PDHonline Course C184 (3 PDH)

Reclaimed Asphalt Pavement (RAP)

Instructor: Vincent D. Reynolds, MBA, PE

2020

PDH Online | PDH Center

5272 Meadow Estates Drive
Fairfax, VA 22030-6658
Phone: 703-988-0088
www.PDHonline.com

An Approved Continuing Education Provider

INTRODUCTION

Reclaimed asphalt pavement (RAP) can be used as an aggregate in the cold recycling of asphalt paving mixtures in one of two ways. The first method (cold mix plant recycling) involves a process in which RAP is combined with new emulsified or foamed asphalt and a recycling or rejuvenating agent, possibly also with virgin aggregate, and mixed at a central plant or a mobile plant to produce cold mix base mixtures.(1) The second, more common, method involves a process in which the asphalt pavement is recycled in-place (cold in-place recycling (CIPR) process), where the RAP is combined without heat and with new emulsified or foamed asphalt and/or a recycling or rejuvenating agent, possibly also with virgin aggregate, and mixed at the pavement site, at either partial depth or full depth, to produce a new cold mix end product.(2) Most states have used cold in-place recycling in conjunction with a hot mix overlay or chip seal.

PERFORMANCE RECORD

Documented performance of cold plant mix recycling projects is not widely available. According to a 1994 survey of all state transportation agencies, at least 32 states have used or are using RAP in cold recycling of asphalt pavements.(3) Although cold recycling has been reportedly practiced in these states, data are unavailable to differentiate whether cold plant mix recycling, CIPR, or both, are being used. In all likelihood, CIPR is probably being utilized more frequently, especially on low-volume roads where transport costs to plant sites are likely to be higher.

The states that appear to have had the most experience with CIPR techniques include California, Indiana, Kansas, New Mexico, Oregon, and Pennsylvania. The performance of CIPR projects in Indiana has been described as structurally comparable to those of cold mixes in which conventional aggregates and asphalt emulsions have been used.(4) Over 800 lane-km (500 lane-miles) of roadways in New Mexico have been successfully recycled using CIPR, and the extensive recycling experiences in California and Pennsylvania have also been very promising.(5) There have been approximately 672 km (420 mi) of low-volume roads in Oregon that were cold in-place recycled between 1984 and 1989, and over 75 percent of these projects were rated fair or better.(6) The performance of eight CIPR projects located throughout Pennsylvania were considered good to satisfactory, as long as a double seal coat was placed over the recycled cold mix.(7)

Performance studies indicate that CIPR retards or eliminates the occurrence of reflective cracking from environmental distress, depending on the depth of treatment and crack depth.(8) Improper emulsion application can result in high residual asphalt content (leading to flushing) and excessive processing can result in high fines content (leading to rutting due to low stability).

MATERIAL PROCESSING REQUIREMENTS

Cold Plant Mix Recycling

Processing requirements for cold mix recycling are similar to those for recycled hot mix. Recycled asphalt pavement must be processed into a granular material prior to use in cold mix applications. A typical RAP plant consists of a crusher, screening units, conveyors, and stackers.

Cold In-Place Recycling

CIPR (like hot in-place recycling (HIPR)), requires a self-contained, continuous train operation that includes ripping or scarifying, processing (screening and sizing/crushing unit), mixing of the milled RAP, and the addition of liquid rejuvenators. Special asphalt-derived products such as cationic, anionic, and polymer modified emulsions, rejuvenators and recycling agents have been developed especially for CIPR processes. These hydrocarbon materials are sometimes, but not always, used to soften or lower the viscosity of the residual asphalt binder in the RAP material so that it is compatible with the newly added binder.

ENGINEERING PROPERTIES

Some of the engineering properties of RAP that are of particular interest when RAP is used in cold recycled applications include its gradation, asphalt content, and the penetration and viscosity of the asphalt binder.

Gradation: The aggregate gradation of processed RAP is somewhat finer than virgin aggregate. This is due to mechanical degradation during asphalt pavement removal and processing. RAP aggregates usually can satisfy the requirements of ASTM D692 for coarse aggregate and ASTM D1073 for fine aggregate.(9,10)

Asphalt Content: The asphalt content of most old pavements will comprise approximately 3 to 7 percent by weight and 10 to 20 percent by volume of the pavement. Due to oxidation aging, the asphalt cement has hardened and consequently is more viscous and has lower penetration values than the virgin asphalt cement.

