Current Practice of Cold In-Place Recycling of Asphalt Pavements

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As part of a study to develop standard design procedures and specifications for cold in-place recycling of asphalt pavements, a literature review and a survey of state and local highway agencies and contractors were performed. The results indicate a diversity of cold in-place recycling use, design, and construction. Cold in-place construction can be divided into three distinct types: (a) a stabilization process, (b) a single unit miller or mixer process, and (c) a process using full construction trains. Several promising recycling agents have been identified and some guidelines for compaction and curing have been developed. Specific mix design procedures and structural design show great variation among users, however, and no single method can be recommended. Cold in-place recycling construction involves milling or pulverizing the existing pavement, reduction in size, mixing, laydown, and compaction. Most agencies then apply a fog seal, surface treatment, or thin overlay as a wearing surface. Overall, cold in-place recycling has shown satisfactory performance and considerable cost savings over conventional overlays. Further evaluation of procedures, specifications, and performance is recommended, however, to standardize this practice.

Recycling of asphalt pavements was performed as early as 1915. However, widespread attention was not paid to this method until the mid-1970s as a result of the shortage of asphalt caused by the oil embargo as well as the continuing decline in the availability of quality aggregates. The potential savings in materials, energy, and costs from recycling prompted development of the necessary equipment and processes.

Federal support for recycling, in Federal Highway Administration Demonstration Project No. 39, "Recycling Asphalt Pavements," helped focus national attention on the subject. As a result, state, county, and city highway departments worked with suppliers and contractors to produce asphalt pavements using several recycling techniques.

Recycling is generally classified by the type of operation used to perform it. The Asphalt Institute, the Asphalt Recycling and Reclaiming Association (ARRA), the National Asphalt Pavement Association (NAPA) and the U.S. Army Corps of Engineers classify recycling as

- Hot-mix recycling (plant),
- Cold-mix recycling (plant or in place), or
- Surface recycling (in place).

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In general, this classification scheme considers that hot-mix recycling involves removal and mixing at a central plant, whereas cold-mix recycling may be performed in place or at a central plant. Field practice has made hot-mix recycling synonymous with central plant recycling, and cold-mix recycling synonymous with in-place recycling. For the purpose of this paper, the following definitions are used:

- Cold in-place recycling (CIR): The reuse of milled, crushed, or planed asphalt pavement that has already served its intended purpose, with or without the addition of aggregate or recycling agent (or both), to form a paving material that can be laid, compacted, and cured in place without the addition of heat.
- Reclaimed asphalt pavement (RAP): Asphalt pavement or paving mixture removed from its original location.
- Recycling agent (RA): Any compound or material used as an admixture to alter or improve the properties of the asphalt pavement or to improve the properties of the asphalt binder in the recycled asphalt paving mixture.

These definitions correspond closely to those currently being balloted by the American Society for Testing and Materials (ASTM) Committee D04, Road and Paving Materials.

There are three distinct types of CIR processes being used in the United States, ranging from the equivalent of a soil stabilization process to a specialized multiple-unit construction train specifically developed for CIR. The three types of CIR currently in use are the following:

- Type 1: Rip/pulverize and compact. Pulverizing equipment is used to produce RAP that can be used as base course material, usually with the addition of an emulsion or recycling agent.
- Type 2: Single Unit Recycler. A single unit mills the in-place pavement and mixes the milled material with a recycling agent, if desired, to produce a stabilized base course, and sometimes a wearing course, material.
- Type 3: Recycling Train. A multiple unit train with milling, crushing and screening, and pugmill units that produces a RAP that can be accurately controlled and used as either a base or a wearing course.

Type 1 CIR is a process analagous to bituminous stabilization. The in-place pavement is ripped or pulverized, or both, by multiple passes of a pulverizer. Normally the pavement structure above the base is recycled. Some of the base course may or may not be mixed with the RAP. Virgin aggregate can also be added in front of the pulverizer or to the RAP windrow. Additional asphalt emulsion or a rejuvenating agent can be added to the RAP windrow or the pulverizer. The pulverized and modified RAP is placed with either a grader or a conventional paver. This process produces a good-quality asphalt base material to which surface treatment or asphalt concrete wearing surface can be applied. Shown in Figure 1 is the Type 1 CIR process.

