Performance-Based Mix-Design Method for Cold In-Place Recycling of Bituminous Pavements for Maintenance Management

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The high cost and environmental impact of pavement rehabilitation have led to an increase in the use of cold in-place recycling (CIR) as an effective alternative to other rehabilitation strategies. However, currently there is not a universally accepted or standard mix design for CIR. This project is being undertaken with the objective of developing a performance-based mix-design procedure for CIR through laboratory evaluation and limited field verification. This project focuses on partial-depth CIR with asphalt emulsions as the recycling agent. After modified Marshall mix design recommended by AASHTO Task Force 38 was evaluated, a Superpave gyratory compactor and technology were used to develop a volumetric mix design. This requires specimens to be prepared at densities similar to those found in the field. It also suggests that specimens should be cured at 60°C (140°F) for 24 h. This allows for the most consistent specimens and most effectively utilizes the time of laboratory personnel. It is also recommended that the resilient modulus of specimens prepared with the new mix design be used for pavement structural design.

As early as 1915, pavement materials were recycled for road rehabilitation. However, pavement recycling has greatly increased since the mid-1970s, largely because of the oil embargo but also because of a decrease in the availability of good quality aggregates. Several benefits arise from pavement recycling including conservation of materials and energy, preservation of the environment, and reduction in cost. Because of these benefits, many agencies such as the FHWA and state highway agencies began to promote recycling (*1*).

This paper focuses on cold in-place recycling (CIR). CIR projects have been performed successfully since the early 1980s in states such as Kansas (*2*), Oregon (*3*), California (*4*), and New Mexico (*5*). However, some projects have not performed as well as expected. This may be due to the wide variation in mix-design procedures, tests, and criteria. This suggests that a standard mix design should be developed in order to obtain more consistent results in the field as well as to promote the technology. In response to the above need, AASHTO, the American Road and Transportation Builders Association, and the Associated General Contractors of America formed Special Joint Task Force 38. The group produced guidelines for CIR design, but they could not develop a mix design based on performance (*6*). Therefore, a research project has been undertaken in order to develop a performance-based mix design that can be used as a standard for the CIR industry.

CIR PROCESS

There are two methods of cold recycling: CIR and cold central plant recycling. CIR is generally preferable because trucking is reduced, which saves time, money, energy, and

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the environment. The CIR process is completed on grade and typically consists of milling the existing pavement to a specified depth (usually 50 to 100 mm), screening and crushing the reclaimed asphalt pavement (RAP) to meet specifications (typically 25 to 37.5 mm), mixing the RAP with the additives (emulsions, recycling agents, fly ash/cements, lime slurry), and spreading and compacting the mixture. CIR can be accomplished with a single-unit train or a multiunit train. The single-unit train consists of a milling machine that does the cutting, RAP sizing, and blending at the cutting head (*7*). The recycled mix is then placed either in a windrow or directly into a paver hopper. The multiunit train consists of a milling machine, a trailer-mounted screening/crushing unit, and a trailer-mounted pugmill mixer.

A conventional asphalt paver is usually used to place the recycled mixture (typically 50 to 100 mm thick). After placement, compaction starts once the emulsion breaks. Breaking is the point at which the color of the mix changes from brown to black. Compaction is then performed first by a large 20.87-Mg (23-ton) pneumatic-tired roller and then by a 9.98-Mg (11-ton) steel double-drum vibratory roller. A new surface course is placed on the CIR mixture after curing for 1 to 2 weeks. This surface course is usually a hot-mix asphalt (HMA) overlay, but it can also be a surface treatment such as a chip seal for roads with a lower volume of traffic.

Weather is a limiting factor on CIR mixes. The minimum air temperature is specified in the range from 10°C to 16°C (50°F to 60°F). In addition, CIR should not be done in the presence of rain or fog.

Absolutely the most important aspect to consider for successful CIR mixtures is project selection. Many of the failed CIR projects were caused by improper project selection. The selection process should include assessing the existing pavement conditions; sampling and testing pavement materials, including the base, subbase, and subgrade; and studying the pavement's history and traffic (*6*).

