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Foreword

Prominent among the concerns of the pavement construction industry, and funding agencies everywhere, are the conservation of materials, protection of the environment, and economy of construction/rehabilitation procedures.

Pavement recycling with asphalt is a procedure that eminently and realistically meets these concerns, especially since it is economical of energy, materials, and money.

In asphalt pavement recycling, materials reclaimed from old pavement structures are reprocessed along with some new materials to produce asphalt mixtures meeting all normal specification requirements. The recycled mixtures may be placed on the same roadbeds from which the reclaimed materials came; but they can be used anywhere that asphalt mixtures are needed.

Asphalt recycling is not new; its history stretches back several decades. However, increasing economic and environmental needs have brought added emphasis and many technical refinements to recycling processes.

Recycled pavements vary widely in their contents of reclaimed materials, new aggregates, asphalt, and recycling agents. Reclaimed pavement materials may range from as little as 10 percent to as much as 70 percent of the final mixture. The vast majority of the projects, however, incorporate between 10 and 50 percent reclaimed asphalt pavement in the final mixture.

Although there are other procedures for recycling pavements with asphalt, this manual reviews processes and design methods for hot-mix recycling only.

This second edition is enhanced with the inclusion in Chapter II of the only known design method for recycling hot mixtures.

The experience of many engineers, contractors, equipment manufacturers, asphalt producers, and others has gone into this manual. We are grateful for the help these experts have freely given. As further advances in pavement recycling using asphalt products are developed, the data will be incorporated into future editions of this manual.

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College Park, Maryland 20740, USA
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(301-277-4258)
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Some Important Technical Publications of
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1.01 ASPHALT PAVEMENTS ARE REUSABLE—The useful life of an asphalt pavement structure depends on a number of factors. The main ones are the amount and weight of traffic, weather, quality of materials, subgrade strength, drainage, and quality of construction.

Timely maintenance can extend the pavement’s usefulness. Eventually, though, disintegration begins and the pavement needs to be rebuilt. Even so, the old materials do not have to be wasted. They can be recycled as part of the reconstruction process. Therefore, an asphalt pavement structure is a reusable resource.

1.02 RECYCLING DEFINED—The following definitions are used in this manual:

**Asphalt Pavement Structure**—A pavement structure, placed above the subgrade or improved subgrade, with all courses consisting of asphalt-aggregate mixtures, or a combination of asphalt courses and untreated aggregate courses.

**Recycling**—The reuse, usually after some processing, of a material that has already served its first-intended purpose.

**Hot-Mix Recycling**—A process in which reclaimed asphalt pavement materials, reclaimed aggregate materials, or both, are combined with new asphalt, and/or recycling agents, and/or new aggregate, as necessary, in a central plant to produce hot-mix paving mixtures. The finished product meets all standard material specifications and construction requirements for the type of mixture being produced.

**Reclaimed Asphalt Pavement (RAP)**—Removed and/or processed pavement materials containing asphalt and aggregate.

**Reclaimed Aggregate Material (RAM)**—Removed and/or processed pavement materials containing no reusable binding agent.

**Extracted Aggregate**—Aggregate separated from a sample of aged asphalt pavement.

**Extracted Asphalt**—Asphalt extracted from a sample of aged asphalt pavement.

**Recycled Mixture**—The finished mixture of reclaimed asphalt pavement, new asphalt cement, recycling agent (if needed), and reclaimed or new
graded aggregate. The mixture meets accepted standards for use in any particular course of the pavement structure.

Asphalt Recycling Agent—An organic material with chemical and physical characteristics selected to restore aged asphalt to desired specifications.

1.03 RECYCLING AS AN ALTERNATIVE—Hot-mix recycling is one of several alternative methods of rehabilitating distressed asphalt pavements. Included in the alternatives are to: (1) hot-mix recycle; (2) cold-mix recycle; (3) surface recycle; (4) reconstruct with all new materials; (5) patch and thick overlay; (6) patch and thin overlay; (7) patch (routine maintenance). All of the options should be considered before one is selected.

The first step is to establish the probable causes of distress. Toward this end, the original pavement design and construction records are reviewed. Field tests, including deflection, are then performed; and laboratory tests are made on pavement samples. The results are analyzed for the purpose of deciding which alternative rehabilitation method is most suitable.

The evaluation of each option should be based on pavement design principles. Consideration should be given to expected performance, environmental influences, projected traffic volume and weights, pavement geometrics, and economics (initial costs and projected maintenance costs).

Maintenance, seal coats, overlays, and new construction are covered in other Asphalt Institute publications. This manual concentrates on one recycling alternative: hot-mix recycling.

1.04 REASONS FOR HOT-MIX RECYCLING—Hot-mix recycling is a proven process that may be used to upgrade worn-out pavements. In addition, a major benefit is realized by adding asphalt to untreated granular material in the lower layers of the pavement structure, and then placing the material back in the same thickness. This increase in the thickness of the layers that are asphalt-bound increases the strength of the pavement structure, thus increasing its load-carrying capacity. By this means, existing composite structural sections can be converted to high-quality thick-lift or Full-Depth® asphalt pavements (a Full-Depth asphalt pavement is one in which asphalt mixtures are used for all courses above the subgrade or improved subgrade).

On the basis of cost-effectiveness alone, hot-mix recycling of existing pavements should be a major consideration in planning road rehabilitation.

An important reason for recycling is the need to conserve natural resources. Economy, ecology, and energy conservation are all served.

*The term FULL-DEPTH is registered by The Asphalt Institute with the U.S. Patent Office.
when asphalt and aggregate—the two most frequently used pavement construction materials—are reused to provide a strengthened and improved roadway.

1.05 ADVANTAGES OF HOT-MIX RECYCLING—Economy and conservation of natural resources have already been mentioned as benefits of hot-mix recycling. There are a number of other distinct benefits:

- Significant structural improvements can be obtained with little or no change in thickness.
- Additional right-of-way is not needed.
- Frost susceptibility may be reduced.
- Surface and base distortion problems can be corrected.
- Existing mix deficiencies can be corrected.
- Problems are few:

Air-quality problems at the plant site may arise if appropriate and available equipment is not used, or if too high a percentage of reclaimed asphalt pavement is specified for the recycled mixture.

Obtaining a quality product may require more care than starting with new materials.

1.06 HOT-MIX RECYCLING METHODS—All hot-mix recycling of reclaimed asphalt pavements is done by the heat-transfer method. Recycled mixtures can and have been successfully produced in both batch and drum-mix plants. Some plant modifications are required, however, and they are described in Chapter VI.

In batch plants the heat-transfer method comprises the use of superheated aggregate (new and/or reclaimed) to increase the temperature of the reclaimed asphalt pavement.