Type 2 CIR (Figure 2), uses a planer or milling machine to plane or mill part or all of the in-place pavement. Virgin aggregate can be spread on the pavement surface and incorporated into the milling operation. Additional asphalt emulsion or a rejuvenating agent can be added in the milling chamber. A conventional paver is usually used to lay the recycled mixture. Type 2 CIR can produce a high-quality asphalt base or wearing surface at a rate of approximately 1 to 2 lane-miles/day.

Type 3 CIR consists of a multiple-unit construction train with milling, crushing and screening, and pugmill units (Figure 3). The milling unit mills the in-place pavement to partial or full depth, and conveys the milled RAP material to the crushing and screening unit. The RAP is screened, and the oversized material is crushed. The RAP then proceeds to a pugmill, where asphalt emulsion or a recycling agent (or both) is added. After mixing, the recycled material is deposited in a windrow behind the train. The windrow is picked up and placed in the hopper of a conventional laydown machine. A high-quality asphalt base or wearing surface can be produced. Depending on the condition of the existing pavement, depth of recycling, terrain, and traffic, this train can recycle 2 to 6 lane-miles 12-ft wide/day.

Recycling has shown cost savings over conventional paving and potential for further development. Cold recycling, in particular, has potential because of the wide range of pavement types and conditions that make it technically and economically

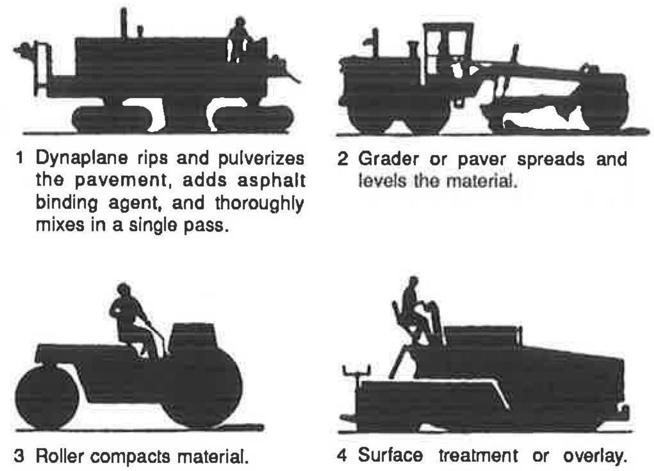

FIGURE 2 Type 2 CIR.

viable. CIR has recently been identified for further study because of the following benefits:

- Original profile, crown, and slope may be improved;
- Existing crack patterns are destroyed;
- Hauling costs for materials are greatly reduced;
- Production rate is high (up to 500 tons/hr);
- Only thin overlay or chip seal surfacing may be required;
- Engineering costs are low; and
- Dust, fume, and smoke pollution are minimized.

Wider acceptance and use of cold in-place recycling is allowing better documentation of cost savings and technical advantages. The wider use is also providing data on CIR performance. However, a review of completed projects indicates that diverse procedures, tests, and criteria have evolved. The diversity suggests that additional development of standards for CIR is required if consistent performance in the field

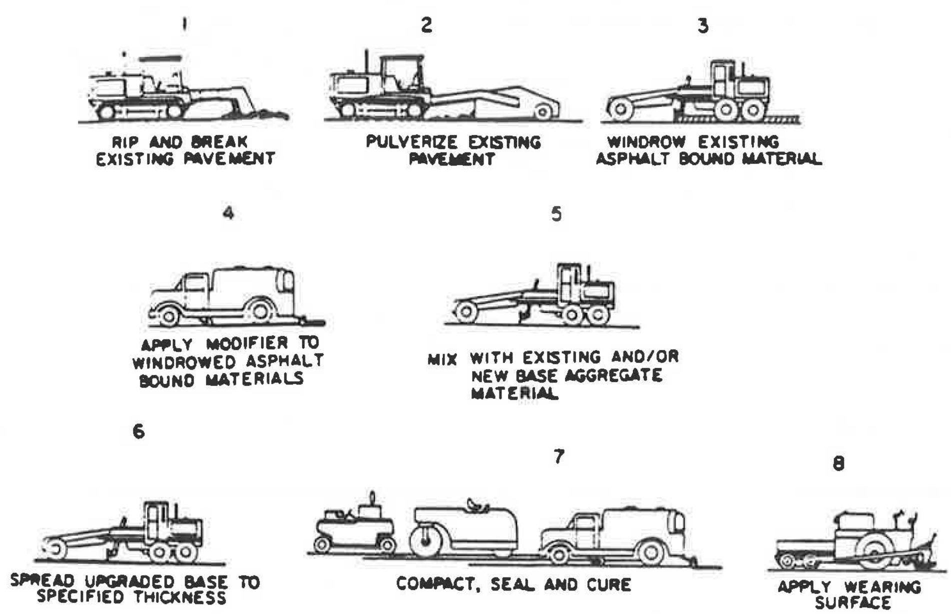

FIGURE 1 Type 1 CIR.