Most pavement distresses can be successfully corrected with CIR. These include fatigue cracking, transverse thermal cracking, reflection cracking, and raveling. CIR destroys the existing cracking and produces a crack-free layer for the new surface course. However, not all pavements are good candidates for CIR. Some of the pavement distresses and conditions that are less successfully corrected include the following (*6*):

- Rutted pavements caused by too high asphalt content;
- Failures caused by a wet, unstable base, subbase, or subgrade;
- Failures caused by heaving or swelling in underlying soils;
- Stripped pavements;
- Presence of numerous manhole or drainage outlets;
- Excessive steep grades (5 percent and 760 m), which reduce production;
- Heavily shaded areas, which increase curing times and need to be considered during design;
- Asphalt pavements less than 50 mm (2 in.); and
- Excessive roadway accesses such as driveways.

Other factors need to be considered when the decision to use CIR is being made, such as project size, pavement width, traffic volumes, and congestion.

An Internet website has been developed with the purpose of being a central focus area for CIR technology that can be easily accessed by individuals interested in CIR (*8*).

EXPERIMENTAL WORK PLAN

Because of limited funds and limited time, the mix-design will be developed for partial-depth CIR, which is defined as a rehabilitation technique that reuses a portion of the existing asphalt-bound materials (*1*). In addition, it was decided that the additive to be evaluated would be limited to asphalt emulsions with the Superpave gyratory compactor (SGC) being used for the volumetric mix design.

A work plan has been formulated for the experimental work of developing a mix design, and it consists of five phases. The first is identification of sensitivities for CIR mixtures. The important distress modes to consider in the mix design are rutting, fatigue cracking, thermal cracking, and water sensitivity. The second phase is procurement of the test samples, including the RAP and emulsions. To have representative samples, the RAP needed to be obtained from different regions. The three places where RAP was obtained were Kansas, Connecticut, and Ontario. For the third phase of the work plan, the modified Marshall mix-design method recommended by AASHTO Task Force 38 is evaluated. The fourth phase is development of a new performance-based mix-design method. The final phase is a limited field evaluation.

EVALUATION OF MODIFIED MARSHALL MIX DESIGN

The modified Marshall mix design, recommended by AASHTO Task Force 38, was evaluated with two RAP samples. The first RAP was from Kansas and used a CSS-1h asphalt emulsion. The second RAP was from Ontario and used a HF150P asphalt emulsion. The procedure is summarized below. However, for the complete detailed procedure refer to the Task Force 38 report (*6*). The mix design is composed of two parts.

The first part is determination of the optimum emulsion content (OEC) and the second part is determination of the optimum water content (OWC). The steps for the first part are summarized as follows:

- Weigh sufficient RAP to fabricate 62.5-mm (2.5-in.) specimens into individual pans and heat at mixing temperature (25°C) for 1 h. Prepare three specimens for each emulsion content (EC).
- Add sufficient water to obtain 3 percent total liquids content and mix for 1 min.
- Add emulsion heated to 60°C (140°F) and mix until evenly dispersed but less than 2 min.
- Fabricate specimens by applying 50 blows of the Marshall hammer to each face at 25°C (77°F).
- Cure specimens in their molds for 6 h at 60°C.
- Remove molds from the oven and allow specimens to cool on their sides overnight and extrude.
- Test specimens for bulk specific gravity (25°C).
- Bring specimens to 25°C for 2 h and test for stability and flow (AASHTO T245).
- Determine maximum specific gravity for each EC.

Data from the described procedure were used to determine the OEC.

In the second part, three specimens, each with different water contents (WCs) below and above 3 percent, were fabricated at the OEC. A similar procedure was used to determine the OWC.

Table 1 presents the gradation of the Kansas and Ontario RAPs used in this study. Tables 2 and 3 present the tabulated results for parts one and two, respectively.

The OEC for the Kansas RAP was determined to be 1.2 percent based on the highest stability value. The OWC was found to be 3.0 percent based on the highest stability and optimum air voids. The OEC for the Ontario RAP was determined to be 1.2 percent based on the highest stability value. The OWC was found to be 2.2 percent based on the highest stability and optimum air voids. However, there was one noticeable problem with the mixtures. The air voids in the mixes were higher than the design parameter of 9 to 14 percent air voids suggested by AASHTO Task Force 38. One possible reason for this problem is the gradation of the RAP, which has a very small amount of fine material. The coarse RAP does not allow for proper compaction. In addition, CSS-1h is usually best used with dense-graded mixtures.

