



**PDHonline Course C184 (3 PDH)**

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## **Reclaimed Asphalt Pavement (RAP)**

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**PDH Online | PDH Center**

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## RECLAIMED ASPHALT PAVEMENT

## Material Description

### ORIGIN

Reclaimed asphalt pavement (RAP) is the term given to removed and/or reprocessed pavement materials containing asphalt and aggregates. These materials are generated when asphalt pavements are removed for reconstruction, resurfacing, or to obtain access to buried utilities. When properly crushed and screened, RAP consists of high-quality, well-graded aggregates coated by asphalt cement.

Asphalt pavement is generally removed either by milling or full-depth removal. Milling entails removal of the pavement surface using a milling machine, which can remove up to 50 mm (2 in) thickness in a single pass. Full-depth removal involves ripping and breaking the pavement using a rhino horn on a bulldozer and/or pneumatic pavement breakers. In most instances, the broken material is picked up and loaded into haul trucks by a front-end loader and transported to a central facility for processing. At this facility, the RAP is processed using a series of operations, including crushing, screening, conveying, and stacking.

Although the majority of old asphalt pavements are recycled at central processing plants, asphalt pavements may be pulverized in place and incorporated into granular or stabilized base courses using a self-propelled pulverizing machine. Hot in-place and cold in-place recycling processes have evolved into continuous train operations that include partial depth removal of the pavement surface, mixing the reclaimed material with beneficiating additives (such as virgin aggregate, binder, and/or softening or rejuvenating agents to improve binder properties), and placing and compacting the resultant mix in a single pass.

Reliable figures for the generation of RAP are not readily available from all state highway agencies or local jurisdictions. Based on incomplete data, it is estimated that as much as 41 million metric tons (45 million tons) of RAP may be produced each year in the United States.<sup>(1)</sup>

Additional information on recycling of asphalt pavement can be obtained from the following organizations:

National Asphalt Pavement Association  
5100 Forbes Boulevard  
Lanham, Maryland 20706-4413

Asphalt Institute  
Research Park Drive  
Lexington, Kentucky 40512

Asphalt Recycling and Reclaiming Association  
#3 Church Circle, Suite 250  
Annapolis, Maryland 21401

### CURRENT MANAGEMENT OPTIONS

#### Recycling

The majority of the RAP that is produced is recycled and used, although not always in the same year that it is produced. Recycled RAP is almost always returned back into the roadway structure in some form, usually incorporated into asphalt paving by means of hot or cold recycling, but it is also sometimes used as an aggregate in base or subbase construction.

It has been estimated that as much as approximately 33 million metric tons (36 million tons), or 80 to 85 percent of the excess asphalt concrete presently generated, is reportedly being used either as a portion of recycled hot mix asphalt, in cold mixes, or as aggregate in granular or stabilized base materials.<sup>(2)</sup> Some of the RAP that is not recycled or used during the same construction season that it is generated is stockpiled and is eventually reused.

#### Disposal

Excess asphalt concrete is disposed of in landfills or sometimes in the right of way. In most situations, this occurs where small quantities are involved, or where the material is commingled with other materials, or facilities are not readily available for collecting and processing the RAP. It is estimated that the amount of excess asphalt concrete that must be disposed is less than 20 percent of the annual amount of RAP that is generated.

### MARKET SOURCES

In most cases, recycled hot mix asphalt can be obtained from central RAP processing facilities where asphalt pavements are crushed, screened, and stockpiled for use in asphalt concrete production, cold mix, or as a granular or stabilized base material. Most of these processing facilities are located at hot mix asphalt plant sites, where the RAP is either sold or used as feedstock for

the production of recycled hot mix asphalt pavement or recycled cold mix.

The properties of RAP are largely dependent on the properties of the constituent materials and asphalt concrete type used in the old pavement. Since RAP may be obtained from any number of old pavement sources, quality can vary. Excess granular material or soils, or even debris, can sometimes be introduced into old pavement stockpiles. The number of times the pavement has been resurfaced, the amount of patching and/or crack sealing, and the possible presence of prior seal coat applications will all have an influence on RAP composition. Quality control is needed to ensure that the processed RAP will be suitable for the prospective application. This is particularly the case with in-place pavement recycling.

## **HIGHWAY USES AND PROCESSING REQUIREMENTS**

Milled or crushed RAP can be used in a number of highway construction applications. These include its use as an aggregate substitute and asphalt cement supplement in recycled asphalt paving (hot mix or cold mix), as a granular base or subbase, stabilized base aggregate, or as an embankment or fill material.

### **Asphalt Concrete Aggregate and Asphalt Cement Supplement**

Recycled asphalt pavement can be used as an aggregate substitute material, but in this application it also provides additional asphalt cement binder, thereby reducing the demand for asphalt cement in new or recycled asphalt mixes containing RAP.

When used in asphalt paving applications (hot mix or cold mix), RAP can be processed at either a central processing facility or on the job site (in-place processing). Introduction of RAP into asphalt paving mixtures is accomplished by either hot or cold recycling.