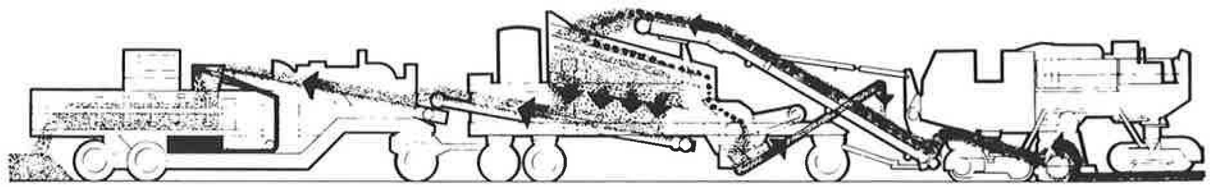

FIGURE 3 Type 3 CIR construction train.

is to be achieved. The ARRA supported this study on CIR in order to work toward development of standards for CIR.

A questionnaire was developed and sent to members of the pavement-recycling industry, including user agencies, contractors, and suppliers. The questionnaire responses represent a current survey of CIR practice.

A total of 300 questionnaires were distributed. Of these, 93 were returned (31 percent). The questionnaire was also printed in the January 1987 issue of *Better Roads* magazine, resulting in an additional 26 responses. Replies were received from a total of 45 state highway agencies and the District of Columbia, as well as numerous counties, cities, and private contractors. States that did not respond to the questionnaire were contacted to complete the list of CIR users.

CIR USE

Of the 50 state highway agencies responding to the questionnaire or telephone inquiry, 24 (48 percent) report past or current use of CIR. Five agencies indicate that they have produced only experimental sections, whereas others, notably Oregon, New Mexico, California, and Pennsylvania, report projects constructed under a wide variety of conditions. New Mexico reported the completion of over 500 lane-miles of CIR since 1984. Three states also indicated that although they do not use CIR for travel lanes, they do use milled material for shoulder construction. The use of CIR by agencies is shown in Table 1 and their geographic distribution is shown in Figure 4.

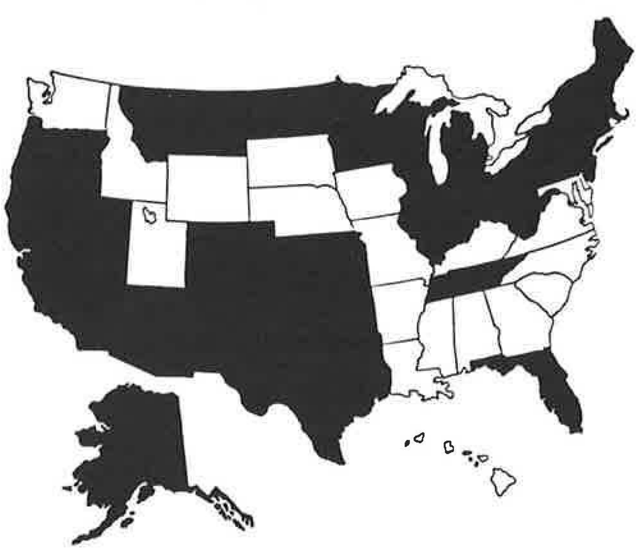

FIGURE 4 Geographic distribution of states using CIR (shaded states report CIR use).

In addition to the reported use by state agencies, eight counties and two cities reported use of CIR. The use by these agencies ranges from one project to regular use of CIR. Eight contractors also indicated involvement in CIR projects for cities, counties, and states throughout the United States.

The survey indicates variety in the types of roads on which CIR projects have been undertaken. Based on the questionnaires, CIR of county roads and secondary highways makes up equal proportions of CIR projects (31 percent each). City streets account for 19 percent, and primary and Interstate highways make up the remaining 19 percent (12 percent and 7 percent shares respectively) (see Figure 5).