TABLE 1 RAP Gradation (Processed)

	Kansas RAP	Ontario RAP	Connecticut RAP
Sieve Size	% Passing	% Passing	% Passing
37.5 mm	100	100	100
25 mm	100	100	98.4
19.1 mm	90.4	96.1	92.4
12.5 mm	76.1	86.0	82.9
9.5 mm	65.5	74.7	72.2
4.75 mm	42.6	48.3	47.6
2.00 mm	23.3	27.1	28.9
1.18 mm	15.8	12.1	16.3
0.6 mm	8.7	4.1	8.2
0.3 mm	3.5	1.1	3.0
0.15 mm	1.5	0.3	0.8
0.075 mm	0.4	0.1	0.2

TABLE 2 Modified Marshall Mix-Design Data for Cold In-Place Recycling, Mix 1—Varying Emulsion Contents

Kansas RAP w/CSS-1h Emulsion					
Emulsion %	0.5	1.0	1.5	2.0	2.5
Water %	3.0	3.0	3.0	3.0	3.0
Bulk SG	2.042	2.019	2.011	1.991	1.991
Max. SG	2.453	2.444	2.434	2.413	2.405
Air Voids (%)	16.8	17.4	17.4	17.5	17.2
Unit Weight (pcf)	127.1	125.6	125.2	123.9	123.9
Stability (lbs)	1733	1675	1833	1667	1664
Flow (1/100 in.)	12.0	15.0	17.0	19.8	20.7
Ontario RAP w/HF150P Emulsion					
Emulsion %	0.5	1.0	1.5	2.0	2.5
Water %	2.0	2.0	2.0	2.0	2.0
Bulk SG	2.093	2.108	2.092	2.114	2.100
Max. SG	2.469	2.450	2.431	2.417	2.402
Air Voids (%)	15.2	14.0	13.9	12.6	12.6
Unit Weight (pcf)	130.2	131.2	130.2	131.6	130.7
Stability (lbs)	1499	1581	1390	1254	1222
Flow (1/100 in.)	14.5	13	16	11	19

NOTE: 1 lb/ft^3 (pcf) = 16.02 kg/m^3; 1 in. = 2.54 cm; 1 lb = 0.45 kg; SG = specific gravity.

TABLE 3 Modified Marshall Mix-Design Data for Cold In-Place Recycling, Mix 2—Varying Water Contents

Kansas RAP w/CSS-1h Emulsion					
Emulsion %	1.2	1.2	1.2	1.2	1.2
Water %	2.0	2.5	3.0	3.5	4.0
Bulk SG	2.014	2.033	2.038	2.034	2.019
Max. SG	2.415	2.418	2.419	2.418	2.413
Air Voids (%)	16.6	15.9	15.7	15.9	16.3
Unit Weight (pcf)	125.3	126.6	126.9	126.6	125.7
Stability (lbs)	1758	1867	2107	1942	1725
Flow (1/100 in.)	19.7	20.0	17.7	17.3	18.3
Ontario RAP w/HF150P Emulsion					
Emulsion %	1.2	1.2	1.2	1.2	1.2
Water %	1.5	2.0	2.5	3.0	3.5
Bulk SG	2.056	2.061	2.074	2.082	2.078
Max. SG	2.485	2.486	2.483	2.487	2.490
Air Voids (%)	17.3	17.1	16.5	16.3	16.5
Unit Weight (pcf)	128.0	128.3	129.1	129.6	129.4
Stability (lbs)	1378	1274	1300	1300	1144
Flow (1/100 in.)	16.5	15	15	13	10.5

NOTE: 1 lb/ft^3 (pcf) = 16.02 kg/m^3; 1 in. = 2.54 cm; 1 lb = 0.45 kg; SG = specific gravity.

During the evaluation, the following problems and disadvantages were identified with the modified Marshall procedure:

- The first and foremost disadvantage with this procedure is the amount of time needed to perform the entire procedure. The procedure can take more than 8 days to perform. This amount of time may be more than most contractors and department of transportation engineers are willing to allocate for one mix design.
- The procedure does not give any specifications for when new aggregate should be added to the mixture. There should be some specification for the gradation of the mixture, either a general specification or an agency specification.
- The amount of material needed to fabricate 62.5-mm (2.5-in.) specimens was about 1000 g, which was less than that suggested in the procedure (1150 g).
- The procedure does not mention how long to cure the specimen to allow the mixture to break.
- The procedure does not state how long to heat the emulsion in the oven.
- To determine bulk specific gravity, the procedure requires immersing the specimens for 3 to 5 min in the water. However, because of higher air voids found in CIR mixes it may be better to keep the specimens in the water for the full 5 min.
- The procedure does not clearly state how to determine the optimum values for the emulsion and WCs.
- The design has no bearing on how well the mix will perform. The critical need of the industry is to show how the mix performs.

