TECHNICAL BULLETIN ON DESIGN AND CONSTRUCTION OF CRACK ATTENUATING MIXES (CAM)

by

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TABLE OF CONTENTS

LIST OF FIGURES

Figure **Page**

LIST OF TABLES

Table **Page**

INTRODUCTION

The crack attenuating mix (CAM) is proposed as a thin, long-lasting, cost effective surface mix for pavement maintenance and preservation. Developed under TxDOT research study 0-5598, this very fine mix is designed to pass both the current Hamburg wheel test (HWTT) to ensure moisture susceptibility and good rut resistance and strict overlay tester (OT) requirements to ensure good crack resistance. It is typically placed as a 1-inch thick mat. This mix has been evaluated in several districts around Texas, and the performance to date has been very good.

A new statewide specification is under preparation and will be available in 2009. This comprehensive specification includes all aspects of material selection, mix design, and construction. The design of the mix relies on the traditional volumetric approach, wherein the optimal asphalt content (OAC) is designed based on achieving 98 percent lab molded density with 50 gyrations of a Superpave gyratory compactor (SGC). Once the OAC is determined, samples are then molded to 93 percent of maximum theoretical density, required to pass TxDOT's current Hamburg requirement, and last more than 750 cycles in the overlay tester. These volumetric requirements were established early in the research project and are known to work well for mixtures reduced with PG 76-22 binders and good quality Class A aggregates. However, in several recent projects major problems were identified in attempting to establish the OAC that also meets these performance test requirements. These problems included:

- TxDOT is encouraging districts to move away from the PG 76-22 binders because of cost and availability issues. The most recent CAM projects have used a PG 70-22 binder and there is even consideration to move to a PG 64-22. The 50 gyration/98 percent density does not appear reasonable for the lower PG graded binders as it appears to recommend too much asphalt, which gives problems passing the HWTT.
- The high-quality granite and sandstone aggregates are not available statewide. Districts want to use locally available materials. Passing the performance requirements is more difficult and sometimes impossible with lower-quality aggregates.
- If the current volumetric design fails the performance tests then there is little guidance on what to do next. The new specification has options to increase the number of gyrations up to 100 and/or waive either of the performance tests. This could lead to major confusion and potentially lower-quality mixes.
- Mixes designed with the current volumetric method for PG binders lower than PG 76-22 are resulting in too much asphalt in the mix. This condition is costly and could possibly introduce skid and stability problems.

In this report a new mix design procedure is proposed that builds on the fact that in the CAM design the aggregates and asphalt are paid for separately. The proposed procedure attempts to define a window of asphalt contents where both cracking and rutting requirements are satisfied. The OAC is defined as the middle of the acceptable range. The volumetrics are then checked after the performance tests are satisfied. This procedure has several advantages. It will rapidly identify aggregate/asphalt combinations that will not work so that costly re-runs of the volumetric designs will be avoided. In one recent project at least 10 re-designs of a CAM were performed before it was concluded that the proposed mix would not work. This new procedure can save money by identifying a window of asphalt content that will provide satisfactory performance.

Figure 1 shows the design procedure proposed in this bulletin. TxDOT is encouraged to evaluate this approach on upcoming projects; it should be run in parallel with the current volumetric procedure. Meeting both the HWTT and OT test criteria is a new concept in Texas, and this requirement will create many challenges for TxDOT and the hot mix industry. The new procedure will help minimize these challenges.