### **Hot Mix Asphalt (Central Processing Facility)**

Recycled hot mix is normally produced at a central RAP processing facility, which usually contains crushers, screening units, conveyors, and stackers designed to produce and stockpile a finished granular RAP product processed to the desired gradation. This product is subsequently incorporated into hot mix asphalt paving mixtures as an aggregate substitute. Both batch plants and drum-mix plants can incorporate RAP into hot mix asphalt.

### **Hot Mix Asphalt (In-Place Recycling)**

Hot in-place recycling is a process of repaving that is performed as either a single or multiple pass operation using specialized heating, scarifying, rejuvenating, laydown, and compaction equipment. There is no processing required prior to the actual recycling operation.

### **Cold Mix Asphalt (Central Processing Facility)**

The RAP processing requirements for cold mix recycling are similar to those for recycled hot mix, except that the graded RAP product is incorporated into cold mix asphalt paving mixtures as an aggregate substitute.

### **Cold Mix Asphalt (In-Place Recycling)**

The cold in-place recycling process involves specialized plants or processing trains, whereby the existing pavement surface is milled to a depth of up to 150 mm (6 in), processed, mixed with asphalt emulsion (or foamed asphalt), and placed and compacted in a single pass. There is no processing required prior to the actual recycling operation.

### **Granular Base Aggregate**

To produce a granular base or subbase aggregate, RAP must be crushed, screened, and blended with conventional granular aggregate, or sometimes reclaimed concrete material. Blending granular RAP with suitable materials is necessary to attain the bearing strengths needed for most load-bearing unbound granular applications. RAP by itself may exhibit a somewhat lower bearing capacity than conventional granular aggregate bases.

### **Stabilized Base Aggregate**

To produce a stabilized base or subbase aggregate, RAP must also be crushed and screened, then blended with one or more stabilization reagents so that the blended material, when compacted, will gain strength.

### **Embankment or Fill**

Stockpiled RAP material may also be used as a granular fill or base for embankment or backfill construction, although such an application is not widely used and does not represent the highest or most suitable use for the RAP. The use of RAP as an embankment base may be a practical alternative for material that has been stockpiled for a considerable time period, or may be commingled from several different project sources. Use as an embankment base or fill material within the same right of way may also be a suitable alternative to the disposal of excess asphalt concrete that is generated on a particular highway project.

## MATERIAL PROPERTIES

### Physical Properties

The properties of RAP are largely dependent on the properties of the constituent materials and the type of asphalt concrete mix (wearing surface, binder course, etc.). There can be substantial differences between asphalt concrete mixes in aggregate quality, size, and consistency. Since the aggregates in surface course (wearing course) asphalt concrete must have high resistance to wear/abrasion (polishing) to contribute to acceptable friction resistance properties, these aggregates may be of higher quality than the aggregates in binder course applications, where polishing resistance is not of concern.

Both milling and crushing can cause some aggregate degradation. The gradation of milled RAP is generally finer and more dense than that of the virgin aggregates. Crushing does not cause as much degradation as milling; consequently, the gradation of crushed RAP is generally not as fine as milled RAP, but finer than virgin aggregates crushed with the same type of equipment.

The particle size distribution of milled or crushed RAP may vary to some extent, depending on the type of equipment used to produce the RAP, the type of aggregate in the pavement, and whether any underlying base or subbase aggregate has been mixed in with the reclaimed asphalt pavement material during the pavement removal.

During processing, virtually all RAP produced is milled or crushed down to 38 mm (1.5 in) or less, with a maximum allowable top size of either 51 mm (2 in) or 63 mm (2.5 in). Table 13-1 lists the typical range of particle size distribution that normally results from the milling or crushing of RAP. Milled RAP is generally finer than crushed RAP. Studies on pavements in California, North Carolina, Utah and Virginia have shown that before and after milling, the pavement fraction passing a 2.36 mm (No. 8) sieve can be expected to increase from a premilled range of 41 to 69 percent to a postmilled range of 52 to 72 percent. The fraction passing a 0.075 mm (No. 200) sieve can be expected to increase from approximately 6 to 10 percent to a range of 8 to 12 percent.<sup>(3)</sup> Most sources of RAP will be a well-graded coarse aggregate, comparable to, or perhaps slightly finer and more variable than, crushed natural aggregates.

The unit weight of milled or processed RAP depends on the type of aggregate in the reclaimed pavement and the moisture content of the stockpiled material. Although available literature on RAP contains limited data pertaining to unit weight, the unit weight of milled or processed RAP has been found to range from 1940 to 2300 kg/m<sup>3</sup> (120 to 140 lb/ft<sup>3</sup>), which is slightly lower than that of natural aggregates.

Information on the moisture content of RAP stockpiles is sparse, but indications are that the moisture content of the RAP will increase while in storage. Crushed or milled RAP can pick up a considerable amount of water if exposed to rain. Moisture contents up to 5 percent or higher have been measured for stored crushed RAP.<sup>(4)</sup> As noted earlier, during periods of extensive precipitation, the moisture content of some RAP stockpiles may be as high as 7 to 8 percent.<sup>(5)</sup> Lengthy stockpiling of crushed or milled RAP should, therefore, be kept to a minimum.