These observations suggest that this procedure may not be the best mix-design method for CIR. In addition, because the Superpave mix design has been successfully used for HMA, it was decided to modify the Superpave mix design for CIR in this project. In the process of developing the performance-based mix-design method, the disadvantages of the modified Marshall mix design would be addressed.

Development of a Performance-Based Mix Design

Pilot Study

A pilot volumetric mix design using the SGC was performed for the Kansas, Ontario, and Connecticut RAPs. The purpose of this pilot study was to determine how the different materials react to compaction of the SGC. The density values obtained from this study will be used to help determine the amount of compaction that will be needed for the remainder of the experimental testing as well as for the development of the new mix design. The modified Marshall mix-design procedure was used for the pilot modified Superpave mix design with some adjustments as follows:

- Weigh 4000 g of RAP into individual pans and heat at mixing temperature (25°C) for 1 h. Heat emulsion and molds at 60°C for 1 h. Prepare two specimens for each EC.
- Add sufficient water to obtain 3 percent total liquids content and mix for 1 min.
- Add emulsion and mix until evenly dispersed but less than 2 min.
- Allow the mixture to cure for 1 h to allow the emulsion to break before compaction.
- Fabricate specimens using the SGC by applying 52 gyrations at 600 kPa at an angle of gyration of 1.25° at 25°C.
- Extrude specimens from the molds and cure for 6 h at 60°C.

- Remove specimens from the oven and allow specimens to cool on their sides overnight.
- Test specimens for bulk specific gravity (25°C).
- Determine maximum specific gravity for each EC.

The data from this procedure were used to determine OEC. At this OEC, two specimens with different WCs below and above 3 percent were fabricated. A similar procedure was used to determine the OWC.

Tables 4 and 5 present the tabulated results for parts one and two of the mix design, respectively. The OEC for the Kansas RAP was determined to be 1.4 percent at air voids of 11 percent. The OWC was found to be 2.9 percent at 11 percent air voids.

The air voids for the Ontario RAP was in the range of 6 to 9 percent, which indicates that the compactive effort was too high. However, the SGC measures the height of each specimen after every gyration, which can be used in conjunction with the measured bulk specific gravity to determine the number of gyrations where the specimens are at the optimum 11 percent air voids. The point where the four various ECs average 11 percent air voids is then taken to be the proper number of gyrations. For this mixture it was determined that 25 gyrations were necessary (Figure 1). Therefore, the OEC for the Ontario RAP was determined to be 1.2 percent and the OWC was found to be 2.1 percent.

The OEC for the Connecticut RAP was determined to be 1.2 percent at the maximum unit weight of 2116.07 kg/m^3 (132.1 lb/ft^3), which resulted in air voids of 13.4 percent (Figure 2*a*). The OWC was found to be 2.3 percent at the maximum unit weight of 2136.9 kg/m^3 (133.4 lb/ft^3), which resulted in air voids of 12.6 percent (Figure 2*b*).

TABLE 4 Modified Superpave Mix-Design Data for Cold In-Place Recycling to Determine OEC

Kansas RAP w/CSS-1h Emulsion				
Emulsion %	0.5	1.0	1.5	2.0
Water %	3.0	3.0	3.0	3.0
Bulk SG	2.157	2.155	2.155	2.141
Max. SG	2.436	2.429	2.422	2.414
Air Voids (%)	11.5	11.3	11.0	11.3
Unit Weight (pcf)	134.2	134.2	134.2	133.2
Ontario RAP w/HF150P Emulsion				
Emulsion %	0.5	1.0	1.5	2.0
Water %	3.0	3.0	3.0	3.0
Bulk SG	2.287	2.307	2.311	2.315
Max. SG	2.506	2.495	2.486	2.479
Air Voids (%)	8.8	7.6	7.0	6.6
Unit Weight (pcf)	142.3	143.6	143.8	144.1
Connecticut RAP w/HF150P Emulsion				
Emulsion %	0.5	1.0	1.5	2.0
Water %	3.0	3.0	3.0	3.0
Bulk SG	2.115	2.127	2.115	2.112
Max. SG	2.462	2.453	2.446	2.434
Air Voids (%)	14.1	13.3	13.5	13.2
Unit Weight (pcf)	131.6	132.4	131.6	131.5

NOTE: 1 lb/ft^3 (pcf) = 16.02 kg/m^3; SG = specific gravity.

