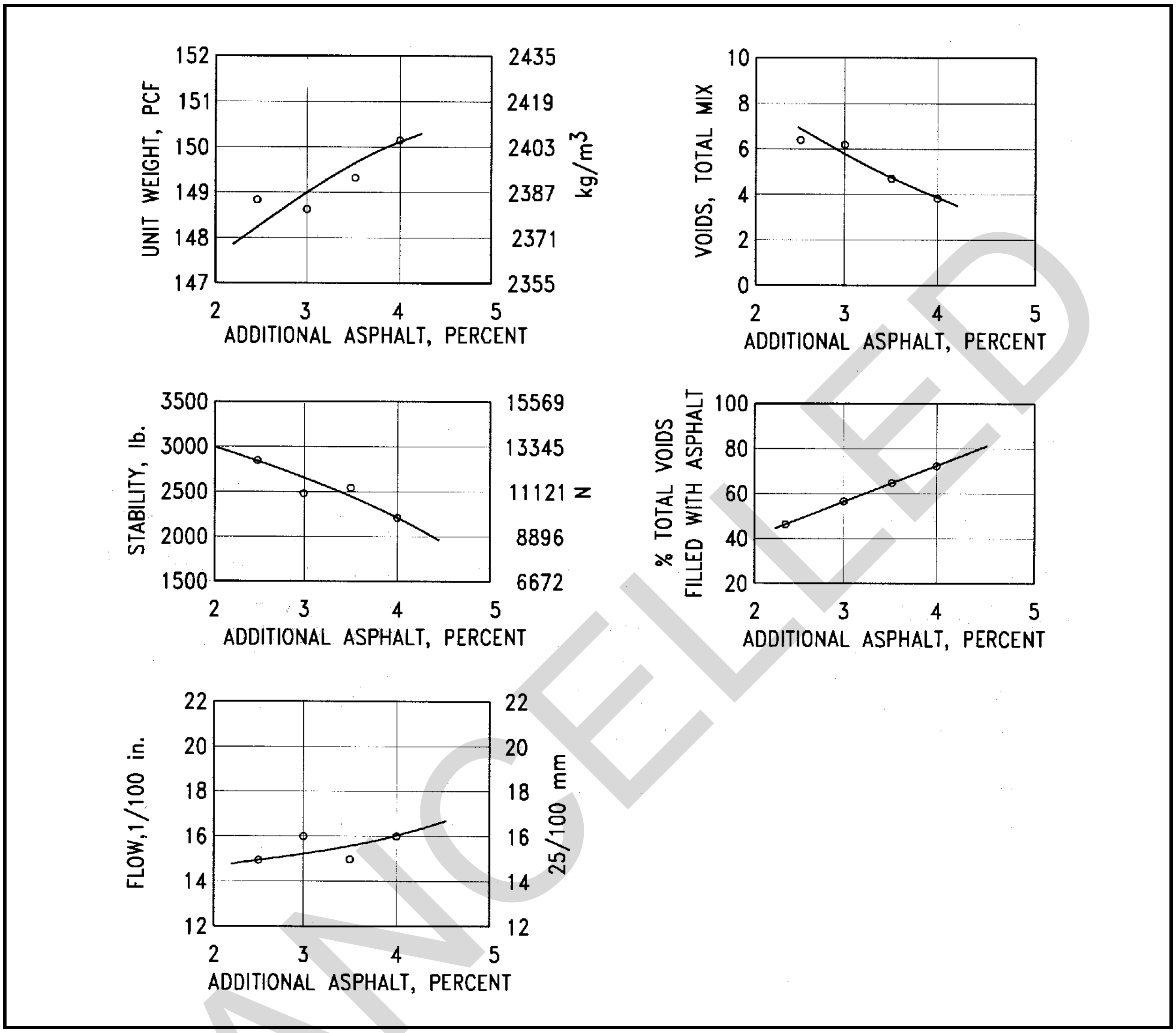

Figure B-4 Recycled hot-mix asphalt mix design for recycled hot mix; AC-2.5 asphalt cement with no recycling agent