Although agencies reported CIR use on all types of roads, most place some restrictions on CIR. Twenty percent of agencies restrict CIR to rural areas, and an additional 20 percent limit its use to roads with low traffic volumes. Other agencies specify what component of the pavement structure the RAP may consist of, with most restricting its use to base course material. Of the projects reported, 95 percent consisted of RAP base courses. Of these projects, 12 percent involved only a fog, sand, or slurry seal to the RAP base course. Thirty-three percent of the RAP base course projects were surfaced with single or double bituminous surface treatments, and the remaining 50 percent were surfaced with an asphalt concrete wearing course.

REASONS FOR USING CIR

Reasons for using CIR are divided among development of new equipment, materials, performance criteria, scarcity of materials, and cost savings. Among these reasons, scarcity of materials, particularly gravel and crushed aggregate, were noted by 27 percent of the respondents. Asphalt is reported to be generally available, and several states report that the ready availability of hot-mix asphalt concrete makes the use of CIR unnecessary.

Other reasons for using CIR include high production rate, minimum traffic disruption, ability to retain original road profiles, reduction of environmental concerns, and growing concern for depletion of petroleum reserves. Reasons for not using CIR include concern over cost savings, stability of the finished product, and public and industry reservations about the process.

SPECIFICATIONS

Just over one-half (56 percent) of the agencies using CIR have developed specifications for its use. The remaining agencies report the use of field experience or other agency specifications for CIR projects. Thirty-seven percent of the agencies

TABLE 1 STATE USE OF COLD IN-PLACE RECYCLING (CIR)

	Yes	No	Comments
Alabama		X	
Alaska	X		
Arizona	X		Some concern over low stability
Arkansas		X	Have used for shoulder
California	X		
Colorado	X		
Connecticut	Exp (1)		
Delaware		X	
Florida	Exp (2)		
Georgia		X	Have used milled material for shoulders
Hawaii		X	Hot mix available
Idaho		X	Have used some planed material for shoulders
Illinois	X		
Indiana	X		
Iowa		X	Hot mix available
Kansas	X		
Kentucky		X	
Louisiana		X	
Maine	X		
Maryland		X	Use hot mix
Massachusetts	X		
Michigan	X		
Minnesota	Exp[a]		
Mississippi		X	
Missouri		X	
Montana	X		
Nebraska		X	
Nevada	X		
New Hampshire	X		
New Jersey	Exp (1)		
New Mexico	X		Wide variety of projects
New York	X		
North Carolina		X	
North Dakota	X		Very limited experience
Ohio	X		Coal haul road Base material
Oklahoma	X		
Oregon	X		
Pennsylvania	X		
Rhode Island		X	
South Carolina		X	
South Dakota		X	Cost not justified
Tennessee	Exp (1)		Good base available
Texas	X		Prefer hot mix Low-volume roads
Utah		X	
Vermont	X		
Virginia		X	
Washington		X	
West Virginia	X		
Wisconsin	X		
Wyoming		X	Have used cold plant recycling
District of Columbia		X	

NOTE: Exp ( ) = Experimental Project (number of projects).
[a]No information provided on number of experimental projects.

reported use of standard test methods, although actual test methods used varied greatly.

Due to the rapid development of CIR, it is reasonable to expect that specifications and test methods are still evolving. Even those agencies with extensive experience and ongoing research have revised their specifications several times. In general, agencies have used American Association of State Highway and Transportation Officials (AASHTO) or ASTM tests and specifications, adjusting requirements based on experience with completed projects.

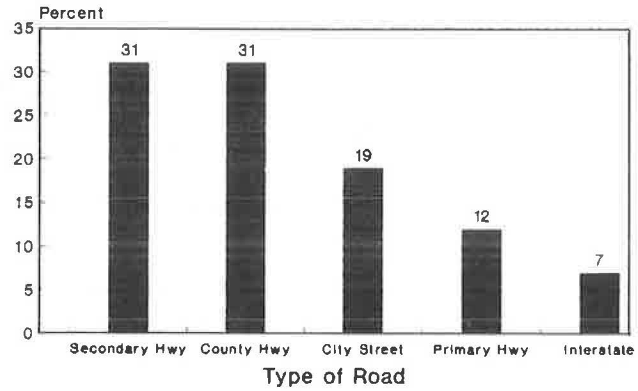

FIGURE 5 CIR use by type of road.