TABLE 5 Modified Superpave Mix-Design Data for Cold In-Place Recycling to Determine OWC

Kansas RAP w/CSS-1h Emulsion				
Emulsion %	0.5	1.0	1.5	2.0
Water %	3.0	3.0	3.0	3.0
Bulk SG	2.157	2.155	2.155	2.141
Max. SG	2.436	2.429	2.422	2.414
Air Voids (%)	11.5	11.3	11.0	11.3
Unit Weight (pcf)	134.2	134.2	134.2	133.2
Ontario RAP w/HF150P Emulsion				
Emulsion %	0.5	1.0	1.5	2.0
Water %	3.0	3.0	3.0	3.0
Bulk SG	2.287	2.307	2.311	2.315
Max. SG	2.506	2.495	2.486	2.479
Air Voids (%)	8.8	7.6	7.0	6.6
Unit Weight (pcf)	142.3	143.6	143.8	144.1
Connecticut RAP w/HF150P Emulsion				
Emulsion %	0.5	1.0	1.5	2.0
Water %	3.0	3.0	3.0	3.0
Bulk SG	2.115	2.127	2.115	2.112
Max. SG	2.462	2.453	2.446	2.434
Air Voids (%)	14.1	13.3	13.5	13.2
Unit Weight (pcf)	131.6	132.4	131.6	131.5

NOTE: 1 lb/ft^3 (pcf) = 16.02 kg/m^3; SG = specific gravity.

Experimental Program to Develop New Mix Design

An experimental program was undertaken in order to consider the effects of certain important variables on the CIR mix design. The Connecticut RAP and HFMS-2T emulsion were used for this investigation. Unit weight was the response that was chosen for this analysis, because this is the most important factor to consider for

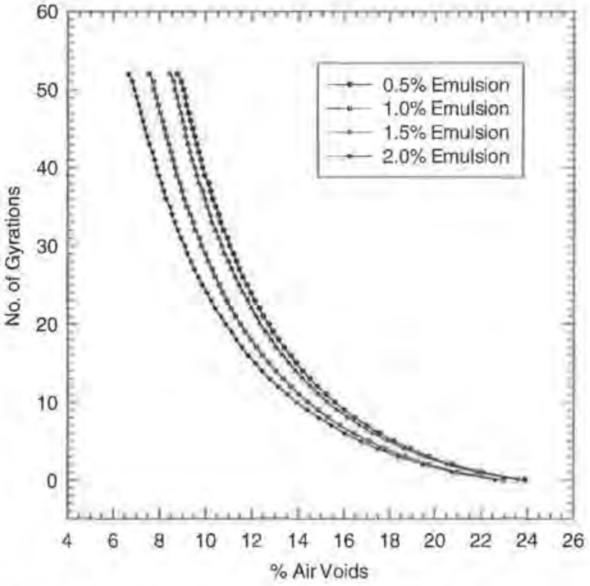
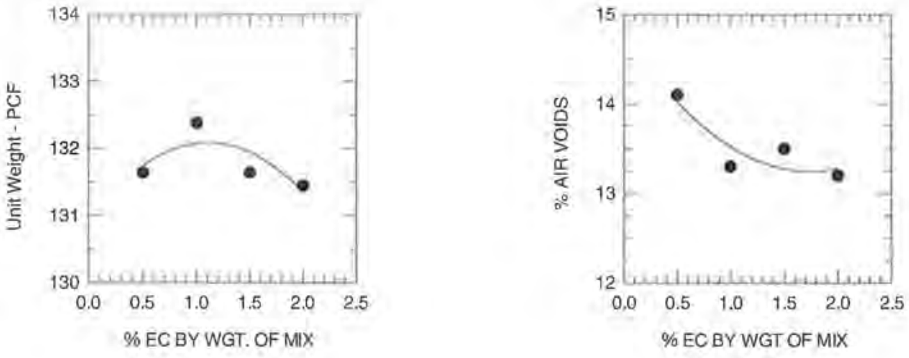
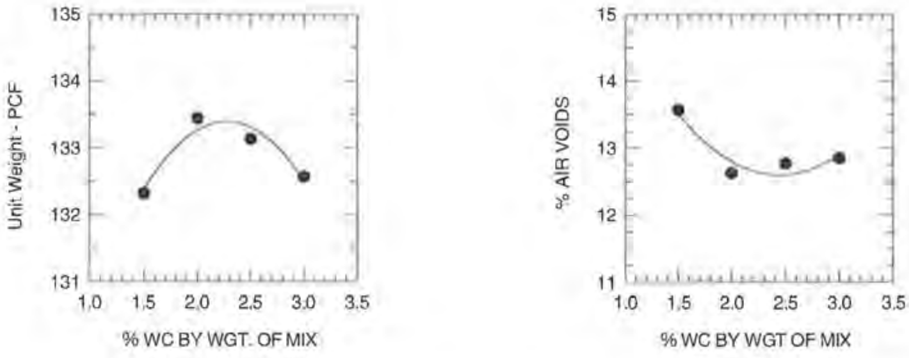