APPENDIX C

SUMMARY OF DESIGN METHOD FOR SLURRY SEALS

C-1. INTRODUCTION.

a. The design method for determining the emulsion requirement consists of determining the surface area of the job aggregate and calculating the amount of asphalt required to coat the surface area with a film thickness of 8 microns. The absorption characteristics of the aggregate are determined using the CKE test. The total asphalt is the asphalt required for coating the aggregate plus the asphalt required to satisfy the aggregate absorption.

b. The water required for a given mixture is determined by a cone test as described in ASTM D 3910. Water is added to a slurry mixture until a flow of 25.4 millimeters (1 inch) is obtained on a reference plate. The consistency of the mixture when the 25.4 millimeter (1-inch) flow is obtained must be such that there is no segregation in the mixture. Portland cement or hydrated lime can be added to aid in overcoming the segregation; the cone test can serve as an aid for determining the amount of portland cement or hydrated lime required in the mixture.

C-2. SURFACE AREA DESIGN METHOD. The surface area design method includes three considerations: the calculation of the amount of asphalt required to coat the surface area of the job aggregate, the absorption characteristics of the aggregate, and the total asphalt content.

a. Surface area asphalt calculation.

(1) The surface area of the job aggregate is determined by multiplying the percent of aggregate passing a given sieve by a surface area factor based on the sieve size. The surface area of the aggregate is determined for each particle size (group) and then summed to obtain the total surface area. The surface area units are given in square meters per kilogram (feet per pound) of aggregate. The surface area factors are shown in table C-1. The total surface area (SA) is then corrected to obtain a corrected surface area (CSA); CSA = SA x 2.65/ASG, where ASG is the apparent specific gravity of the aggregate. When the surface area and the desired bitumen film thickness are known, the volume of asphalt required can be obtained. From these parameters the asphalt required to coat the surface area is calculated. The equation for calculation of the surface area asphalt, SAA, is as follows:

$$SAA = \begin{array}{l} \textit{Metric}:\ \ CSA \times t \times 0.99941 \times SG_A \\ \textit{U.S. Customary}:\ \ CSA \times t \times 0.02047 \times SG_A \end{array} \qquad \text{(eq E-1)}$$

where

SAA = surface area asphalt, percent of dry aggregate weight

CSA = corrected surface area, square meters per kilogram (feet per pound) of dry aggregate

t = asphalt film thickness, microns

SG_A = specific gravity of the asphalt

0.99941 (0.02047) = conversion coefficient for the units of the equation

Table C-1
Factors Used in Calculating Surface Area of Slurry Seal Aggregate

	Surface Area Factors	
Sieve Size	Square Meters Per Kilogram of Aggregate	Square Feet per Pound of Aggregate
9.5 millimeter (3/8 inch)	0.00409	0.02
4.75 millimeter (No. 4)	0.00409	0.02
2.36 millimeter (No. 8)	0.00819	0.04
1.18 millimeter (No. 16)	0.01639	0.08
600 m (No. 30)	0.02867	0.14
300 m (No. 50)	0.06144	0.30
150 m (No. 100)	0.12289	0.60
75 m (No. 200)	0.32771	1.60

(2) If the specific gravity of the asphalt is not known, the asphalt required to coat the aggregate may be calculated by assuming SG_A = 1.0. The error that results from assuming SG_A = 1.0 is small and will not greatly affect the final design requirements.

b. Aggregate absorption. The absorption requirements of the aggregate are determined by using the Centrifuge Kerosene Equivalent (CKE) described in ASTM D 5148. In this test, 100 grams of minus 4.75 millimeter (No. 4) material is centrifuged in the presence of kerosene for 2 minutes. The amount of kerosene retained by the aggregate is assumed to approximate the amount of asphalt that the aggregate will absorb. The kerosene absorbed (KA) by the aggregate is converted to a percentage of the dry weight of the aggregate.

c. Total asphalt.