In the drum-mix process heat-transfer also takes place. Three major approaches have been used. One process depended entirely on indirect heating by the exhaust gases. The second process used convection heating by containing the complete combustion process and by turbulent air mixing action which develops a uniform gas temperature distribution. The third process heats the new or reclaimed aggregate in the front of the drum, introduces the reclaimed asphalt pavement at approximately the center of the drum and heats (by convection and conduction), and mixes through the remainder of the drum.

The resulting mixture, from either batch or drum-mix plants, at conventional mix temperatures is discharged into a surge bin or haul trucks. The recycled material is placed on the roadway using conventional paving and compaction equipment.
Chapter II

MATERIALS EVALUATION

2.01 SCOPE—Recycled hot-mix is a blend of reclaimed and new materials formulated to achieve a paving mixture with specified physical properties. The first step is a materials evaluation, followed by a mix-design (Marshall or Hveem Method). All materials should be tested and evaluated to find the optimum blend meeting the mix requirements. To that end, this chapter discusses procedures and tests for both reclaimed and new materials.

2.02 SAMPLING—Several methods have been developed for obtaining representative samples of materials. Among them are the methods for sampling asphalt such as The Asphalt Institute’s Manual Series No. 18; Sampling Asphalt Products for Specification Compliance, the American Society for Testing and Materials (ASTM) Designation D 140, the American Association of State Highway and Transportation Officials (AASHTO) Method of Test T 40; aggregates, ASTM D 75 (AASHTO T 2); and asphalt paving mixtures ASTM D 979 (AASHTO T 168). Regardless of the method used, however, engineering judgment is required in developing the sampling plan.

The technique known as random sampling is one of the best yet devised. With it the sampling location is selected in such a way that all possible locations within the section to be investigated are equally likely to be chosen. The choice is unbiased because it is made entirely by chance, using a table of random numbers.

An added advantage of using the random sampling procedure, which is based on statistical methods, is that both the amount of work and the cost involved probably can be reduced.

The procedure for the random sampling of paving materials detailed in The Asphalt Institute’s Soils Manual, Manual Series No. 10 or ASTM Designation D 3665, may be used to select sampling locations.

The crushing or milling of reclaimed asphalt pavement may alter the gradation of the aggregate portion. Therefore, samples submitted for testing should represent the cold feed stock piles at the plant site. Stockpile sampling is described in the AASHTO Method of Test T-2

2.03 RECLAIMED ASPHALT PAVEMENT—The design of asphalt paving mixtures containing reclaimed asphalt pavement requires certain laboratory tests in addition to the usual Marshall or Hveem procedures.
First, the composition of the reclaimed asphalt pavement must be determined. This will include:
(a) Aggregate gradation,
(b) Asphalt content,
(c) Asphalt viscosity at 60 °C (140°F).

Then, the gradation of the reclaimed aggregate materials, if any, must be determined. This information is used to define the quantity of new asphalt cement that is needed, and the gradation and quantity of additional aggregates.

The aggregate and the asphalt in the reclaimed asphalt pavement have properties that must be evaluated separately. Therefore, it is necessary to extract the aged asphalt from a representative sample of the reclaimed asphalt pavement.

(a) Aggregate Evaluation—A sieve analysis, ASTM C 117 and C 136 (AASHTO T 11 and T 27), is performed on the aggregate portion of the reclaimed asphalt pavement sample to determine the gradation. Any deficiencies can be corrected by blending appropriate sieve fractions of new and/or reclaimed aggregate with reclaimed asphalt pavement aggregate.

(b) Extraction—The method used should be ASTM Designation D 2172 (AASHTO T 164). The purpose of the extraction is quantitative separation of the aggregate and asphalt.

(c) Asphalt Evaluation—The asphalt content of the reclaimed asphalt pavement is determined on the basis of the relative weights of the extracted asphalt and aggregate. The extracted asphalt is reclaimed from solution by ASTM Method D 1856 (AASHTO T 170). Its consistency then is determined on the basis of viscosity at 60 °C (140°F), ASTM D 2171 (AASHTO T 202). This determination is necessary to estimate the required amount and grade of asphalt to be used in the recycled mix design.

It is suggested that when not more than 20 percent reclaimed asphalt pavement (RAP) is to be incorporated in the mix; the viscosity of the extracted asphalt is not necessary. The grade of asphalt to be used in the recycled mix will normally be the same grade used for conventional mixes.

2.04 NEW ASPHALT—New asphalt cement, added to the mixture of reclaimed asphalt pavement and new aggregate, serves two purposes. It increases the total asphalt content to meet the requirements of the mixture; and it blends with the aged asphalt in the reclaimed portion of the
mixture to yield an asphalt meeting the desired specifications. Generally, AC-10, AC-5 or AC-2.5 (AR-4000, AR-2000 or AR-1000; 85-100, 120-150 or 200-300 pen.) asphalt cements are used for this purpose. These asphalt should meet standard specifications, ASTM D 3381 or D 946 (AASHTO M 226 or M 20).

2.05 RECYCLING AGENTS—Recycling agents are organic materials with chemical and physical characteristics selected to restore aged asphalt to desired specifications. In selecting the recycling agent, the viscosity characteristics of the combined aged asphalt and recycling agent are the determining factors.

A number of recycling agents have been successfully used in the design of recycled mixtures, although there are currently no nationwide American standard specifications for these materials. In 1976, a Pacific Coast Conference of Asphalt Users and Producers established a committee of asphalt producers and user agencies to develop functional specifications for recycling agents, and in 1979 the same group adopted a set of tentative specifications for this purpose. These tentative specifications were submitted to ASTM for consideration in the development of standards for these materials. These proposed recycling agent specifications were published in the 1980 Proceedings of the Association of Asphalt Paving Technologists (Volume 49). (Consult with the manufacturer for selection of a recycling agent.)

2.06 UNTREATED AGGREGATE—Any aggregate normally used for asphalt concrete, reclaimed aggregate material, or both may be added to the reclaimed asphalt pavement to produce a mix with the desired gradation. Preliminary testing of the combined aggregates is necessary to determine the correct quantity of each to be used in the recycled mixture.

When selecting the new or reclaimed aggregate, consider whether the mix is to be used as an asphalt-concrete base or surface course. The mixture must have the desired gradation and meet the test criteria of the design procedure and pavement structural selection. It must also have enough workability to allow proper placement.

2.07 COMBINED AGGREGATE—The blend of reclaimed and new aggregates should meet specified gradation criteria, such as one of the mix gradations described in The Asphalt Institute’s publication, Model Construction Specifications for Asphalt Concrete and Other Plant-Mix Types (SS-1).