FIGURE 1 Number of gyrations versus percent air voids for Ontario RAP and HF150P at different ECs (3.0 percent WC).



OEC = 1.2 %

(a)



OWC = 2.3%

(b)

FIGURE 2 Pilot mix design with Connecticut RAP using the SGC: (*a*) different ECs at 3 percent WC; (*b*) different WCs at 1.2 percent EC (1 lb/ft^3 = 16.02 kg/m^3).

new CIR pavements. The variables under study include EC, total liquid content (TLC), curing time, and curing temperature (Table 6). The EC had four levels ranging from 0.5 to 2.0 percent of total mix by weight, in 0.5 percent increments. This range has two ECs above and below the OEC, which was determined in the pilot study. This range also covers most ECs that would be found in the field.

The two levels used for TLC were 3.5 and 4.0 percent. TLC was used as a parameter instead of WC because of its frequent use as a parameter for mix designs. In addition, TLC is a more fundamental measure of the moisture in the mixtures, instead of WC, because the emulsion also contains some water. The TLC of 3.5 percent was chosen because that is the optimum content that was found from the pilot study for the Connecticut material—1.2 percent EC + 2.3 percent WC = 3.5 percent TLC. The TLC of 4.0 percent was chosen because it is a typical field value.

Literature and the results from the questionnaire survey show that there are a wide range of curing times for mix-design specimens, anywhere from 1 h to 3 days. In addition, many mix designs use a combination of curing times and temperatures. Therefore, the curing times of 6 h and 24 h were chosen for this study because these times appear to be the most appropriate for the working schedules of laboratory personnel.

The two most common temperatures for curing specimens after compaction are 60°C and room temperature, which is about 25°C. Furthermore, these temperatures most accurately simulate field conditions; 60°C is a typical value for the highest temperature that pavement reaches during a summer day and 25°C is a typical pavement temperature during summer nights. Therefore, these two temperatures were chosen for the experimental program.

Compaction Level

To investigate the effects of these parameters on CIR mixtures, it was imperative that the densities of the lab-

TABLE 6 Experimental Design: Connecticut RAP with HFMS-2T Emulsion

Emulsion Content, %		0.5		1.0		1.5		2.0	
Total Liquid Content, %		3.5	4.0	3.5	4.0	3.5	4.0	3.5	4.0
Curing Temp., F	Curing Time, Hours								
140	24	2	2	2	2	2	2	2	2
	6	2	2	2	2	2	2	2	2
77	24	2	2	2	2	2	2	2	2
	6	2	2	2	2	2	2	2	2

NOTE: Two specimens were prepared for each cell.
140°F = 60°C; 77°F = 25°C.

oratory specimens simulate field densities. Therefore, actual field densities were obtained from the project that was the source of the RAP. The unit weight that was obtained for the project for the sampling data was 2082.4 kg/m^3 (130 lb/ft^3). Therefore, 2082.4 kg/m^3 was the desired unit weight for the laboratory specimens. To achieve this density, one or more of the parameters of the SGC needed to be changed from the HMA specifications. The possible parameters to change are number of gyrations, vertical compaction pressure, angle of gyration, and speed of gyration. However, a study performed on the SGC at the Asphalt Institute during the Strategic Highway Research Program (9) indicated that the speed of gyration has little effect and vertical pressure has only a small effect on density. The angle of gyration was found to have the greatest influence on the density. However, the angle of gyration of 1.25° was shown as the best angle for proper densification (9). Therefore, the number of gyrations was chosen as the parameter to change in this study.

The SGC collects the height data of the specimen for each gyration during the compaction process. This information, along with the mass of the mix, can be used to estimate the specific gravity of the specimen after every gyration. This is accomplished by measuring the bulk specific gravity of the compacted specimen and comparing it with the estimated specific gravity after the last gyration. A correction factor, a ratio of the measured to estimated bulk specific gravity, is then applied to the estimated specific gravity to arrive at the corrected specific gravity for each gyration (*10*). This procedure was used on the data gathered from the pilot study, and 37 gyrations were found to achieve a density of 2082.4 kg/m^3 for the Connecticut material. Thus, 37 gyrations were used to compact the specimens for the experimental program.