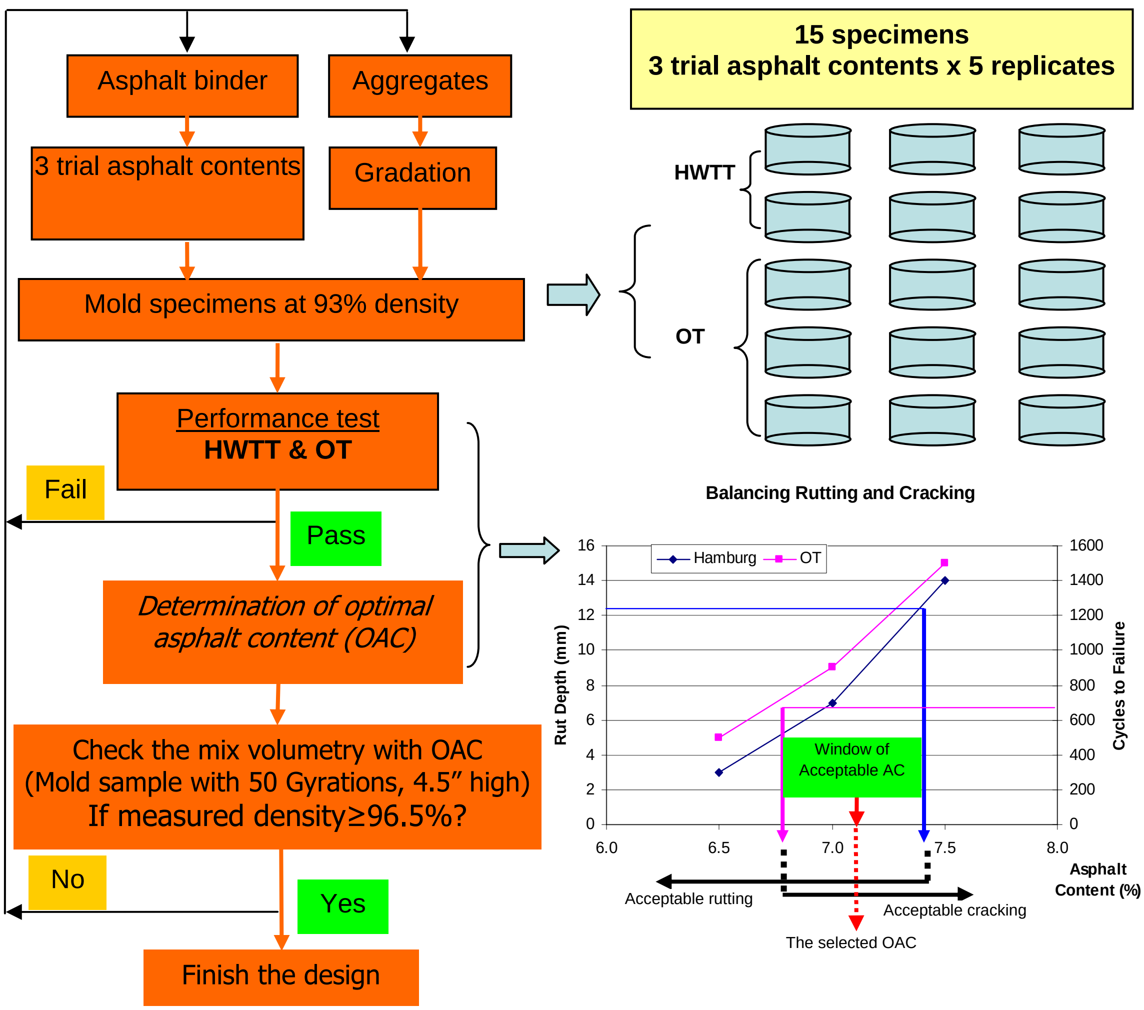


Figure 1. The Flowchart for Design of CAM Overlay.

MINIMUM AGGREGATE PROPERTIES

The first step in the process is to identify locally available aggregates that meet the quality and gradation requirements of Tables 1 and 2. If at all possible 100 percent Class A aggregates should be used, but recent projects have used a blend of Class A materials with high-quality Class B limestone screenings. Successful designs have been placed with granite, sandstone, and crushed gravel aggregates.

All materials used in the CAM should be crushed, high-quality materials preferably (but not necessarily) from the same source. Softer limestone materials should be avoided. Also currently recycled asphalt pavement (RAP) is not permitted in the CAMs. River sands are also not permitted as they typically have problems passing the HWTT.

Table 1. Aggregate Quality Requirements.

Property	**Test Method**	**Requirement**
Coarse Aggregate		
Surface Aggregate Classification (SAC)	Aggregate Quality Program (AQMP)	As shown on plans
Deleterious material, %, max	Tex-217-F, Part I	1.0
Decantation, %, max	Tex-217-F, Part II	1.5
Micro-Deval abrasion, %, max	Tex-461-A	Note 1
Los Angeles abrasion, %, max	Tex-410-A	30
Magnesium sulfate soundness, 5 cycles, %, max	Tex-411-A	20
Coarse aggregate angularity, 2 crushed faces, %, min	Tex 460-A, Part I	95[2]
Flat and elongated particles @ 5:1, %, max	Tex-280-F	10
Fine Aggregate		
Linear shrinkage, %, max	Tex-107-E	3
Combined Aggregate[3]		
Sand equivalent, %, min	Tex-203-F	45

1. Not used for acceptance purposes. Used by the engineer as an indicator of the need for further investigation.
2. Only applies to crushed gravel.
3. Aggregates, without mineral filler, or additives, combined as used in the job-mix formula.