Alternatively, ASTM Specification D 3515 or established state or local criteria may be used in determining the gradation and quality requirements of the combined aggregates.

In addition, the blend of aggregates should be checked for resistance to stripping. Using an accepted water sensitivity test and the same asphalt chosen for the project, determine whether a mineral filler or anti-stripping agent is needed.
The immersion compression test, "Effect of Water on Cohesion of Compacted Bituminous Mixtures," ASTM Designation D 1075 (AASHTO T 165), is recommended for compacted mixtures containing asphalt cement. Retained strength should exceed 75 percent. See also Cause and Prevention of Stripping in Asphalt Pavements (ES-10), The Asphalt Institute.
Chapter III

RECYCLING HOT-MIX DESIGN

3.01 SCOPE—This chapter presents the step-by-step process necessary to proportion the reclaimed materials, select the grade and quantity of asphalt cement (plus recycling agent, if needed) and prepare a final design for the recycled mixture. This is the hot-mix method of recycling, using from 10 to 70 percent reclaimed asphalt pavement. Batch plants can handle up to 50 percent (without some auxiliary method of preheating RAP), with the most practical range being 10 to 35 percent; drum-mix plants can handle up to 70 percent, with 10 to 50 percent being a practical range.

3.02 PREPARATORY STEPS—This mix-design procedure uses either the Marshall or the Hveem method,* as follows:

The aggregate from a reclaimed asphalt pavement is blended with reclaimed aggregate materials and/or new aggregate that is required to obtain a combined aggregate gradation meeting the specification requirements. Once the relative aggregate proportions are determined, a total asphalt demand is calculated. A grade of new asphalt is then selected (plus recycling agent, if needed) to restore the aged asphalt and provide a final binder that meets the functional requirements of the asphalt specifications while satisfying the asphalt demand of the mix. Following these determinations, the mix design by either Marshall or Hveem procedure is performed and the exact quantity of total binder determined.

3.03 MIX DESIGN—With the information obtained from the materials evaluation (Chapter II) the recycled hot-mix design may be formulated. Viscosity at 60 °C (140 °F), ASTM Designation D 2171 (AASHTO T 202), is the test measurement used in this procedure to identify asphalt in the reclaimed asphalt pavement and in the recycled mixture.

Figure III-1 is a flow chart setting forth the steps for this design procedure. The steps are:

1) Combined Aggregates in the Recycled Mixture—Using the gradation of the aggregate from the reclaimed asphalt pavement, the reclaimed aggregate material, if any, and new aggregate, a combined gradation meeting the desired specification requirements is calculated.

*The Marshall and Hveem methods of mix design are fully described in Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types (MS-2), The Asphalt Institute.
AGGREGATE GRADATION, ASPHALT CONTENT AND VISCOSITY OF EXTRACTED ASPHALT FROM RECLAIMED ASPHALT PAVEMENTS (RAP)

GRADATION OF RECLAIMED AGGREGATE MATERIAL (RAM) AND/OR NEW AGGREGATE

(1) CALCULATE COMBINED AGGREGATE IN RECYCLED MIX

(2) APPROXIMATE ASPHALT DEMAND OF COMBINED AGGREGATES

(3) ESTIMATED PERCENT NEW ASPHALT IN THE MIX*

(4) SELECT GRADE OF NEW ASPHALT

(5) TRIAL MIX DESIGNS BY MARSHALL AND HVEEM METHOD†

(6) SELECT JOB MIX FORMULA

*IN SOME CASES A RECYCLING AGENT MAY BE INCORPORATED, PAR. 2.05
†MIX DESIGN METHODS FOR ASPHALT CONCRETE AND OTHER HOT-MIX TYPES (MS-2), THE ASPHALT INSTITUTE

Figure III-1—Flow chart of mix-design procedure.
TABLE III-1 FORMULAS FOR PROPORTIONING MATERIALS
FOR RECYCLED HOT MIXTURES
(Where blend of aggregates in the mix is kept constant)

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<th>For Asphalt Content</th>
<th>by wt. of total mix</th>
<th>by wt. of aggregate</th>
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<tr>
<td>% New Asphalt, $P_{nb}$</td>
<td>$\frac{(100^2 - rP_{sb})P_b}{100(100 - P_{sb})}$</td>
<td>$\frac{(100 - rP_{sb})}{100}$</td>
</tr>
<tr>
<td>% RAP, $P_{sm}$</td>
<td>$\frac{100(100 - r) - (100 - r)P_b}{100 - P_{sb}}$</td>
<td>$\frac{(100 + P_{sb})(100 - r)}{100}$</td>
</tr>
<tr>
<td>% New Agg. and/or RAM, $P_{ns}$</td>
<td>$r - \frac{rP_b}{100}$</td>
<td>$r$</td>
</tr>
</tbody>
</table>

Total | 100 | $100 + P_b$ |

% New Asphalt to Total Asphalt Content, $R$ | $\frac{100P_{nb}}{P_b}$ | $\frac{100P_{nb}}{P_b}$ |

$P_{sm}$ = Percent salvage mix (RAP) in recycled mix
$P_b$ = Asphalt content of recycled mix, %
$P_{sb}$ = Asphalt content of salvaged mix (RAP), %
$P_{nb}$ = Additional asphalt and/or recycling agent in recycled mix, %
$P_{ns}$ = Percent additional aggregate (new or reclaimed aggregate material)
$r$ = Percent new and/or reclaimed aggregate material to total aggregate in recycled mix
$R$ = Percent new asphalt and/or recycling agent to total asphalt in recycled mix
After the blend of aggregate (aggregate in the RAP, new aggregates and/or RAM) have been established, the amount of new aggregate (and/or RAM) is expressed as \( r \), in percent.

For example, suppose the following blend was established for a recycled mix:

- 60% reclaimed aggregate (RAM)
- 15% new aggregate
- 25% RAP aggregate

The amount of new aggregate and RAM is 75%. Hence, \( r = 75 \). Table III-1 contains formulas for proportioning materials for recycled asphalt hot mixes where the blend of aggregates in the mix is kept constant.

(2) **Approximate Asphalt Demand of the Combined Aggregates**—

The approximate asphalt demand of the combined aggregates may be determined by the Centrifuge Kerosene Equivalent (CKE) test included in The Asphalt Institute Hveem Method of Mix Design, or calculated by the following empirical formula:

\[
P = 0.035a + 0.045b + Kc + F\]

where:

- \( P \) = approximate total asphalt demand of recycled mix, percent by weight of mix
- \( a \) = percent* of mineral aggregate retained on 2.36mm (No. 8) sieve
- \( b \) = percent* of mineral aggregate passing the 2.36mm (No. 8) sieve and retained on the 75 \( \mu \)m (No. 200) sieve
- \( c \) = percent of mineral aggregate passing 75 \( \mu \)m (No. 200) sieve
- \( K \) = 0.15 for 11-15 percent passing 75 \( \mu \)m (No. 200) sieve
  - 0.18 for 6-10 percent passing 75 \( \mu \)m (No. 200) sieve
  - 0.20 for 5 percent or less passing 75 \( \mu \)m (No. 200) sieve
- \( F \) = 0 to 2.0 percent. Based on absorption of light or heavy aggregate. In the absence of other data, a value of 0.7 is suggested

*Expressed as a whole number.