Test Results and Data Analysis

The bulk specific gravity of each specimen was measured twice. The first measurement took place 2 h after the end of the curing period. The delay was used to allow the specimens heated to 60°C to cool to room temperature. To maintain consistency for all specimens, the specimens that were cured at 25°C were also left for 2 h after the curing period. The second measurement was performed 1 week after compaction to allow all water to leave the specimen.

The unit weight data for the first and the second measurements are presented in Tables 7 and 8. An analysis of variance was performed on these data to investigate the effects of the variables with Minitab statistical software. It was found that all four parameters were statistically significant for the unit weight values that were determined 2 h after curing. A two-sample *t*-test was performed on the values for the two unit weight measurements to determine whether there is a difference between them. Results show that the unit weights just 2 h after curing are higher than the unit weights after 1 week. Closer inspection of the data shows that the largest difference between the two measurements occurs for the specimens that were cured for 6 h and the specimens that were cured at 25°C. The reason for this, as common sense suggests, is that the short time and cooler temperature do not allow all the mixing

TABLE 7 Unit Weights (lb/ft^3) for Experimental Program Using Connecticut RAP with HFMS-2T Emulsion: 2 h After Curing

	Curing Temperature							
	77° F				140° F			
	Curing Time (Hours)							
	24		6		24		6	
	Total Liquid Content (%)							
Emul. Content (%)	3.5	4.0	3.5	4.0	3.5	4.0	3.5	4.0
0.5	132.6	131.9	132.5	130.3	129.9	129.6	132.5	131.3
1.0	129.0	131.6	132.4	133.2	129.8	129.5	131.6	131.2
1.5	131.0	131.8	135.1	135.2	134.4	131.4	130.3	130.4
2.0	131.0	130.6	132.2	131.4	133.6	133.5	132.5	131.4

NOTE: 77°F = 25°C; 140°F = 60°C; 1 lb/ft^3 = 16.02 kg/m^3.

TABLE 8 Unit Weights (lb/ft^3) for Experimental Program Using Connecticut RAP with HFMS-2T Emulsion: 1 Week After Curing

	Curing Temperature							
	77° F				140° F			
	Curing Time (Hours)							
	24		6		24		6	
	Total Liquid Content (%)							
Emul. Content (%)	3.5	4.0	3.5	4.0	3.5	4.0	3.5	4.0
0.5	132.0	130.9	130.2	132.8	130.2	130.1	131.3	130.6
1.0	128.5	130.3	131.1	131.1	129.8	129.7	131.0	131.0
1.5	130.6	130.8	133.6	133.1	134.6	131.6	129.9	130.0
2.0	130.4	129.8	131.7	131.0	133.8	133.8	132.3	131.0

NOTE: 77°F = 25°C; 140°F = 60°C; 1 lb/ft^3 = 16.02 kg/m^3.

water to leave the specimen. One week allows most, if not all, of the water to leave the specimen. The 24-h curing time and the 60°C curing temperature more easily allow the water to be removed from the specimen, which results in less difference between values.

Based on the preceding analysis, the specimen preparation specification has been formulated for the new modified Superpave mix design. The tentative specifications are as follows:

- The specimens would be cured for 24 h at 60°C after compaction.
- A minimum of four ECs would be used.
- The number of gyrations used to compact the specimens should be adjusted to achieve densities similar to those found in the field.

Figure 3 presents the results from the experimental program for the Connecticut material, which was cured for 24 h at 60°C, at 3.5 and 4.0 percent TLC, respectively.

The moisture sensitivity of the mixture will also be evaluated to determine its long-term stripping susceptibility by the use of AASHTO T283.

PERFORMANCE ANALYSIS

CIR mixtures in accordance with the new volumetric mix design will be examined for their performance. The choice of which materials to use depends on the locations for field verification. Currently, plans call for two sites for limited field verification, one in Arizona and the other in Connecticut. The performance of the CIR mixtures prepared for the new mix design will be evaluated. The three distress modes to be investigated for performance analysis will be permanent deformation or rutting, fatigue cracking, and low-temperature cracking.