(1) The total asphalt requirement is obtained by adding the percent asphalt required for the film thickness and the percent asphalt required for absorption. All percentages are based on the dry weight of the aggregate. The total is obtained as follows:

$$AR = SAA + KA \qquad \text{(eq E-2)}$$

or

$$AR = \begin{array}{l} \textit{Metric}:\ \ (CSA \times t \times 0.99941 \times SG_A) + KA \\ \textit{U.S. Customary}:\ \ (CSA \times t \times 0.02047 \times SG_A) + KA \end{array} \qquad \text{(eq E-3)}$$

where

AR = total asphalt required, percent of dry aggregate weight

KA = kerosene absorbed, percent of dry aggregate weight

(2) The required percentage of emulsion can be calculated by dividing the total asphalt required for the aggregate by the percentage of asphalt residue in the emulsion. A sample calculation for determining the asphalt content is presented in paragraph *SAMPLE CALCULATION OF ASPHALT REQUIREMENTS FOR A SLURRY SEAL AGGREGATE*.

C-3. CONE TEST.

a. The cone test is used to determine the amount of water required to form a workable mixture as described in ASTM D 3910. This test uses the sand absorption cone described in ASTM C 128. The cone is placed over a baseplate. The baseplate has concentric circles inscribed in diameters that are equal to and larger than the large end of the cone. The radius of each circle increases in 12.7 millimeter (1/2-inch) increments. The cone is loosely filled with a slurry mixture, struck off, and then removed to allow the slurry mixture to “flow” over the baseplate. A mixture with a flow of 25.4 millimeters(1 inch) is considered to contain the right amount of water for field workability. Mixtures which will not flow 25.4 millimeters (1 inch) require additional water to obtain the desired flow. If the flow cannot be obtained without segregation of the mixture, the addition of 0.5 to 4 percent portland cement or hydrated lime may help to reduce the segregation. Flows greater than 25.4 millimeters (1 inch) indicate excess water or segregation.

b. If portland cement or hydrated lime is added to reduce segregation and its addition has not been included in the design gradation, the total bitumen content of the mixture should be corrected to include the effects of the portland cement or hydrated lime. As a rule, the asphalt content should be increased by 0.6 percent for every percent of additional portland cement or hydrated lime added to the mixture.

C-4. SAMPLE CALCULATION OF ASPHALT REQUIREMENTS FOR A SLURRY SEAL AGGREGATE.

a. The ASG equals 2.96, and the aggregate gradation includes 2 percent portland cement.

Sieve Size	Percent Passing	Surface Area Factor square meters per kilogram (feet per pound) of Aggregate	Surface Area square meters per kilogram (feet per pound) of Aggregate
9.5 mm (3/8 inch)	100	0.00409 (0.02)	0.409 (2.00)
4.75 mm (No. 4)	99.5	0.00409 (0.02)	0.407 (1.99)
2.36 mm (No. 8)	95.6	0.00819 (0.04)	0.783 (3.82)
1.18 mm (No. 16)	77.8	0.01639 (0.08)	1.275 (6.22)
600 m (No. 30)	52.0	0.02867 (0.14)	1.491 (7.28)
300 m (No. 50)	24.5	0.06144 (0.30)	1.505 (7.35)
150 m (No. 100)	10.7	0.12289 (0.60)	1.315 (6.42)
75 m (No. 200	6.4	0.32771 (1.60)	2.097 (10.24)
		Total SA	9.282 (45.32)

Corrected SA (CSA) = SA x 2.65/2.96 = 8.310 square meters per kilogram (40.57 square feet per pound) of aggregate.

b. Aggregate absorption requirements. The aggregate gradation includes 2 percent portland cement.