Penetration and Viscosity: Depending on the amount of time the original pavement had been in service, recovered RAP binder may have penetration values from 10 to 80 and absolute viscosity values at 60°C (140°F) in a range from as low as 2,000 poises to as high 50,000 poises or greater.(11)

DESIGN CONSIDERATIONS

To satisfy the engineering requirements for use in cold recycled asphalt concrete pavements, it is usually necessary to rejuvenate or augment the asphalt binder in RAP to lower the viscosity and/or increase penetration. This is done by the addition of one or more recycling agents, consisting of either an emulsified or foamed asphalt and/or a rejuvenating agent. Some additional aggregate may also be added to adjust the mix gradation or air voids content.

Cold Plant Mix Recycling

Mix Design

The specifications and design of cold plant mix recycling of asphalt pavements are referred to in ASTM D4215.(12) Cold plant mixtures can be dense-graded or open-graded. Cold-laid asphalt mixes may be used for surface, base, or subbase courses.

Although there are no universally accepted mix design methods for cold mix recycling, the Asphalt Institute recommends and most agencies use a variation of the Marshall mix design method.(13) General procedures include a determination of the aggregate gradation and asphalt content of the processed RAP, determination of the percentage (if any) of new aggregate to be added, calculation of combined aggregate in recycled mix, selection of the type and grade of new asphalt, determination of the asphalt demand of the combined aggregate, estimation of the percent of new asphalt required in the mix, and adjustment of asphalt content by field mix trials.(14)

The percent asphalt demand of combined aggregates can be determined by means of a formula that takes into account the various sieve size fractions of the combined RAP and virgin aggregate. These size fractions include the percentage retained on the 2.36 mm (No. 8) sieve, the percentage between the 2.36 mm (No. 8) and 0.075 mm (No. 200) sieves, and the percentage passing the 0.075 mm (No. 200) sieve. The percent of new asphalt is the difference between the percent asphalt demand and the percent of asphalt contained in the RAP.(1) Using the determined asphalt content, Marshall specimens can be prepared at various emulsion percentages to determine an optimum asphalt content on the basis of applicable stability and air voids criteria.

Structural Design

The AASHTO Design Guide(15) is applicable to recycled cold mix paving mixtures. While there are no universally accepted structural layer coefficient values for asphalt cold mix, it is generally recognized that cold mix asphalt is not the structural equivalent of hot mix asphalt, but is superior to gravel or crushed stone base courses. Asphalt cold mix is generally not recommended for use as a wearing surface, but only in base course layers because of both structural and durability considerations. The structural capacity of recycled cold mix can be considered equal to that of conventional cold mix paving materials.(16)

Although most agencies have not published structural layer coefficient values for conventional or recycled cold mixes, a layer coefficient value of 0.25 to 0.35 for an asphalt stabilized base is considered within a reasonable range. Pennsylvania DOT has assigned a structural layer coefficient of 0.30 for a bituminous-aggregate stabilized base,(7) which is a conventional cold mix.

Cold In-Place Recycling

Mix Design

The Asphalt Institute has recommended a modified Marshall mix type procedure for the design of CIPR mixes.(13) Such a design initially involves obtaining samples of the candidate pavement to determine the gradation of the aggregate, the asphalt content, and the penetration and viscosity of the asphalt binder. Marshall specimens are prepared at various emulsion percentages, as initially determined by calculating the asphalt demand on the basis of aggregate gradation and deducting the percentage of asphalt in the RAP.(16) The optimum asphalt content can be determined by a stability and air voids analysis, with target air voids in the 8 to 10 percent range, or the specimens may be evaluated using indirect tensile strength or resilient modulus testing.(17)

It has recently been shown that the addition of virgin aggregates (20 to 25 percent) in the CIPR process results in less voids and, consequently, less flushing, and improved stability.(14) The amount of recycling agent (either new asphalt or modifying oil) also has a significant effect on the behavior of the mix, with the ideal range of recycling agent being somewhere between 2 and 3 percent by weight of dry RAP.(18)

Structural Design

CIPR is generally considered for rehabilitation of pavements showing distress to depths about 100 to 150 mm (4 to 6 in). It can handle a pavement section in poorer condition and with more cracking than HIPR, provided that the pavement section (when recycled) is structurally sound and adequately drained.

The AASHTO Design Guide [15] is recommended for the thickness design of cold in-place recycled asphalt mixes. Since there is essentially little or no difference in the composition and structural properties of recycled cold mix and cold in-place recycled paving materials, the range of structural layer coefficients recommended for recycled cold mixes (0.25 to 0.35) are also applicable for cold in-place recycled mixes. CIPR mixes are not recommended for use as a wearing surface.