With an approximate asphalt demand established, this will provide a basis for a series of trial mixes for a mix design. Trial mixes will vary in asphalt contents in 0.5 increments on either side of the calculated approximate asphalt demand.

For example, suppose that the approximate asphalt demand was calculated to be 6.2 percent. A series of trial mixes might then range from 5.0 to 7.0 percent or from 5.5 to 7.5 percent.
(3) *Estimated Percent of New Asphalt in Mix*—The quantity of new asphalt to be added to the trial mixes of the recycled mixture, expressed as percent by weight of total mix is calculated by the following formula:

\[ P_{nb} = \frac{(100^2 - r P_{nb}^2)P_b}{100 (100 - P_{nb})} - \frac{(100 - r)P_{sb}}{100 - P_{sb}} \]

where:

- \( P_{nb} = \) percent*, asphalt content of recycled mix (approximate asphalt demand by CKE or empirical formula in item (2) above)
- \( r = \) asphalt demand by CKE or empirical formula in item (2) above
- \( P_b = \) percent*, asphalt content of reclaimed asphalt pavement asphalt demand, determined by CKE or empirical formula in item (2) above
- \( P_{sb} = \) percent*, asphalt content of reclaimed asphalt pavement **Plus recycling agent, if used.

*Expressed as a whole number.

For example, suppose the asphalt content, \( P_{sb} \) of the RAP is 4.7 percent and \( r = 75\% \), then

\[ P_{nb} = \frac{(100^2 - 75 \times 4.7)P_b}{100 (100 - 4.7)} - \frac{(100 - 75)4.7}{100 - 4.7} = 1.01 \ P_b - 1.23 \]

The percentages of new asphalt for any asphalt content may now be readily determined.

*Note: The formula above is for asphalt content expressed as percent by weight of total mix. If asphalt contents are expressed as percent by weight of aggregate the formula for calculating quantity of new asphalt is:

\[ P_{nb} = P_b - \frac{(100 - r)P_{sb}}{100} \]

(See Table III-1.)*

(4) *Select Grade of New Asphalt*—Using Figure III-2, a target viscosity of the asphalt blend is selected. A commonly selected target point is the viscosity at the mid-range of an AC-20 asphalt† or 2,000 poises.

†The relationships between the various grading systems for asphalt cement are shown in Figure III-4.
The percent of the new asphalt, \( P_{nb} \), to the total asphalt content, \( P_b \), is expressed by the following formula:

\[
R = \frac{100 \ P_{nb}}{P_b}
\]

For example, suppose the mix described in Step (3) is to have an estimated asphalt content of 6.2 percent. The amount of new asphalt to be added (from Step 3) is:

\[
P_{nb} = 1.01 \times 6.2 - 1.23 = 5.0 \text{ percent}
\]

Then;

\[
R = \frac{100 \ (5.0)}{6.2} = 81
\]

The grade of new asphalt (and/or recycling agent) is determined using a log-log viscosity versus percent new asphalt blending chart such as Figure III-2. A target viscosity for the blend of recovered asphalt and the new asphalt (and/or recycling agent) is selected. The target viscosity is usually the viscosity of the mid-range of the grade of asphalt normally used depending on type of construction, climatic conditions, amount and nature of traffic.

Plot the viscosity of the aged asphalt in the RAP on the left hand vertical scale, Point A, as illustrated in Figure III-2. Draw a vertical line representing the percentage of new asphalt, \( R \), calculated above and determine its intersection with the horizontal line representing the target viscosity, Point B. Then draw a straight line from Point A, through Point B and extend it to intersect the right hand scale, Point C. Point C is the viscosity at 60 °C (140 °F) of the new asphalt (and/or recycling agent) required to blend with the asphalt in the reclaimed asphalt pavement to obtain the target viscosity in the blend. Select the grade of new asphalt that has a viscosity range that includes or is closest to the viscosity at Point C.

To plot a point using the vertical scale, consider expressing the viscosity using 10 raised to some power. For example, 75,000 poises would be \( 7.5 \times 10^4 \). To plot the point on the vertical scale, 7.5 would be interpolated on the scale between \( 10^4 \) and \( 10^5 \).
NEW ASPHALT OR RECYCLING AGENT IN BLEND,
R, PERCENT BY WEIGHT

Figure III-2—Asphalt viscosity blending chart.
Note: It is suggested that when selecting a grade of asphalt cement for recycling that the following guide be used:

- Up to 20% RAP = No change in asphalt grade
- 21% RAP or More = Do not change more than one grade (i.e. from AC-20 to AC-10)

(5) **Trial Mix Design**—Trial mix designs are then made using the Marshall or Hveem apparatus. The formulas shown in Table III-1 are used for proportioning the ingredients: new asphalt, $P_{nb}$, reclaimed asphalt pavement (RAP), $P_{sm}$ and new and/or reclaimed aggregate (RAM), $P_{ns}$.

Keep in mind that if two different aggregate sources are utilized, such as new aggregate and RAM, that the percentages of each of these sources must be determined and the total equal $P_{ns}$. For example the aggregate blend consisted of

- 60% RAM
- 15% New aggregate
- 25% RAP aggregate

$r = 75$

If $P_{ns}$ in a trial mix is to be 61.4 percent, then the percent of RAM (in the total mix) will be $61.4 \times (60/75) = 49.1$ percent and the percent new aggregate with be $61.4 \times (15/75) = 12.3$. The total equals 61.4 percent.