The asphalt cement content of RAP typically ranges between 3 and 7 percent by weight. The asphalt cement adhering to the aggregate is somewhat harder than new asphalt cement. This is due primarily to exposure of the pavement to atmospheric oxygen (oxidation) during use and weathering. The degree of hardening depends on several factors, including the intrinsic properties of the asphalt cement, the mixing temperature/time (increases with increasing high temperature exposure), the degree of asphalt concrete compaction (increases if not well compacted), asphalt cement/air voids content (increases with lower asphalt/higher air voids content), and age in service (increases with age).

**Table 13-1. Typical range of particle size distribution for reclaimed asphalt pavement (RAP) (percent by weight passing).**

Screen Size (mesh)	Percent Finer After Processing or Milling
37.5 mm (1.5 in)	100
25 mm (1.0 in)	95 - 100
19 mm (3/4 in)	84 - 100
12.5 mm (1/2 in)	70 - 100
9.5 mm (3/8 in)	58 - 95
7.5 mm (No. 4)	38 - 75
2.36 mm (No. 8)	25 - 60
1.18 mm (No. 16)	17 - 40
0.60 mm (No. 30)	10 - 35 <sup>a</sup>
0.30 mm (No. 50)	5 - 25 <sup>b</sup>
0.15 mm (No. 100)	3 - 20 <sup>c</sup>
0.075 mm (No. 200)	2 - 15 <sup>d</sup>
a. Usually less than 30 percent b. Usually less than 20 percent c. Usually less than 15 percent d. Usually less than 10 percent	

The RAP obtained from most wearing surface mixes will usually have an asphalt content in the 4.5 to 6 percent range. The recovered asphalt from RAP usually exhibits low penetration and relatively high viscosity values, depending on the amount of time

the original pavement has been in service. Penetration values at 25°C (77°F) are likely to range from 10 to 80 while the absolute viscosity values at 60°C (140°F) may range from as low as 2,000 poises (equivalent to AC-20) up to as high as 50,000 poises or greater, depending on the extent of aging. Viscosity ranges from 4,000 to 25,000 poises can normally be expected from the asphalt cement that is recovered from RAP material.<sup>(6)</sup> Table 13-2 provides a summary of the typical ranges of physical properties of RAP, other than gradation.

**Table 13-2. Physical and mechanical properties of reclaimed asphalt pavement (RAP).**

Type of Property	RAP Property	Typical Range of Values
Physical Properties	Unit Weight	1940 - 2300 kg/m <sup>3</sup> (120-140 lb/ft <sup>3</sup> )
	Moisture Content	Normal: up to 5% Maximum: 7-8%
	Asphalt Content	Normal: 4.5-6% Maximum Range: 3-7%
	Asphalt Penetration	Normal: 10-80 at 25°C (77°F)
	Absolute Viscosity or Recovered Asphalt Cement	Normal: 4,000 - 25,000 poises at 60°C (140°F)
Mechanical Properties	Compacted Unit Weight	1600 - 2000 kg/m <sup>3</sup> (100-125 lb/ft <sup>3</sup> )
	California Bearing Ratio (CBR)	100% RAP: 20-25% 40% RAP and 60% Natural Aggregate: 150% or higher

### Chemical Properties

Mineral aggregates constitute the overwhelming majority (93 to 97 percent by weight) of RAP. Only a minor percentage (3 to 7 percent) of RAP consists of hardened asphalt cement. Consequently, the overall chemical composition of RAP is essentially similar to that of the naturally occurring aggregate that is its principal constituent.

Asphalt cement is made up of mainly high molecular weight aliphatic hydrocarbon compounds, but also small concentrations of other materials such as sulfur, nitrogen, and polycyclic hydrocarbons (aromatic and/or naphthenic) of very low chemical reactivity. Asphalt cement is a combination of asphaltenes and maltenes (resins and oils). Asphaltenes are more viscous than either resins or oils and play a major role in determining asphalt viscosity. Oxidation of aged asphalt causes the oils to convert to resins and the resins to convert to asphaltenes, resulting in age hardening and a higher viscosity binder.<sup>(7)</sup>

### Mechanical Properties

The mechanical properties of RAP depend on the original asphalt pavement type, the method(s) utilized to recover the material, and the degree of processing necessary to prepare the RAP for a particular application. Since most RAP is recycled back into pavements, there is a general lack of data pertaining to the mechanical properties for RAP in other possible applications.

The compacted unit weight of RAP will decrease with increasing unit weight, with maximum dry density values reported to range from 1600 kg/m<sup>3</sup> (100 lb/ft<sup>3</sup>) to 2000 kg/m<sup>3</sup> (125 lb/ft<sup>3</sup>).<sup>(8)</sup> California Bearing Ratio (CBR) values for RAP material containing trap rock aggregate have been reported in the 20 to 25 percent range. However, when RAP is blended with natural aggregates for use in granular base, the asphalt cement in the RAP has a significant strengthening effect over time, such that specimens containing 40 percent RAP have produced CBR values exceeding 150 after 1 week.<sup>(9)</sup>

Table 13-2 provides a summary of the mechanical properties of RAP discussed in the preceding paragraphs.

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