CONSTRUCTION PROCEDURES

Cold Plant Mix Recycling

Material Handling and Storage

RAP is produced by milling, ripping, breaking, crushing, or pulverizing types of equipment. To ensure that the final RAP product will perform as intended, inspection of incoming RAP and rejection of contaminated loads (excess granular material, surface treatment, joint sealant, etc.) should be undertaken. Some jurisdictions also require that RAP from a particular project not be blended or commingled with RAP from other projects.

Once processed, RAP can be handled and stored as a conventional aggregate material. However, because of the variability of RAP in comparison with virgin aggregates, many agencies do not permit the blending of RAP from different projects into combined stockpiles. The Asphalt Institute recommends that the height of RAP stockpiles be limited to a maximum of 3 meters (10 ft) to help prevent agglomeration of the RAP particles.[19]

Experience has proven that conical stockpiles are preferred to horizontal stockpiles and will not cause RAP to re-agglomerate or congeal in large piles. RAP has the tendency to form a crust (due to a solar/thermal effect from the sun) over the first 200-250 mm (8 to 12 in) of pile depth for both conical and horizontal stockpiles. This crust tends to help shed water, but is easily broken by a front-end loader and may help keep the rest of the pile from agglomerating. RAP has a tendency to hold water and not to drain over time like an aggregate stockpile. Therefore, low, horizontal, flat stockpiles are subject to greater moisture accumulation than tall, conical stockpiles. It is not unusual to find RAP moisture content in the 7 to 8 percent range during the rainy season at facilities using low, horizontal stockpiling techniques.[20]

RAP stockpiles are typically left uncovered because covering with tarps can cause condensation under the tarp and add moisture to the RAP stockpile. For this reason, RAP stockpiles are either left uncovered or RAP is stored in an open-sided building, but under a roof.[20]

When large quantities of RAP from different sources are available, it is advisable to keep stockpiles separated and identified by source. Consistent RAP from a "composite" or "blended" pile can be produced using a crushing and screening operation and reprocessing stockpiles from different sources. Material handling machinery, such as front-end loaders and bulldozers, should be kept from driving directly on the stockpile. Agglomeration can result, making it very difficult for the loader to handle the RAP.

Mixing, Placing, and Compacting

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. RAP is mixed with new aggregate and emulsified or foamed asphalt in either a central plant or a mobile plant. The blend is then placed as conventional cold mix asphalt. The pavement removal or milling is performed with a self-propelled rotary drum cold planing machine with RAP transferred to trucks for removal from the job site. Cold mix asphalt is usually placed on low-volume roadways with traffic volumes less than 3,000 vehicles per day and covered with either a double surface treatment or a hot mix wearing surface.[21]

Cold plant mix recycling can be accomplished either by hauling the RAP to a central processing location, where it is crushed, screened, and blended with a recycling agent in a central mixing plant, or the RAP can be processed at the project site and prepared in a mobile mixing plant that has been transported to the job site. In either case, a pugmill mixing plant is commonly used.[24]

Recycled cold mix material can be normally placed with a conventional paver, provided the mixing moisture can be adequately controlled to a level not requiring aeration. Cold mix pavement construction requires several warm days and nights for adequate curing.[6] Successful placement using conventional pavers requires that the mix be sufficiently fluid to avoid tearing. Alternatively, a Jersey or towed spreader can be used. Using a Jersey or towed spreader (which is essentially a front-wheeled hopper fastened to the front of tractor or the rear of a haul truck), the cold mix is dumped into a hopper and falls directly on the road where it is spread and struck off to the required thickness.

The same equipment and techniques used to compact and cure conventional cold mix asphalt pavements are applicable to recycled cold mix.

Quality Control

To ensure the consistency and quality of a recycled cold plant mix, quality control of the RAP is essential. Random samples of the RAP or recycled material should be analyzed for aggregate gradation, asphalt cement content, and moisture content. The recycled material must be closely inspected to make sure that the RAP is consistent in size and appearance and that subgrade soil (or other possible contaminants) have not been included in the RAP.

Plant operations should be monitored to ensure that the proper amount of emulsified or foamed asphalt is being added and that the moisture content of the recycled mix is in the proper range for maximum compaction at the project site. The amount of any additional aggregate being mixed with the RAP should also be monitored. Loose samples of the recycled mix should be obtained and extraction tests performed to monitor mix gradation and asphalt content, as well as moisture content. Mixes should be sampled in accordance with AASHTO T168.(22)

Achieving the proper compaction or densification of the paving material is essential to proper performance. A test strip should be used at the start of the project to establish a target density and number of roller passes needed to achieve that density. The in-place density of the cold mix paving material can then be monitored by using a nuclear density gauge in accordance with ASTM D2950.(23)