SAMPLING PROCEDURES

Responding agencies indicated that RAP samples are selected at the site based on judgment versus statistical procedures by a ratio of two to one. This percentage also corresponds to the high percentage of projects that are designed based on field experience and on-site adjustment.

The types of RAP samples include cores, blocks, or loose samples. Sixteen percent of the agencies collect block samples, whereas core and loose samples are divided equally in frequency of collection (42 percent each).

ADDITION OF AGGREGATES AND RECYCLING AGENTS

Addition of virgin aggregate to the RAP appears to be a standard practice. Two-thirds of the agencies using CIR (69 percent) allow addition of aggregate. The primary reasons for adding aggregate are to provide additional material when a thin pavement is being recycled, or to correct a gradation problem in the original material. The aggregate is normally added in front of the milling machine. An alternative is to recycle a partial depth of the underlying base course. Responding agencies recommend laboratory-extracted gradation analysis of RAP to determine the amounts and sizes of aggregates to be added. The use of virgin aggregate on CIR projects ranges from 15 to 50 percent (the amount of salvaged base ranges from 33 to 50 percent).

The type and amount of binder or additive used in CIR received the most varied responses. Part of this variability in field performance is related to the relatively low amount of experience with CIR. Another source of variation was the wide difference in the type of binder obtained from different suppliers.

Questionnaires indicated that slow-setting and medium-setting asphalt emulsions were most often used. Almost one-third of the respondents cited CMS-2 and CSS-1h. High-float emulsions (HFE) have also been used with success. New Mexico reports the successful use of HFE, with or without a polymer. The polymerized HFE is recommended as a very forgiving material, capable of being reworked and compacted successfully even after rain. Other recycling agents cited are emulsified recycling agent (ERA) grade materials, medium curing (MC) cutbacks, and commercial rejuvenators.

One third of the respondents report conducting a laboratory mix design to determine the required amount of binder/additive. The most frequently mentioned procedure was the Marshall procedure (16 percent of respondents). One fourth of responding agencies relied on field workability or experience and 18 percent report targeting for a total asphalt residual of between 4 and 6 percent. Responses show that the amount of binder/additive used ranges from 1 to 3 percent for asphalt emulsion, with 1½ percent the most frequently recommended starting point. This is equivalent to a 0.6 to 2 percent residual asphalt addition for emulsions.

MIX DESIGN

Eighty percent of all agencies reporting CIR experience analyze RAP for asphalt content and aggregate gradation. However, subsequent mix design methods vary significantly on specific procedures and criteria. Of the agencies queried, 47 percent process or crush samples in the laboratory, 31 percent use samples taken from field-pulverized or milled RAP, and the remaining 22 percent process samples in the laboratory by heating and breaking down bulk samples.

No standard compaction method or effort could be determined from the responses, which cited 50 blow Marshall, 75 blow Marshall, kneading, and gyratory methods of compaction with no distinct consensus. Curing after compaction is reported to be 1 hr, 5 hr, 16 hr, 1 day, 3 days, or 7 days. Curing temperatures included room temperature, 77°F, 105°F, 120°F, 140°F and 250°F. These issues require further development and standardization.

Strength and plastic flow are measured in the Marshall procedure by two thirds of the agencies conducting mix designs (20 out of 30 responses). The Hveem and indirect tension tests are used equally by remaining agencies.

Ninety percent of the agencies conducting Marshall testing optimize density and stability, and less than half of these agencies (40 percent) apply flow criteria. Voids in the total mix are used by 45 percent of the agencies.

STRUCTURAL DESIGN

Structural capacity of CIR is considered by most respondents to be the equal of conventional materials. In the majority of cases, existing materials are replaced with an equal thickness of RAP without a formal structural design. Only 11 agencies reported evaluating the material for thickness design. Three agencies assign layer coefficients between .14 and .44, two use Marshall, one uses indirect tension, and three use Hveem procedures. The structural design procedure presented in the Asphalt Institute's *Manual MS-21* (*1*), was cited by two agencies.