Cup No. (a)	Tare Weight Grams (b)	Sample Weight Grams (c)	Weight Before Centrifuging Grams (d = b + c)	Weight After Centrifuging Grams (e)	KA Percent (f = e - d)
1	215.3	100.0	315.3	321.0	5.7
2	215.9	100.0	315.9	321.6	5.7
				Average KA	5.7

c. Total asphalt requirements. The factors involved in calculating the asphalt contents are as follows:

(1) Asphalt = SS-lh asphalt emulsion.

(2) Design film thickness (t) = 8 microns.

(3) Apparent specific gravity of aggregate (ASG) = 2.96.

(4) Specific gravity of asphalt (SG_A) = 1.028.

(5) Kerosene absorption (KA) = 5.7 percent.

(6) Corrected surface area (CSA) =
Metric: 8.310 square meters per kilogram of aggregate
U.S. Customary: 40.57 square feet per pound of aggregate.

(7) Total asphalt required (AR) =
Metric: (CSA x t x SG_A x 0.99941) + KA
U.S. Customary: (CSA x t x SG_A x 0.02047) + KA

(8) AR =
Metric: (8.310 x 8 x 1.028 x 0.99941) + 5.7 = 6.83 + 5.7 = 12.53 percent.
U.S. Customary: (40.57 x 8 x 1.028 x 0.02047) + 5.7 = 6.83 + 5.7 = 12.53 percent.

(9) AR = 12.53 percent of dry aggregate weight.

(10) Residue asphalt content in emulsion = 63 percent by weight.

(11) Emulsion required = $\dfrac{AR \times 100}{\text{Residue asphalt content in emulsion}}$

(12) Emulsion required = $\dfrac{12.53 \times 100}{63}$ = 19.9 percent of dry aggregate weight, that is, 19.9 kilograms (pounds) of emulsion is required for every 100 kilograms (pounds) of dry aggregate.

GLOSSARY OF SPECIAL TERMS

The most common terms related to asphalt concrete pavements are not defined here since they may be found in many references, primarily in ASTM D8. Certain terms whose definitions have not been universally accepted or that have limited usage are defined for this manual as follows:

a. Coarse aggregate. The aggregate retained on the Number (No.) 4 sieve, as described in American Society for Testing and Materials (ASTM) E11.

b. Fine aggregate. The aggregate passing the 4.75 millimeter (No. 4) sieve and retained on the 75 m (No. 200) sieve, often referred to as sand. Natural sand (fine aggregate) is that material which is found naturally and not manufactured by crushing.

c. Mineral filler. Mineral aggregate particles passing a 75 m (No. 200) sieve or commercially available materials such as lime or cement.

d. Asphalt base course. One or more courses of asphalt mixture placed on a subbase or subgrade to serve as a base course. This mixture is sometimes called a black base. An asphalt base course is covered with an intermediate course and surface course.

e. Intermediate course. That portion of a pavement placed on the base course to serve as a leveling or transition layer between the base and surface courses. Intermediate courses are sometimes called leveling or binder courses.

f. Surface course. The top course of an asphalt concrete pavement. The surface course is referred to as wearing course by many pavement engineers.

g. Optimum asphalt content. The asphalt content of a paving mixture, determined by the Marshall or gyratory methods of design, that satisfies the applicable Department of Army and Air Force pavement mix design criteria.

h. Marshall stability value. The maximum load in Newtons (pounds) that can be applied to a specimen of asphalt concrete paving mixture when tested in the Marshall apparatus.

i. Flow. The deformation, measured in 25 hundredths of a millimeter (hundredths of an inch), that occurs in a compacted specimen of a paving mixture at the point where maximum load begins to decrease when subjected to the Marshall stability test.

j. The components of a compacted bituminous mixture are shown below. A given volume of compacted bituminous concrete consists of air, bitumen, and aggregate.

k. Void calculations of compacted asphalt mixture.