Cold In-Place Recycling

Mixing, Placing and Compacting

A typical CIPR train consists of a cold milling machine (with water added as necessary for cooling and dust control) that is capable of reclaiming the old asphalt pavement to depths from about 100 mm (4 in) to 150 mm (6 in). CIPR plants consist of a screening and sizing or crushing unit, as well as a mixing unit for the addition of polymer-modified high-float emulsion, as determined by the mix design, and also water, if required. Mixing may be accomplished using a motor grader blade, a rotary pulvimixer, a windrow type mixer, or a traveling plant pugmill, which offers the highest degree of grading control.(24) A reclaim/paver unit is also part of the system to place the recycled cold mix. The mixing and placement units are combined in some trains in what are referred to as mixer-pavers. Care must be taken during the CIPR operation to avoid the incorporation of the granular base material into the mixer.

After about 30 minutes of curing and drying, the material is compacted with a large rubber-tired roller, followed by a vibratory steel drum roller. Compaction of CIPR paving mixtures is normally accomplished at a moisture content of less than 2 percent at a minimum of 97 percent of laboratory maximum density.

Curing

Following about 2 weeks of additional curing during favorable weather conditions, preferably at temperatures at or in excess of 16°C (60°F), a hot mix asphalt overlay is generally applied.

Quality Control

As with HIPR, the crucial step in the quality control of CIPR mixes is in the initial process of project selection. If an existing pavement exhibits distress resulting from a subgrade or base failure, it cannot be remedied simply by recycling the surface layer. Pavements that have been rutted, heavily patched, or chip-sealed are not good candidates for CIPR projects. Also, core specimens of the pavement being considered for CIPR should be taken and examined for variations in pavement layers, delaminations, and saturated material adjacent to voids or delaminations.

To ensure the success of a CIPR mix, quality control of the RAP is essential. Random samples of the RAP or recycled material should be analyzed for aggregate gradation, asphalt content, and moisture content. The recycled material must be closely inspected to make sure that the RAP is consistent in size and appearance and that subgrade soil (or other possible contaminants) have not been included in the RAP.

Field quality control measures during CIPR operations include monitoring the depth of scarification, the coating of the aggregate by the emulsion, the proper curing of the emulsion, the visual appearance and possible segregation of the recycled material, the compaction procedure, and appearance of the recycled pavement surface after compaction. Loose samples of the recycled mix should be obtained and extraction tests performed to monitor mix gradation and emulsion content, as well as moisture content. The moisture content of recycled pavement should be less than 1 percent of the existing pavement prior to recycling.(25)

Achieving the proper compaction or densification of the recycled paving material is essential to proper performance. The in-place density of the recycled mix should be monitored by using a nuclear density gauge in accordance with ASTM D2950.(23)

UNRESOLVED ISSUES

While cold asphalt pavement recycling technologies are well established, there is still a need for additional performance information, particularly with regard to creep (rutting resistance), fatigue endurance, and durability. In addition, there is a need to assess whether RAP can be used in wearing surface cold mixes. Further investigation is also needed to evaluate the ability of cold recycled plant mixes to perform on higher traffic volume roadways. There is also a need for more correlation of field and laboratory measurements to refine guidelines for laboratory prediction of field performance, including, for instance, laboratory curing procedures that best simulate field conditions.

Some specific issues that require resolution include:

- further information on the variability of RAP, especially from blended stockpiles;
- a consensus regarding mix design and testing procedures for plant recycled cold mix and CIPR asphalt mixtures;
- the suitability of CIPR for use with surface treatments and/or rubberized paving materials;
- a more accurate determination of the structural layer coefficient for plant recycled cold mix and CIPR asphalt mixtures; and
- an environmental evaluation of any potentially harmful impacts from cold mix plant recycling and/or cold in-place recycling.