Table 2. Recommended CAM Gradation Band .

Sieve Size	Fine Mixture (% Passing by Weight or Volume)
1/2"	100
3/8"	98.0 – 100.0
#4	70.0 – 90.0
#8	40.0 – 65.0
#16	20.0 – 45.0
#30	10.0 – 30.0
#50	10.0 – 20.0
#200	2.0 – 10.0

The new specification mandates the use of 1 percent lime as an anti-stripping agent in all mixes. However, successful CAMs have been placed without the lime. The lime will definitely help with the mixes containing the lower PG binders. The need for lime should be based on the outcome of the performance tests; if problems are observed with passing the Hamburg, then lime should be considered.

MIX DESIGN PROCEDURE

In accordance with the flowchart shown in Figure 1, this mix design procedure is composed of six steps:

1) select trial asphalt content;
2) run maximum specific gravity;
3) mold samples to 93 percent density;
4) run Overlay and Hamburg testing;
5) select the optimal asphalt content; and
6) check mixture volumetrics.

Detailed information is presented below.

<u>Step 1: Select Trial Asphalt Content</u>

Depending on traffic level, climate conditions, and available budgets, PG 64-22, PG 70-22, PG 70-28 or PG7 6-22 asphalt binder can be selected for the CAM. Three trial asphalt contents for each binder are proposed in Table 3. Note: this range of binders is outside the minimum range specified in SS 3165 where a minimum of 7 percent binder is required. The 7 percent binder is thought adequate for higher graded PG binders, but it may be too high for PG 64-22 binders. With experience, the minimum binder level in SS 3165 may need to be changed.

Table 3. Recommended Trial Asphalt Content.

Asphalt Type	Asphalt Content		
	Low	Middle	High
PG 76-22	6.8	7.4	8.0
PG 70-22	6.4	6.8	7.2
PG 70-28	6.4	6.8	7.2
PG 64-22	6.0	6.3	6.6

The only designs that have currently been placed used either the PG 76-22 or PG 70-22.

<u>Step 2: Run the Theoretical Maximum Specific Gravity at each Asphalt Content</u>

Before molding test samples, for each trial asphalt content determine the specific gravity in accordance with Part II of Tex-227-F, Theoretical Maximum Specific Gravity of Bituminous Mixtures. The standard method for determining this specific gravity should be used including using the metal vacuum pycnometer shown in Figure 2.

Figure 2. Specific Gravity Testing Using Metal Vacuum Pycnometer.

Step 3: Mold Samples to 93 percent Density

Following the TxDOT recommendation (in Tex-242-F for the HWTT and Tex-248-F for the OT), mold five samples at each asphalt content, two of them for Hamburg testing and three for overlay testing. In total, 15 samples for the three trial asphalt contents are prepared for testing. Based on the RICE gravities obtained in step 2, all samples are molded to the specified density of 93 ± 1 percent (after cutting). Figure 3 shows the scheme for preparing samples.