(1) Percent voids total mix (VTM). The percentage of the compacted asphalt concrete mixture not occupied by the aggregate or asphalt cement.

$$VTM = \frac{v_{air}}{v_{total}} \times 100$$

(2) Voids in mineral aggregate (VMA). The percentage of the compacted bituminous mixture not occupied by the aggregate. The percentage of VTM plus the percentage of asphalt cement by total volume is equal to VMA.

$$VMA = \frac{v_{air} + v_{bitumen}}{v_{total}} \times 100$$

(3) Percent voids filled with asphalt (VF). The percentage of the VMA in the compacted aggregate mass that is filled with asphalt.

$$VF = \frac{v_{bitumen}}{v_{air} + v_{bitumen}} \times 100$$

l. Porous friction course (PFC). A porous friction course (PFC) is an open-graded, free-draining asphalt paving mixture that can be placed on an existing pavement to minimize hydroplaning and to improve skid resistance in wet weather. The course is placed in a layer usually varying from approximately 20 to 25 millimeters (3/4 to 1-inch) in thickness. PFC paving mixtures are produced in asphalt hot-mix plants and placed with conventional asphalt paving machines.

m. Surface recycling. Repaving, heater-planing-scarifying, cold milling, and rejuvenating are methods of surface recycling that are used to increase skid resistance, decrease permeability to air and water, and improve properties of the asphalt binder. Depending on the process used, surface recycling may modify from 5 to 50 millimeters (1/4 to 2 inches) of the pavement surface. Surface recycling, except for some types of repaving, does not increase the strength of the pavement. The cost to scarify and rejuvenate pavement is approximately the same as the cost of an additional 25 millimeters (1 inch) of overlay, but the benefits obtained from the scarification and rejuvenation usually exceed the benefits of the additional 25 millimeters (1 inch) of overlay.

n. Cold-mix recycling. Cold-mix recycling involves reclaiming most or all of the existing bituminous pavement by breaking it to a maximum particle size of 4 centimeters (1-1/2 inch), mixing it with virgin materials, if needed, and reusing the mixture as a pavement material. Cold recycling material can be used to surface secondary roads, if a seal coat is applied, and as a base course for high-quality pavements.

o. Hot-mix recycling. Hot-mix recycling is a process which involves removing the existing hot-mix asphalt, crushing it if necessary, and mixing it in a hot-mix plant with new aggregate, asphalt, and recycling agent, when required. The recycled hot-mix asphalt can be designed for use in all types of pavements. Crushed portland cement concrete has also been used as aggregate for hot recycled mixtures.

p. Microsurfacing. Microsurfacing is the process of applying a latex modified asphalt emulsion slurry to an existing pavement surface. The slurry is mixed and applied similar to asphalt slurry seals except for the specially designed mixing and constant agitation application equipment required by the latex modifier. Microsurfacing applications can contain larger aggregate particles than conventional asphalt slurry seals. This slurry can be used as a rut filler or for re-establishing skid resistance. Curing is normally completed in from 1 to several hours depending on weather conditions.

q. Resin modified pavement (RMP). RMP is a composite pavement surfacing that uses a unique combination of hot-mix asphalt and portland cement concrete (PCC) materials in the same layer. The RMP material is generally described as an open-graded asphalt concrete mixture containing 25 to 35 percent voids which are filled with a resin modified portland cement grout. An RMP layer is typically 5 centimeters (2-inches) thick and has a surface appearance similar to a rough-textured portland cement concrete.

r. Stone matrix asphalt (SMA). SMA, which is also referred to as stone mastic asphalt, is a mixture of aggregate, mineral filler, asphalt cement, and a cellulose fiber or a modified asphalt with or without the fiber. SMA is designed to prevent rutting and abrasion under high loads and/or high tire pressures.

s. Mastic asphalt. Mastic asphalt is a hot-mix asphalt mixture of fine aggregate and asphalt cement forming a mixture free of voids.