REFERENCES

1. Asphalt Institute. *Asphalt Cold-Mix Recycling*, Manual Series No. 21, Lexington, Kentucky, March, 1983.
2. Epps, Jon A. *Cold-Recycled Bituminous Concrete Using Bituminous Materials*. National Cooperative Highway Research Program, Synthesis of Highway Practice 160, July, 1990.
3. Collins, Robert J. and Stanley K. Ciesielski. *Recycling and Use of Waste Materials and By-Products in Highway Construction*. National Cooperative Highway Research Program, Synthesis of Highway Practice No. 199, Transportation Research Board, Washington, DC, 1994.
4. Tia, Mang and Leonard E. Wood. "Use of Asphalt Emulsion and Foamed Asphalt in Cold-Recycled Asphalt Paving Mixtures." *Transportation Research Record No. 898*, Washington, DC, 1983.
5. Wood, Leonard E., Thomas D. White, and Thomas B. Nelson. "Current Practice of Cold In-Place Recycling of Asphalt Pavements." *Transportation Research Record No. 1178*, Washington, DC, 1988.
6. Scholz, Todd V., R. Gary Hicks, David F. Rogge, and Dale Allen. "Use of Cold In-Place Recycling on Low-Volume Roads." *Transportation Research Record No. 1291*, Washington, DC, 1991.
7. Kandahl, Prithvi S. and William C. Koehler. "Cold Recycling of Asphalt-Pavements on Low-Volume Roads." *Transportation Research Record No. 1106*, Washington, DC, 1987.
8. "A Study of the Use of Recycled Paving Materials - Report to Congress," Federal Highway Administration and Environmental Protection Agency, Report No. FHWA-RD-93-147, EPA/600/R-93/095, Washington, DC, June, 1993.
9. ASTM D692-94a. "Standard Specification for Coarse Aggregate for Bituminous Paving Mixtures." American Society for Testing and Materials, *Annual Book of ASTM Standards*, Volume 04.03, West Conshohocken, Pennsylvania.
10. ASTM D1073-94. "Standard Specification for Fine Aggregate for Bituminous Paving Mixtures." American Society for Testing and Materials, *Annual Book of ASTM Standards*, Volume 04.03, West Conshohocken, Pennsylvania.
11. Epps, J. A., D. N. Little, R. J. O'Neal, and B. M. Gallaway. *Mixture Properties of Recycled Central Plant Materials*. American Society for Testing and Materials, Special Technical Publication No. 662, Recycling of Bituminous Pavements, West Conshohocken, Pennsylvania, December, 1977.
12. ASTM D4215. "Standard Specification for Cold-Mixed, Cold-Laid Bituminous Paving Mixtures." American Society for Testing and Materials, *Annual Book of ASTM Standards*, Volume 04.03, West Conshohocken, Pennsylvania.
13. ASTM D1559-89. "Standard Test Method for Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus." American Society for Testing and Materials, *Annual Book of ASTM Standards*, Volume 04.03, West Conshohocken, Pennsylvania.
14. Murphy, D. T. and J. J. Emery. "Modified Cold In-Place Asphalt Recycling." Presented at the 1995 Annual Conference of the Transportation Association of Canada, Victoria, British Columbia.

15. AASHTO Guide for Design of Pavement Structures. American Association of State Highway and Transportation Officials, Washington, DC, 1993.

16. *Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types*. Asphalt Institute. Manual Series No. 2, Lexington, Kentucky, 1993.

17. Kennedy, T. W. and Ignacio Perez, "Preliminary Mixture Design Procedure for Recycled Asphalt Materials." *Recycling of Bituminous Pavements*, American Society for Testing and Materials Special Technical Publication No. 662, West Conshohocken, Pennsylvania, December, 1977.

18. Castedo, Humberto. "Significance of Various Factors in the Recycling of Asphalt Pavements on Secondary Roads." *Transportation Research Record No.1115*, Washington, DC, 1987.

19. *Asphalt Hot-Mix Recycling*. Asphalt Institute. Manual Series No. 20, Second Edition, Lexington, Kentucky, 1986.

20. Decker, D. S. and T. J. Young, "Handling RAP in an HMA Facility"@ *Proceedings of the Canadian Technical Asphalt Association*, Edmonton, Alberta, 1996.

21. Wood, Leonard E., Thomas D. White, and Thomas B. Nelson. "Current Practice of Cold In-Place Recycling of Asphalt Pavements." *Transportation Research Record No. 1178*, Washington, DC, 1988.

22. American Association of State Highway and Transportation Officials. Standard Method of Test, "Sampling Bituminous Paving Mixtures," AASHTO Designation T168-82, Part II Tests, 16th Edition, 1993.

23. ASTM D2950-96, "Standard Specification for Density of Bituminous Concrete in Place by Nuclear Methods." American Society for Testing and Materials, *Annual Book of ASTM Standards*, Volume 04.03, West Conshohocken, Pennsylvania.

24. Epps, J. A., D. N. Little, R. J. Holmgreen, and R. L. Terrel. *Guidelines for Recycling Pavement Materials*. National Cooperative Highway Research Program Report No. 224, Washington, DC, September, 1980.

25. McKeen, R.G., D.I. Hanson, and J.H. Stokes. "New Mexico's Experience with Cold In-Situ Recycling." Presented at the 76th Annual Meeting of the Transportation Research Board, Washington, DC, January, 1997.

[Granular Base] [Embankment or Fill] [Material Description] [Asphalt Concrete (Hot Recycling)]