(6) **Select Job-Mix Formula**

**Design Example 1**

The reclaimed asphalt pavement has an asphalt content of 5.4 percent by weight of total mix. The viscosity of the asphalt recovered from the reclaimed asphalt pavement is 46,000 poises at 60°C (140°F). The grade of asphalt cement normally used is AC-20, and the target viscosity at a temperature of 60°C (140°F) is 2,000 poises. Gradation of RAP, RAM and new aggregate is:

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>RAP AGG.</th>
<th>RAM</th>
<th>NEW AGG.</th>
</tr>
</thead>
<tbody>
<tr>
<td>25.0 mm (1 in.)</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>19.0 mm (3/4 in.)</td>
<td>98</td>
<td>92</td>
<td>100</td>
</tr>
<tr>
<td>9.5 mm (3/8 in.)</td>
<td>85</td>
<td>45</td>
<td>100</td>
</tr>
<tr>
<td>4.75 mm (No. 4)</td>
<td>65</td>
<td>19</td>
<td>94</td>
</tr>
<tr>
<td>2.36 mm (No. 8)</td>
<td>52</td>
<td>5</td>
<td>85</td>
</tr>
<tr>
<td>300 μm (No. 50)</td>
<td>22</td>
<td>1</td>
<td>26</td>
</tr>
<tr>
<td>75 μm (No. 200)</td>
<td>8</td>
<td>0</td>
<td>6</td>
</tr>
</tbody>
</table>
Approximately 30 percent of RAP was selected because (1) a batch plant was to be used for recycling, (2) moisture content of the RAP was 5 percent and (3) this is a practical range for maintaining mix productions. (See Chapter VI for temperature variations for percent of RAP and moisture.)

STEP 1—Combined Aggregates in Recycled Mixture

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>30% RAP Aggr.</th>
<th>60% RAM Aggr.</th>
<th>10% NEW Aggr.</th>
<th>Combined Aggr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>25.0 mm (1 in.)</td>
<td>[100 × 0.3 = 30.0]</td>
<td>+ [100 × 0.6 = 60.0]</td>
<td>+ [100 × 0.1 = 10.0]</td>
<td>= 100.0</td>
</tr>
<tr>
<td>19.0 mm (3/4 in.)</td>
<td>[98 × 0.3 = 29.4]</td>
<td>+ [92 × 0.6 = 55.2]</td>
<td>+ [100 × 0.1 = 10.0]</td>
<td>= 94.6</td>
</tr>
<tr>
<td>9.5 mm (3/8 in.)</td>
<td>[85 × 0.3 = 25.5]</td>
<td>+ [45 × 0.6 = 27.0]</td>
<td>+ [100 × 0.1 = 10.0]</td>
<td>= 62.5</td>
</tr>
<tr>
<td>4.75 mm (No. 4)</td>
<td>[65 × 0.3 = 19.5]</td>
<td>+ [19 × 0.6 = 11.4]</td>
<td>+ [94 × 0.1 = 9.4]</td>
<td>= 40.3</td>
</tr>
<tr>
<td>2.36 mm (No. 8)</td>
<td>[52 × 0.3 = 15.6]</td>
<td>+ [5 × 0.6 = 3.0]</td>
<td>+ [85 × 0.1 = 8.5]</td>
<td>= 27.1</td>
</tr>
<tr>
<td>300 μm (No. 50)</td>
<td>[22 × 0.3 = 6.6]</td>
<td>+ [1 × 0.6 = 0.6]</td>
<td>+ [26 × 0.1 = 2.6]</td>
<td>= 9.8</td>
</tr>
<tr>
<td>75 μm (No. 200)</td>
<td>[8 × 0.3 = 2.4]</td>
<td>+ [0 × 0.6 = 0]</td>
<td>+ [6 × 0.1 = 0.6]</td>
<td>= 3.0</td>
</tr>
</tbody>
</table>

Then: \( r = 60 + 10 = 70 \)

Job Specification
ASTM D 3515, Table 1
3/4 in. (19mm) Nom.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>25.0 mm (1 in.)</td>
<td>100</td>
<td>100.0</td>
<td></td>
</tr>
<tr>
<td>19.0 mm (3/4 in.)</td>
<td>90 - 100</td>
<td>94.6</td>
<td></td>
</tr>
<tr>
<td>9.5 mm (3/8 in.)</td>
<td>56 - 80</td>
<td>62.5</td>
<td></td>
</tr>
<tr>
<td>4.75 mm (No. 4)</td>
<td>35 - 65</td>
<td>40.3</td>
<td></td>
</tr>
<tr>
<td>2.36 mm (No. 8)</td>
<td>23 - 49</td>
<td>27.1</td>
<td></td>
</tr>
<tr>
<td>300 μm (No. 50)</td>
<td>5 - 19</td>
<td>9.8</td>
<td></td>
</tr>
<tr>
<td>75 μm (No. 200)</td>
<td>2 - 8</td>
<td>3.0</td>
<td></td>
</tr>
</tbody>
</table>

\[
P = 0.035a + 0.045b + Kc + F \\
= 0.035 \times 72.9 + 0.045 \times 24.1 + 0.20 \times 3.0 + 1.0 \\
= 5.2 \text{ percent}
\]

STEP 3—Estimated Percent of New Asphalt in Mix

\[
P_{nb} = \frac{(100^2 - r P_b)P_b - (100 - r)P_{sb}}{100 (100 - P_{sb})} \\
= \frac{(100^2 - 5.4 \times 70)P_b - (100 - 70)5.4}{100 (100 - 5.4)} \\
= 1.02 P_b - 1.71
\]
For an approximate asphalt demand of 5.2 percent;

\[ P_{nb} = 1.02 (5.2) - 1.71 = 3.6 \text{ percent} \]

The percent of new asphalt, \( P_{nb} \), to total asphalt, \( P_b \), will then be;

\[ R = \frac{100 (3.6)}{5.2} = 69 \text{ percent}. \]

**STEP 4—Select Grade of New Asphalt**

On Figure 111-3, Point A is the viscosity of the aged asphalt at 46,000 poises \((4.6 \times 10^4)\). Point B is located from a target viscosity of 2,000 poises \((2.0 \times 10^3)\) and \( R = 69 \). The projected line from Point A through Point B to Point C indicated that the viscosity of the new asphalt is \(7.0 \times 10^2\) poises \((700)\).

Since AC-20 is the normal grade of asphalt cement used in the area of construction, climate and traffic, an AC-10 will be chosen for this project. The AC-10 when blended with the aged asphalt in the RAP should result in an AC-20 within acceptable tolerances.

**STEP 5—Trial Mix Design**

Using an aggregate blend of 60 percent RAM, 10 percent new aggregate and 30 percent RAP aggregate, trial mixes of different asphalt contents (varying in 0.5 percent increments) are prepared according to standard Marshall or Hveem mix design procedures.