CONSTRUCTION TECHNIQUES

Current CIR construction practices reflect the three types of CIR. However, there are also variations within these CIR types, especially within Type 1, which is similar to soil stabilization. Despite the variations, a general procedure for current CIR construction can be described.

The first step in CIR is to rip, plane, mill, or pulverize the existing pavement. Equipment used ranges from rippers (25 percent of responses) to state-of-the-art planers or millers. Depths of recycling range from 1½ to 8 in., with 2 to 4 in. reported as optimum. Milling depths greater than 4 in. are reported to reduce operating speed and produce oversize RAP.

In the second step, the RAP material is further reduced to a top size of 1¼ to 2 in. Several agencies specify that the RAP top size should be less than half the depth of the finished recycled layer. Size reduction can be accomplished using a pulverizer, secondary crusher, or single-unit milling machine.

The third step in the process is mixing, performed on the road with blades or discs, in the single milling unit or in the pugmill of the multiple unit train. The multiple unit train has the capability for adding recycling agent or additional aggregate. With other equipment, additional agent/binder can be added at the pugmill/pulverizer, and aggregate can be added in front of the miller/planer. The complete train, with metered pumps and weight scales, offers the best control for varying production rates.

Water is important in CIR, and is introduced at various points in the process. Usually 1 to 2 percent of water is added at the milling head for lubrication and dust control. An additional 1 to 2 percent of prewet water may be added at the pugmill to help the mixing and coating process. This water may be required for proper mixing and to avoid premature emulsion break. Some agencies have reported that lower moisture contents (0.7 percent) may be more desirable. Too much moisture can result in a tender mixture reaction.

After pulverizing and mixing, the RAP is deposited in a windrow on the road surface. The RAP can be picked up and placed in the hopper of a conventional laydown machine for placement (44 percent of responses); alternatively the RAP can be placed by a road grader (36 percent of responses) or struck off by the mold board of the single milling unit (20 percent of responses) (see Figure 6).

CIR compaction is a one- or two-stage operation. The first stage occurs within 1 or 2 hr following laydown. This is performed with static steel, pneumatic or vibratory steel wheel rollers, or a combination of both. In New Mexico a heavy

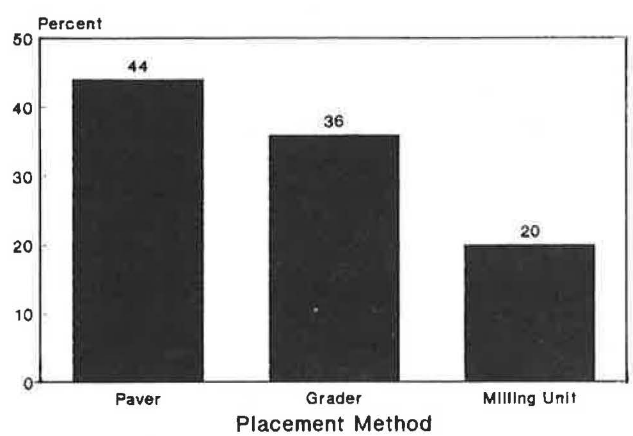

FIGURE 6 Placement methods.

pneumatic roller (35 to 45 ton) is used until the roller "walks out" of the mat, followed by the use of a vibratory roller, with one pass in the vibratory mode and the second in the static mode. A similar mix of rollers is reported from Oregon and Kansas. Although some agencies report success with the single stage of compaction, most indicate that a second-stage compaction is required 3 to 7 days following laydown. The second-stage compaction is accomplished using a steel wheel or pneumatic roller. Traffic is normally allowed on the mat between stages of compaction.

Most agencies reported weather constraints. Fifty percent of the agencies restrict construction to times when temperatures are over 50°F and there is no rain or immediate forecast for rain. Other agencies require temperatures of 40°F or 60°F.

QUALITY CONTROL

Eighty-three percent of the agencies using CIR monitor density. Field density is measured with core samples (27 percent of responses), nuclear density gauge (41 percent of responses), and sand cone (9 percent of responses). Twenty-three percent of the agencies specify instead a rolling procedure. Field density control methods are shown in Figure 7.