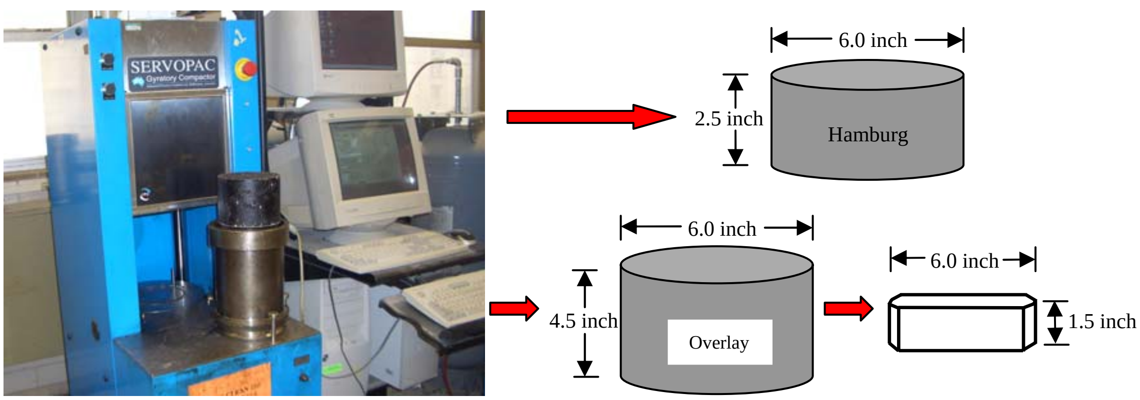
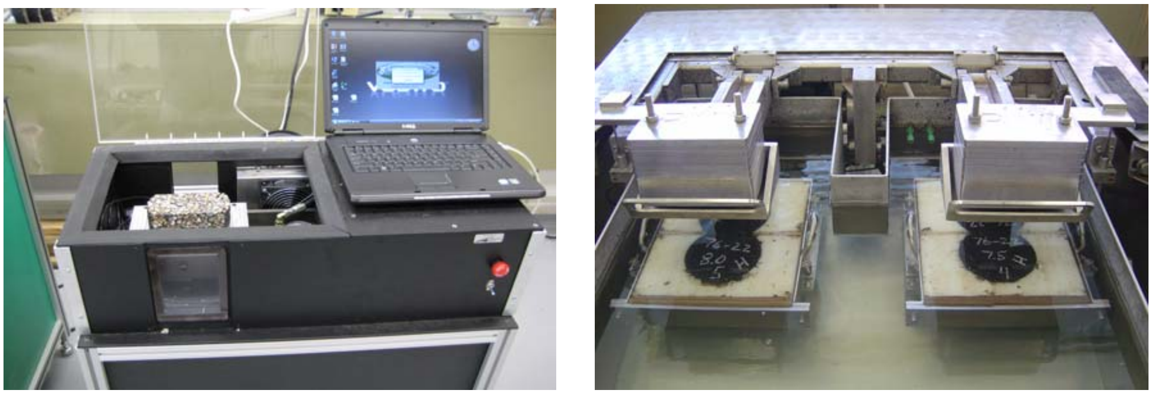


Figure 3. Molding Samples.

Step 4: Run Overlay Testing and Hamburg Testing

In accordance with Tex-248-F run the overlay test, and in accordance with Tex-242-F run the Hamburg test; see Figure 4 (a) and (b), respectively. Record test results.



(a) Overlay Testing (b) Hamburg Testing

Figure 4. Overlay Testing and Hamburg Testing.

<u>Step 5: Select Optimal Asphalt Content</u>

Select the OAC as the asphalt content meeting both the Hamburg rutting and overlay cracking criteria. A window of acceptable asphalt content will usually be determined, as shown in Figure 5. The Hamburg results use the scale on the left and the overlay tester results use the scale on the right. The failure criteria for the HWTT is 12.5 mm and the OT is 750 cycles. The middle value of the window of acceptable asphalt content is selected as the initial OAC.