The formulas in Table 111-1 may be used to determine the percentages of each ingredient in the trial mixes. Since the formula for \( P_{nb} \) was calculated in Step 3, the formulas for proportioning the \( P_{sm} \) and \( P_{ns} \) are:

\[
P_{sm} = \frac{100 (100 - r) - (100 - r)P_b}{100 - P_{sb}} = \frac{100 (100 - 70) - (100 - 70)P_b}{100 - 5.4} = 31.71 - 0.32 P_b
\]

\[
P_{ns} = r - \frac{r P_b}{100} = 70 - \frac{70P_b}{100} = 70 - 0.70P_b
\]
Figure III-3—Asphalt viscosity blending chart (Design Example 1).
When preparing trial mixes in the laboratory, it is suggested that the RAP be heated to mixing temperature and maintained at that temperature. The new aggregate and RAM are normally heated to 10°C (50°F) above
the mixing temperature. When the aggregate and RAP have been weighed out, dry mixing should begin to thoroughly blend the materials before adding new asphalt. Keeping the RAP at elevated temperatures should be held to a minimum. Otherwise, normal mix design procedures are followed.

**STEP 6—Select Job-Mix Formula**

The optimum new asphalt content and the mix design are determined according to established standard Marshall or Hveem mix-design criteria (as is used for virgin materials).

**Design Example 2**

Reclaimed asphalt pavement has an asphalt content of 6.0 percent with a viscosity of 100,000 poises. Gradation of RAP, RAM and new aggregate are the same as for Example 1.

**STEPS 1 and 2—Same as Example 1.**

**STEP 3—Estimated Percent of New Asphalt in Mix**

\[ P_{nb} = \frac{(100^2 - r P_{sb})P_b}{100 (100 - P_{sb})} - \frac{(100 - r)P_{sb}}{100 - P_{sb}} \]

\[ = \frac{(100^2 - 70 \times 6.0)P_b}{100 (100 - 6.0)} - \frac{(100 - 70)6.0}{100 - 6.0} \]

\[ = 1.02 P_b - 1.91 \]

For an approximate asphalt demand of 5.2 percent;

\[ P_{nb} - 1.02 (5.2) - 1.91 = 3.4 \text{ percent} \]

**STEP 4—Select Grade of New Asphalt**

On Figure III-5, Point A is the viscosity of the aged asphalt at 100,000 poises \((1.0 \times 10^5)\). Point B is located using values of 2,000 poises \((2.0 \times 10^3)\) for target viscosity and \(R = 57\), \((100P_{nb}/P_b = 100 \times 3.4/6.0)\) of new asphalt. A line is projected through these two points and intersects the right axis at \(1.8 \times 10^2\) \((180\) poises), Point C.

This is a heavily-traveled roadway where the design engineer is concerned with channelling and normally uses an AC-20 in mix design. Figure III-4 can be used to determine how much of a recycling agent to blend with AC-20 to give an apparent viscosity of 180 poises.
Let the AC-20 be the new asphalt and plot 2,000 poises \((2.0 \times 10^3)\) on the left-hand scale, Point D. The viscosity of the recycling agent is 1 poise. Plot this as Point E on the right-hand scale. Connect Points D and E with a straight line. Now determine what percentage, \(R\), of recycling agent will be required to result in a viscosity of 180 poises for the blend. This is plotted as Point F on the line from D to E. The percentage \(R\) on the horizontal scale indicates 22 percent. This means that a tank of AC-20 containing 22 percent of the recycling agent should have a viscosity of approximately 180 poises. When this blend is added to the mix for a total asphalt content of about 5.2 percent, the viscosity of the total asphalt in the recycled mix should be 2,000 poises—within acceptable limits.

**STEP 5—Trial Mix Design**

Using an aggregate blend of 60 percent RAM, 10 percent new aggregate and 30 percent RAP aggregate, trial mixes of different asphalt contents (varying in 0.5 percent increments on either side of the estimated asphalt demand) are prepared according to standard Marshall or Hveem mix design procedures.

The formulas in Table III-1 may be used to calculate the percentages of each ingredient in the trial mixes. Since the formula for \(P_{nb}\) was calculated in Step 3, the formulas for proportioning \(P_{sm}\) and \(P_{ns}\) are:

\[
P_{sm} = \frac{100 \left(100 - r\right)}{100 - P_{sb}} - \frac{(100 - r)P_b}{100 - P_{sb}}
\]

\[
= \frac{100 \left(100 - 70\right)}{100 - 6} - \frac{(100 - 70)P_b}{100 - 6}
\]

\[
= 31.91 - 0.32 P_b
\]

\[
P_{ns} = r - \frac{rP_b}{100}
\]

\[
= 70 - \frac{70P_b}{100} = 70 - 0.70P_b
\]
Figure III-5—Asphalt viscosity blending chart (Design Example 2).
The percentages of new aggregate and RAM as a blend were determined as $P_{nr}$. However, 60 percent RAM and 10 percent new aggregate are to be used in the aggregate blend. The amount of RAM will then be $P_{ns} \times 60/70$ and the new aggregate will be $P_{ns} \times 10/70$.

When preparing trial mixes in the laboratory, it is suggested that the RAP be heated to and maintained at the mixing temperature. The aggregate is normally heated to mixing temperature plus 10 °C (50 °F). When the aggregate and RAP have been weighed out, dry mixing should begin to thoroughly blend the materials before adding new asphalt. Keeping the RAP at elevated temperatures should be held to a minimum. Otherwise, normal mix design procedures are followed.

STEP 6—Select Job-Mix Formula

The optimum new asphalt content and the mix design are determined according to established standard Marshall or Hveem mix-design criteria (as is used for virgin materials).
Chapter IV

THICKNESS DESIGN

401 THICKNESS DESIGN—The thickness design procedure for a pavement structure employing recycled hot-mix is essentially no different than that required for a pavement using all new materials. The method contained in The Asphalt Institute manual, Thickness Design—Asphalt Pavements for Highways and Streets (MS-1) is recommended. This procedure requires estimates of the anticipated traffic, environmental conditions, subgrade strength, and properties of the recycled mixture.

Increased traffic weight and volume normally require a stronger pavement section than was originally constructed. This can be done economically by designing a Full-Depth asphalt pavement using reclaimed untreated aggregate base materials in the recycled asphalt concrete mixture.

Any drainage deficiencies in the old pavement structure should be corrected before reconstruction proceeds. If any portion of the old subbase or base is to remain, the properties of these materials must be evaluated and appropriate layer coefficients assigned to them for use in the thickness design. Layer coefficients for effective thickness of existing layers can be found in The Asphalt Institute’s Asphalt Overlays for Highway and Street Rehabilitation (MS-17).
RECLAIMING PROCEDURES

5.01 PAVEMENT REMOVAL—Construction procedures for removing old pavement materials and reconstructing with recycled hot mixtures are essentially no different than have been used for several decades. The most commonly used methods for pavement removal are (1) ripping and crushing, and (2) cold milling or planing of the old pavement. Regardless of the method used, it is essential that the reclaimed asphalt pavement be kept separated from the reclaimed untreated aggregate material. Any intermingled materials that do result from the removal process should be stockpiled with or added to the reclaimed asphalt pavement.