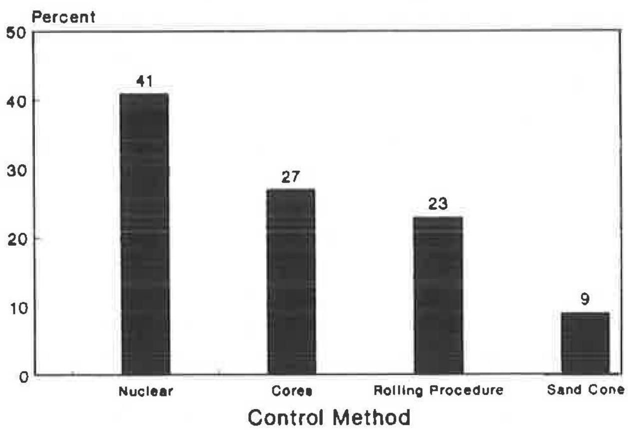

FIGURE 7 Density control of RAP.

Various reference standards are used (Figure 8). The Marshall 50 blow standard is used by 52 percent of the respondents, Marshall 75 blow by 32 percent, static compaction by 12 percent, and gyratory compaction by 4 percent. Each procedure will produce a different, absolute reference density. As a result, discussion of target densities may be relative.

Target densities are reported to range from 85 to 98 percent of the reference density. The lower range of density requirement is usually related to the first stage of compaction. In these cases, agencies specify a second-stage compaction to obtain 90 percent or higher density. This variability in test method and reference standard, when combined with the previously discussed variability in sample preparation and moisture content, indicates the need for research before standard procedures can be widely accepted.

The total moisture content of the RAP may consist of water added to the mix, water added to the the cutting/milling head, and the in-place moisture of the existing pavement. Thirty-seven percent of the agencies test the RAP moisture content.

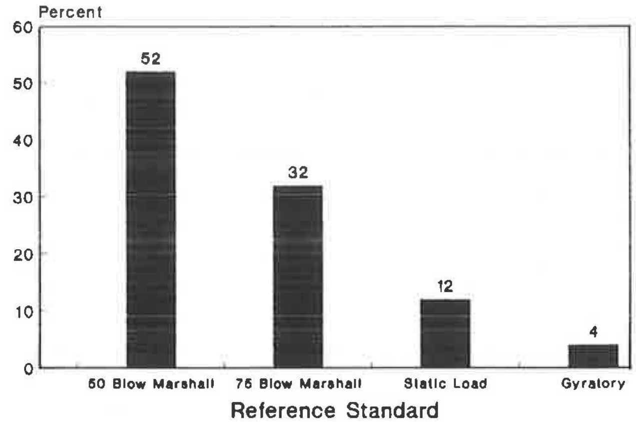

FIGURE 8 Field density reference standard.

The same percentage of agencies also measure the asphalt content of the recycled material, with half of these (18 percent) also testing the extracted asphalt for penetration and viscosity. One out of four agencies also tests the final recycled material for gradation.

Sixty-six percent of the agencies allow field adjustment of the initial mix design. Most of these (60 percent) base their adjustments on a combination of experience and workability. Forty percent reported they also use field laboratory tests for adjustments of mix design. Several agencies expressed a need for development of a rapid field test procedure.

TYPE OF SURFACING

Ninety-five percent of the responding agencies apply a surfacing to the recycled pavement. Of these, 12 percent apply a fog, sand, or slurry seal; 33 percent apply a surface treatment; and 50 percent require an asphalt concrete wearing course (Figure 9). Surface seals are restricted primarily to low-volume roads

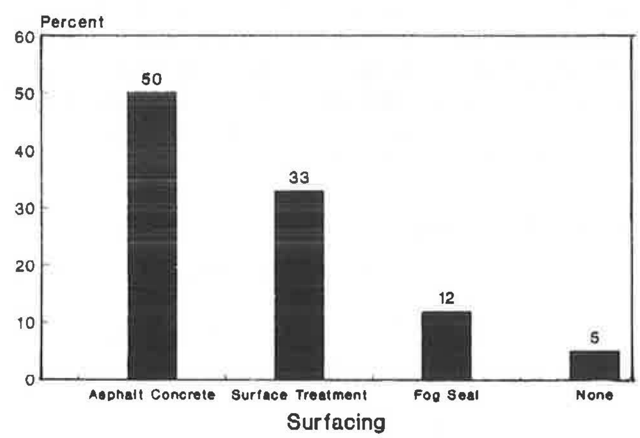

FIGURE 9 Type of surfacing.

or to a nonporous finished surface. The Pennsylvania Department of Transportation recommends double surface treatments for average daily traffic (ADT) of 1,500 and less, and a hot-mix wearing surface for ADT between 1,501 and 3,000. They do not recommend CIR for roads with ADT of 3,000 vehicles/day or with heavy truck traffic.