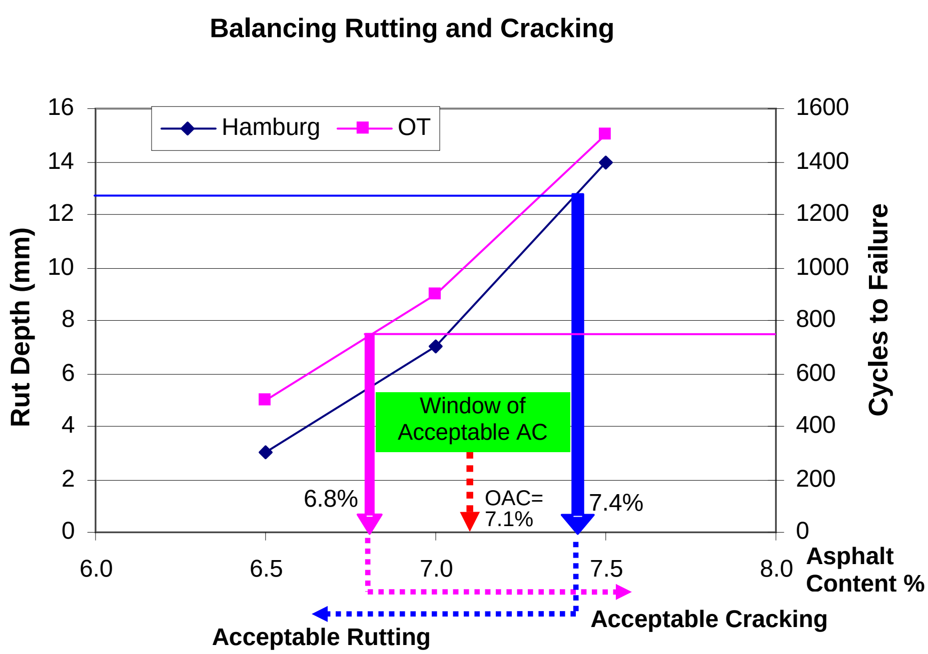


Figure 5. Selecting Optimal Asphalt Content.

Several different results have been found in practice. These include:

a) The samples pass the HWTT and OT requirements at all of the design ACs recommended in Table 3. In that case use the minimum asphalt content as the optimal asphalt content. However, in this scenario there is potential to design a more economical mix, and consideration could be given to do a redesign at a lower value; for example, if a PG 76-22 at 6.8 percent asphalt passed all the performance requirements, then consider a redesign at 6.4 percent asphalt.
b) None of the asphalt contents pass both tests (in that case a new combination of asphalt and aggregates must be used).
c) All samples pass the Hamburg but not the overlay tester. Do a rerun at a higher AC than that specified in Table 3.
d) All samples pass the overlay tester but fail the Hamburg. Consider adding lime to the mix.

Step 6: Check Mixture Volumetrics

In order to meet quality control (QC) and quality assurance (QA), it is also necessary to check the sample's mix volumetric properties at the selected OAC. This will ensure that the mix will not have compaction problems and will provide a target density for the trial and production batch material.

Mold two 4.5-inch high samples with 50 gyrations at the initial selected OAC (i.e., 7.1 percent in Figure 5). If the measured density is between 96.5 percent and 98 percent then the mix design is complete. If the measured density is less than 96.5 percent then increase the OAC by 0.2 percent, provided this is within the acceptable window, and remold the samples. If it is more than 98 percent then reduce the OAC by 0.2 percent, provided this is within the acceptable window. Recheck the density at 50 gyrations.

EXAMPLE CAM MIX DESIGN

The need for the procedure described above was realized on several recent projects where the contractors struggled to arrive at an OAC that also met the performance tests. In one case the contractor was required to use locally available aggregates and PG 70-22 binder. The local aggregate was trap rock, which historically has performed well. After many tries at passing the volumetric procedure, TxDOT and the conractor were about to give up on the design. The main problem was that all of the proposed mixes could not pass the HWTT criteria. A review was made of the proposed mix and three problems were found:

1) The proposed aggregate was out of specifications on the flat and elongated test. This rock was replaced with a Grade 5 rock that was more cubical.
2) Even with the revised aggregates the proposed mix design and the use of 1 percent lime, the optimal asphalt content found from using the volumetric procedure was 7.2 percent. This AC failed the Hamburg test.
3) A redesign with the procedure described above was performed and an AC of 6.8 percent was found to pass the performance tests. At this AC the mix achieved a density of 96.8 percent of optimum at 50 gyrations in the SGC.

Table 4 shows the final mix design in the project.

Table 4. Aggregates and Associated Gradation for San Antonio CAM Design.