(a) Reclaimed Asphalt Pavement—In the ripping and crushing operation, scarifiers, grid rollers, or rippers are used to break up the asphalt pavement. Then it is loaded and hauled to a crushing and screening plant (Figure V-1). Alternatively, the broken-up pavement is pulverized on the roadway by a hammermill or by additional passes of grid or V-cleated roller. Proper material sizing and separation of reclaimed asphalt pavement from the reclaimed aggregate material is more difficult in the latter case.

Specialized cold milling or planing machines have been developed that can reclaim asphalt pavement to controlled depths. In the process, the pavement is reduced to the desired maximum particle size. (Particle size is dependent upon the depth of the cut and forward speed of the cold milling equipment. See Figures V-2 and V-3.)

(b) Reclaimed Aggregate Material—After the asphalt-treated layers have been removed, any remaining aggregate materials that are to be incorporated in the recycled hot-mix may be scarified and removed with loaders, grade trimmers, or other conventional equipment.

When the pavement material removal is completed, any drainage deficiencies may be corrected. After that, the subbase or subgrade is cut, graded, and compacted to proper grade, cross section, and profile.

5.02 PAVEMENT SIZE REDUCTION—The degree to which reclaimed pavement materials must be processed after removal depends
Figure V-1—Reclaimed asphalt pavement crushe (courtesy of Barber-Greene Company).
Figure V-2—Cold-milling (courtesy of Caterpillar Tractor Co.).
largely on the removal method and the requirements of the mix design. Reclaimed asphalt pavement and reclaimed aggregate materials must be processed separately. Asphalt pavement removed by ripping will have to be crushed and screened. Some reclaimed pavement materials may require crushing to reduce the maximum particle size to acceptable limits.* Special machines, such as the one shown in Figure V-1, have been designed for the specific purpose of crushing reclaimed asphalt pavement. None of the fines should be removed from reclaimed asphalt pavement since they contain much of the aged asphalt that is to be recycled. Also, it is important that the crusher used does not produce an increase in fine size material or new fractured faces. Increased fine material and fractured faces create a requirement for more virgin material and higher asphalt content. The result, of course, is increased mix cost and potential processing problems.

5.03 STOCKPILING—The height of reclaimed asphalt pavement stockpiles should be limited to 3 metres (10 feet) maximum. The restriction is to prevent the crushed materials from sticking together because of dead load and high air temperatures. For the same reason, loaders, dozers, and trucks should not be permitted on the stockpile. The reclaimed asphalt pavement should be protected from the weather to keep it as dry as possible. One way to minimize both sticking and excessive moisture is to coordinate the crushing and hot-mixing operations so that a large stockpile of crushed reclaimed asphalt pavement is not necessary.

*Not to exceed a maximum of 95 percent passing a 50mm (2 in.) sieve.
Also, the finer character of the processed RAP material has a tendency to hold moisture and therefore requires greater consideration in protection from rain and snow. Dependent upon the annual moisture in the region, a protective covering may be cost-effective in protecting the crushed RAP material whether the source be cold milled or crushed. A cost analysis will determine the most effective protective procedure. RAP in most geographic areas will retain moisture more than virgin aggregate under the same conditions.

Reclaimed untreated aggregate base and subbase should be stockpiled in the same manner as new aggregate. Proper stockpiling is discussed in Chapter II, *Asphalt Plant Manual* (MS-3), The Asphalt Institute.

The number and location of stockpiles depend on the requirements of the specifications and the type of recycling plant. They should be carefully planned to ensure efficient plant operation.
Chapter VI

CONSTRUCTION

6.01 PLANT PRODUCTION METHODS—When reclaimed asphalt pavement is part of the recycled mixture, some changes in normal plant processes are necessary. A number of procedures have been developed. The objective of each is to heat and dry the reclaimed asphalt pavement without exposing it directly to the high temperature flame and combustion gases in the dryer. Without these changes, recycled mixtures cannot be produced economically and still comply with regulations governing exhaust stack emissions. Equally important is protection of the asphalt in the reclaimed asphalt pavement from further hardening.

Both batch plants and drum-mix plants have been modified for the successful production of hot recycled mixtures. Also, equipment manufacturers produce plants designed expressly for recycling. Because of the variety of procedures involved, each of the plant types will be discussed separately.

6.02 BATCH PLANTS—The only technique that has proven successful in recycling through a batch plant is the heat-transfer method. Briefly, here is how it works.

The reclaimed aggregate material, or new aggregate, or both are proportioned from the cold feed bins. They are then heated in a conventional aggregate dryer. (See Table VI-1 Required Aggregate Temperatures.) From there they are conveyed to the hot storage bins in the usual manner. (For asphalt plants equipped with baghouse dust collectors, extremely high exhaust temperatures could damage the bags. At exhaust gas temperatures over 232°C (450°F), the danger of bag deterioration is extreme.)

Without heating or drying, the reclaimed asphalt pavement is carried directly from the stockpile to the cold feed bin. Necessary is a separate cold feed bin that has steep sides (approaching vertical). The reclaimed material is then conveyed to the weigh hopper (See Figure VI-1). (It is weighed as a fifth material in a normal four-bin batch plant.) There it joins the superheated untreated aggregate. Heat-transfer takes place as the proportioned materials are dropped into the pugmill.

Complete temperature equilibrium in the hot recycled mixture usually is attained some time after the mix leaves the pugmill; storage silos are an aid in this respect.

This batch-plant heat-transfer method minimizes the chance of air pollution; it eliminates the problem of clogged screens; and it prevents reclaimed asphalt pavement build-up on the hot-stone elevator. However,
sometimes a steam cloud is generated; when this occurs, venting of the pugmill may be advisable (See Table VI-2).

The amount of reclaimed asphalt pavement that can be used in the recycled mix depends on (1) the moisture content and stockpile temperature of the reclaimed material, (2) the required temperature of the recycled mix, and (3) the temperature of the superheated aggregate. If the conditions are right, i.e., moisture content of the reclaimed asphalt pavement is at, or near, a minimum and its temperature is close to the surrounding air temperature, as much as 50 percent of the recycled mixture can be reclaimed asphalt pavement.