Surfacing is usually placed 3 to 7 days after RAP placement. Some agencies recommend that the surfacing not be applied until the moisture content of the recycled mix is less than that in the existing pavement before recycling plus 1 percent. Some agencies allow traffic on the compacted, recycled pavement immediately after compaction before overlay. According to the report from New Mexico, traffic of 8,000 vehicles/day was carried on a recycled section of I-40 for a 60-day period with no detrimental effects. Other agencies recommend a 3- to 6-hr curing period before allowing traffic on the pavement.

CIR PERFORMANCE AND COSTS

CIR is still a relatively new option with significant variation in procedures and materials. Reported performance also varies significantly. Overall, however, very positive results have been reported.

An Indiana Department of Highways project constructed in 1981 on a two-lane highway has performed well. Over the past 3 yr, about 500 lane-miles of highway have been successfully recycled in New Mexico using CIR. Extensive experience with CIR in Oregon, Pennsylvania, and California has also been reported to be very promising. In addition, projects performed under FHWA Demonstration Project No. 39, already cited, have shown good performance.

The major problems encountered in implementing CIR involve design of the mix, field control of the finished RAP, and determination of the readiness of the finished pavement for traffic. Other reported problems include low stability, higher cost, raveling, and public opposition.

Despite reservations about using CIR, most agencies report cost savings. Those in Oregon, California, Pennsylvania, and New Mexico report that projects covering a wide range of conditions have proved to be strong contenders to overlays or rehabilitation. Oregon reported savings of close to $1 million for a 15-mi project, and New Mexico reported savings of \$2.44/yd^2 and \$3.88/yd^2 for CIR projects on Interstate highways.

Several cities and counties have reported similar success. Elmira, New York, reported savings of $5.00/ton for materials, and Erie County, New York, reported savings of 36 percent over conventional paving. The 1986 Roads and Bridges survey of public road agencies also indicated that respondents expect their CIR projects to last 10 yr; or as long as hot recycling projects (Figure 10).

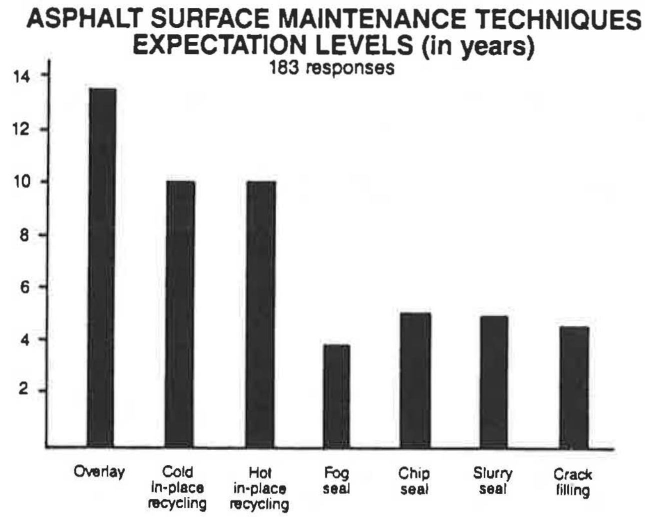

FIGURE 10 Expected life of maintenance.

SUMMARY

The current practice of CIR shows wide diversity in use, design, construction, and testing. This practice ranges from a bituminous stabilization process to a state-of-the-art multiunit construction train that mills, crushes, screens, and mixes the RAP with precise amounts of agent. Although the practices are variable, results have been reported as favorable by virtually all agencies.

These favorable results have encouraged more agencies to use CIR, and equipment and material suppliers to invest in the development of new equipment and materials. As a result, a CIR state of the art is developing.

This state of the art, an improvement over the bituminous stabilization process used in the early 1970s, requires definition and research. Continued research and development should lead to improved CIR mix design, construction, and testing, which should promote the use of CIR and realization of its benefits.

ACKNOWLEDGMENTS

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REFERENCE

1. *Asphalt Cold Mix Recycling*. Manual MS-21, Asphalt Institute, College Park, Md., 1983.

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