	BIN FRACTIONS																	
	Bin No.1		Bin No.2		Bin No.3		Bin No.4		Bin No.5		Bin No.6		Bin No.7					
Aggregate Source:	Knippa		Knippa		EE Hood													
Aggregate Pit:																		
Aggregate Number:																		
Sample ID:	Grade 5		Man Sand		Limestone Screenings								Hydrated Lime			Combined Grad		
Rap?:															Total Bin			
Individual Bin (%):	38.0	Percent	42.0	Percent	19.0	Percent		Percent		Percent		Percent	1.0	Percent	100.0%	Lower & Upper Specification Limits		
Sieve Size:	Cum.% Passing	Wtd Cum. %	Cum.% Passing	Wtd Cum. %	Cum.% Passing	Wtd Cum. %	Cum.% Passing	Wtd Cum. %	Cum.% Passing	Wtd Cum. %	Cum.% Passing	Wtd Cum. %	Cum.% Passing	Wtd Cum. %	Cum. % Passing	Lower	Upper	Within Spec's
3/8"	97.1	36.9	100.0	42.0	100.0	19.0							100.0	1.0	98.9	98.0	100.0	Yes
No. 4	26.6	10.1	99.6	41.8	99.9	19.0							100.0	1.0	71.9	70.0	90.0	Yes
No. 8	0.9	0.3	81.1	34.1	96.6	18.4							100.0	1.0	53.8	40.0	65.0	Yes
No. 16	0.6	0.2	40.9	17.2	69.6	13.2							100.0	1.0	31.6	20.0	45.0	Yes
No. 30	0.6	0.2	20.5	8.6	49.0	9.3							100.0	1.0	19.1	10.0	30.0	Yes
No. 50	0.6	0.2	9.5	4.0	37.2	7.1							100.0	1.0	12.3	10.0	20.0	Yes
No. 200	0.5	0.2	1.3	0.5	25.4	4.8							100.0	1.0	6.6	2.0	10.0	Yes

According to Table 3, three trial asphalt contents, 6.4, 6.8, and 7.2 percent, were selected. After RICE testing, the maximum specific gravities, 2.652, 2.629, and 2.608 were obtained, respectively.

Table 5 presents Hamburg and overlay results. The acceptable asphalt content meeting both Hamburg-rutting and overlay-cracking requirements ranges from 6.4 to 7.1 percent. Beyond a 7.1 percent asphalt binder, the mixture will have a rutting problem, so the initial selected OAC was 6.8 percent.

Table 5. Summary of the Hamburg and Overlay Test Results.

Trial Asphalt Content	Hamburg Test		Overlay Test	
	Rutting Depth (mm)	Pass/Fail	No. of Cycles[1]	Pass/Fail
6.4%	5.2@15000	Pass	>750	Pass
6.8%	6.4@15000	Pass	>750	Pass
7.2%	12.7@15000	Fail	>750	Pass

[1]average of three samples testing

Based on these findings a modification should be considered to the current specification which specifies a minimum AC for CAMs of 7 percent. This value is appropriate for mixes designed with PG 76-22 binders. It may not be appropriate for mixes with lower PG grades, so consideration should be given to the following recommendations.

Table 6. Recommended Minimum Asphalt Contents.

Binder Grade	Minimum OAC
PG 64-XX	6.0 %
PG 70-XX	6.4 %
PG 76-XX	6.8 %

CONSTRUCTION ISSUES

No major construction problems have been reported with the CAMs manufactured and placed to date. The material is placed with a conventional asphalt paver. The new statewide specification has a comprehensive set of construction requirements for this mix. However, because of the thickness of the mat, particular attention should be placed to the temperature of the mat and the need for adequate rolling. Table 7 was taken from the new specification.

The use of infra-red techniques to check thermal uniformity should be encouraged. It is also critical for the rollers to be “bumping the paver.” One project did run into compaction problems where the initial steel wheel breakdown roller had problems. The mat was placed at the correct temperature, but compaction was delayed because of the roller problems and the mat had to be replaced.

The number and type of rollers are the choice of the contractor. The initial recommendation is that no vibratory rollers or pneumatic tired rollers be permitted. Compaction can normally be achieved using a static steel wheel roller. However, based on experience with the mix and the prevailing weather conditions, these recommendations can be changed in order to achieve the required in-place densities (2 to 6 percent).

Table 7. Minimum Pavement Surface Temperatures.

	Minimum Pavement Surface Temperatures in Degrees Fahrenheit	
High Temperature Binder Grade	Subsurface Layers or Night Paving Operations	Surface Layers Placed in Daylight Operations
PG 64	45	50
PG 70	55[1]	60[1]
PG 76	60[1]	60[1]

[1]Contractors may pave at temperatures 10°F lower than the values shown in Table 7 when utilizing a paving process or equipment that eliminates thermal segregation. In such cases, the contractor must use either an infrared bar attached to the paver, a hand-held thermal camera, or a hand-held infrared thermometer operated in accordance with Tex-244-F to demonstrate to the satisfaction of the engineer that the uncompacted mat has no more than 10°F of thermal segregation.