6.03 DRUM-MIX PLANTS—In the normal operation of a drum-mix plant, aggregates are heated, dried, and mixed with asphalt in the mixing drum. Early attempts at hot-mix recycling with these plants usually produced satisfactory mixes but the plants were unable to meet minimum air-pollution standards. Exposure of the reclaimed asphalt pavement to the burner flame and the extremely hot combustion gases caused excessive blue smoke. Frequently there was a build-up of aggregate fines and asphalt on metal flights and end plates that also contributed to the smoke problem.
### TABLE VI-1 REQUIRED AGGREGATE TEMPERATURES

<table>
<thead>
<tr>
<th>Reclaimed Material</th>
<th>Recycled Mix Discharge Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture Content, %</td>
<td>104°C (220°F)</td>
</tr>
<tr>
<td>0</td>
<td>121 (250)</td>
</tr>
<tr>
<td>1</td>
<td>127 (260)</td>
</tr>
<tr>
<td>2</td>
<td>132 (270)</td>
</tr>
<tr>
<td>3</td>
<td>138 (280)</td>
</tr>
<tr>
<td>4</td>
<td>141 (285)</td>
</tr>
<tr>
<td>5</td>
<td>143 (290)</td>
</tr>
</tbody>
</table>

**A. RATIO: 10% RAP/90% Aggregate**

<table>
<thead>
<tr>
<th>Reclaimed Material</th>
<th>Recycled Mix Discharge Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture Content, %</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>146 (295)</td>
</tr>
<tr>
<td>2</td>
<td>154 (310)</td>
</tr>
<tr>
<td>3</td>
<td>163 (325)</td>
</tr>
<tr>
<td>4</td>
<td>171 (340)</td>
</tr>
<tr>
<td>5</td>
<td>179 (355)</td>
</tr>
</tbody>
</table>

**B. RATIO: 20% RAP/80% Aggregate**

<table>
<thead>
<tr>
<th>Reclaimed Material</th>
<th>Recycled Mix Discharge Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture Content, %</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>168 (335)</td>
</tr>
<tr>
<td>2</td>
<td>182 (360)</td>
</tr>
<tr>
<td>3</td>
<td>196 (385)</td>
</tr>
<tr>
<td>4</td>
<td>210 (410)</td>
</tr>
<tr>
<td>5</td>
<td>224 (435)</td>
</tr>
</tbody>
</table>

**C. RATIO: 30% RAP/70% Aggregate**

<table>
<thead>
<tr>
<th>Reclaimed Material</th>
<th>Recycled Mix Discharge Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture Content, %</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>199 (390)</td>
</tr>
<tr>
<td>2</td>
<td>218 (425)</td>
</tr>
<tr>
<td>3</td>
<td>243 (470)</td>
</tr>
<tr>
<td>4</td>
<td>260 (500)</td>
</tr>
<tr>
<td>5</td>
<td>285 (545)</td>
</tr>
</tbody>
</table>

**D. RATIO: 40% RAP/60% Aggregate**

<table>
<thead>
<tr>
<th>Reclaimed Material</th>
<th>Recycled Mix Discharge Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture Content, %</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>241 (465)</td>
</tr>
<tr>
<td>2</td>
<td>271 (520)</td>
</tr>
<tr>
<td>3</td>
<td>302 (575)</td>
</tr>
<tr>
<td>4</td>
<td>338 (640)</td>
</tr>
<tr>
<td>5</td>
<td>366 (690)</td>
</tr>
</tbody>
</table>

**E. RATIO: 50% RAP/50% Aggregate**

**NOTE:** 11°C (20°F) loss between dryer and pugmill assumed in these calculations.

Table courtesy of the National Asphalt Pavement Association.
<table>
<thead>
<tr>
<th>Reclaimed Material Per Batch</th>
<th>Percent Moisture in Reclaimed Material</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Kilograms (Pounds)</td>
<td>m³/min</td>
</tr>
<tr>
<td>454 (1,000)</td>
<td>45 (1,800)</td>
</tr>
<tr>
<td>907 (2,000)</td>
<td>91 (3,200)</td>
</tr>
<tr>
<td>1,361 (3,000)</td>
<td>139 (4,900)</td>
</tr>
<tr>
<td>1,814 (4,000)</td>
<td>184 (6,500)</td>
</tr>
<tr>
<td>2,268 (5,000)</td>
<td>229 (8,100)</td>
</tr>
<tr>
<td>2,722 (6,000)</td>
<td>275 (9,700)</td>
</tr>
</tbody>
</table>

NOTE: Water vapor release time is assumed to be 10 seconds.

Table courtesy of National Asphalt Pavement Association.
Many improvements have recently been made in drum mix recycling plants to accommodate variations in materials as well as to improve thermal efficiency. Several manufacturers produce drum mix plants using the split feed approach. This is the technique most commonly used in the United States. In all of these plants, untreated aggregate enters the drum at the burner end of the drum. The aggregate is dried and superheated.

The aggregate joins the reclaimed asphalt pavement at a point far enough down-stream from the burner to be away from the flame and extremely hot gases. The reclaimed asphalt pavement enters the drum near the center through openings in the shell with chutes that channel the flow of material into the drum. New asphalt cement, recycling agent, or both and mineral filler, if needed are added. Mixing is accomplished in the lower half of the drum. (Figures VI-2, VI-3, and VI-4.)

One manufacturer has developed a plant that does not expose the asphalt to steam in the drum. Called drum mix coater, this plant uses a single-shaft coater-mixer at the drum discharge. Untreated aggregate and reclaimed asphalt pavement are premixed in the drum and discharged by gravity into the coater, where the new asphalt is injected. (Figure VI-5.)

6.04 PRODUCTION TIPS—Plant efficiency and production rate for batch and drum type plants are increased as the percentage of reclaimed asphalt pavement is decreased. In many cases, distinct economic advantages for Full-Depth pavement designs may result if recycled mixtures containing both reclaimed asphalt pavement and reclaimed aggregate base materials are used.

Since the hot-mix recycling of reclaimed asphalt pavements is done by heat-transfer, it is essential that the moisture in the stockpile of reclaimed materials be kept to a practical minimum. Excess moisture renders difficult the attainment of the uncoated-aggregate temperature necessary for effective heat-transfer.

6.05 SPREADING AND COMPACTING—Conventional equipment and procedures are used for spreading and compacting hot-mix recycled mixtures. Spreading temperatures generally range between 104 ° and 138 °C (220 ° and 280 °F). (Figure VI-6.)

The compacting of asphalt paving mixtures is discussed in detail in the Asphalt Paving Manual (MS-8), The Asphalt Institute; see also Factors Affecting Compaction (ES-9), The Asphalt Institute.
Figure VI-2—Drum mixer plant layout (courtesy of Standard Havens).
Figure VI-3—Drum mixer (Cedarapids—courtesy of Iowa Manufacturing Co.).
Figure VI-4—Drum mixer (courtesy of Barber-Greene Company).
Figure VI-5—Drum mixer (courtesy of ASTEC Industries, Inc.).
Figure VI-6—Spreading reclaimed asphalt pavement (courtesy of Barber-Greene Company).
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