The performance of the CIR mixtures, in relation to permanent deformation and fatigue cracking, will be predicted by using the computer program VESYS (*11*). To do this analysis, the incremental static dynamic creep test (ISDCT) will be performed to determine the input data.

The ISDCT determines primary properties (creep or elastic compliance) and distress properties (permanent deformation) of 10.16-cm (4-in.) diameter and 20.32-cm (8-in.) high specimens. Because rutting depends on temperature, three different temperatures will be used for the ISDCT.

Creep compliance and the strength-at-low-temperatures test (AASHTO TP9-94) will be performed with the indirect tensile tester (IDT) to evaluate the resistance to low-temperature cracking. The test will be performed at three temperatures for creep compliance: 0°C, −10°C, and −20°C. The tensile strength will be measured at −10°C.

CONCLUSION AND RECOMMENDATIONS

Evaluation of the modified Marshall mix-design method from AASHTO Task Force 38 has suggested that this method may not be the future of CIR mix designs. The expanding use of the Superpave system deems it vitally necessary to provide a mix design for CIR similar to that for HMA with modifications for the nature of cold mixes. Therefore, a volumetric mix design using the SGC has been developed for use with CIR materials.

The next step is to add performance testing—for example, the ISDCT and the Superpave IDT—to this volumetric mix design to complete the performance-based mix design. The final step will be to build test sections for constructibility and testing of on-site performance.

It is also a tentative recommendation that the resilient modulus of specimens prepared with the new performance-based mix design will be used for pavement structural design.

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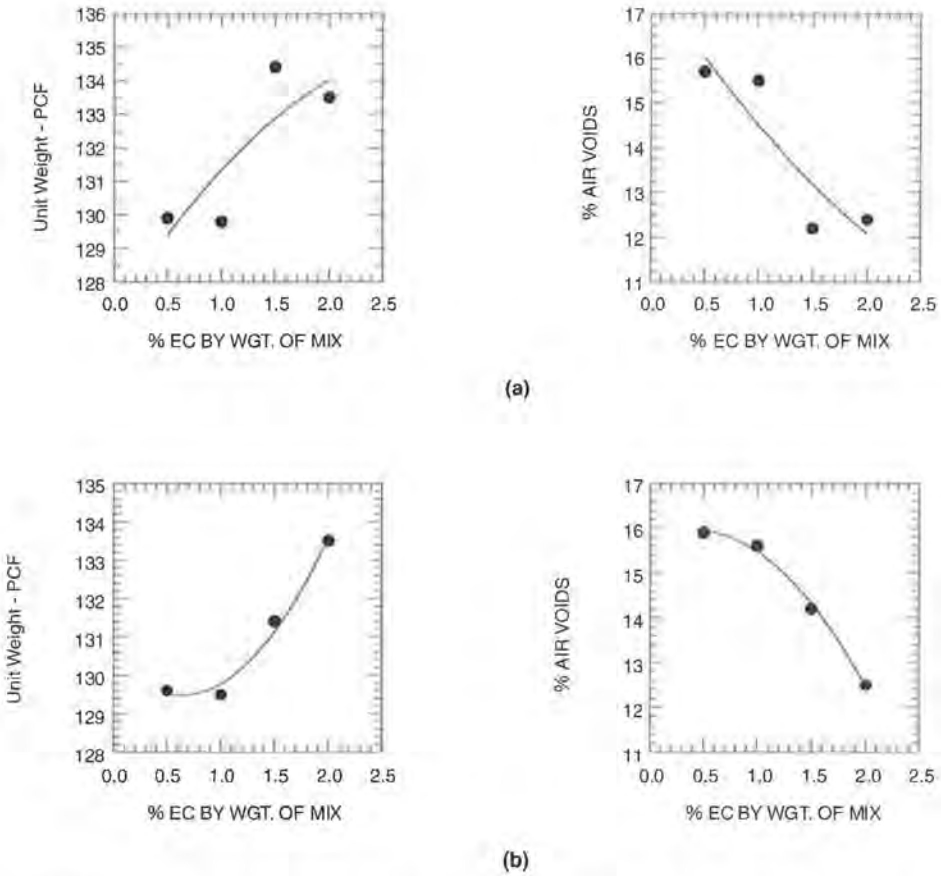

FIGURE 3 Connecticut RAP with 24-h cure at 60°C for the experimental program to develop new mix design: (*a*) TLC = 3.5 percent; (*b*) TLC = 4.0 percent ($1 \text{ lb/ft}^3 = 16.02 \text{ kg/m}^3$).

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