Effects of Laboratory Specimen Preparation on Aggregate-Asphalt Structure, Air-Void Content Measurement, and Repetitive Simple Shear Test Results

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Effects of laboratory compaction devices (rolling wheel, gyratory, and kneading) on asphalt aggregate structure is investigated using image analysis of plane sections cut from specimens. Also investigated are the effects of specimen surface condition (both as-compacted and cut and cored) on air-void structure, air-void content measurement, and repetitive simple shear test-constant height (RSST-CH) results. Image analysis indicates that gyratory compaction produces less aggregate orientation than rolling wheel compaction, and little or no orientation in aggregates that do not have a flaky shape. Image analysis also reveals that the outer periphery of as-compacted specimens has a different air-void and aggregate structure than that found in the specimen interior. Other results from air-void content measurements of gyratory and rolling wheel specimens at different stages of cutting and coring showed that there is little air-void content gradient in specimens that have been cored and cut from larger compacted masses. In addition, it was learned that RSST-CH results for as-compacted and cut and cored specimens cannot be compared because of problems with air-void content measurement and cut and uncut aggregates' different responses to shear stress at the specimen surface.

The main objective of asphalt-aggregate mix laboratory specimen preparation is to duplicate, as closely as possible, compacted mix in the field. Earlier research (*1,2*) indicates that gyratory, rolling wheel, and kneading compaction produce specimens with significantly different permanent deformation responses to repeated shear loading, which indicates that each compaction method causes a particular type of aggregate structure and binder-aggregate film. It also has been shown that fatigue behavior of a compacted mix is influenced by the mixing and compaction viscosities of the binder (*2*).

Air-void content is one of the most important variables affecting the permanent deformation and fatigue performance of a compacted mix (*1–3*). One of the properties desired in laboratory-prepared specimens is a homogenous air-void and aggregate structure. It is therefore important that air-void content be measurable in an accurate and repeatable manner.

The purpose of this study was to investigate the following aspects of laboratory specimen preparation:

1. Effects of laboratory compaction method and binder viscosity at compaction on aggregate orientation, air-void size, air-void shape, and air-void distribution within the specimen;
2. Extent to which compaction mold surfaces change the aggregate structure at the interface between specimen and mold;
3. Differences in measured air-void content between specimens with as-molded surfaces and specimens with all cut surfaces; and
4. Effects of using specimens with all cut surfaces, instead of specimens with as-molded surfaces, on repeated simple shear test-constant height (RSST-CH) and permanent deformation.

MATERIALS AND SPECIMEN PREPARATION

Materials and methods of specimen preparation used for various experiments related to this study are listed below. The Strategic Highway Research Program (SHRP) code is indicated also, as applicable.

Binders:

- Boscan AC-30 (SHRP code AAK-1);
- California Valley AR-4000 (SHRP code AAG-1); and
- Rubberized asphalt or California Coastal asphalt (SHRP code AAD-1) and crumb rubber from vehicle tires.

Aggregates:

- Pleasanton gravel (SHRP code RH), semi-rounded, partially crushed;
- Watsonville granite (SHRP code RB), semi-angular, completely crushed;
- Maryland limestone (SHRP code RD), completely crushed, very flaky; and
- Texas chert (SHRP code RL), rounded, partly crushed.

Gradations:

- Low fines content gradation (2.5 percent fines), and
- Normal fines content gradation (5.5 percent fines), both within ASTM D 3515 specifications and Caltrans standard specifications.

Compaction Method:

- Texas gyratory, 5 degree angle of gyration, 17.5-cm (7-in.) diameter mold;

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- University of California at Berkeley (UCB) rolling wheel; and
- California kneading, 10- and 18.75-cm (4- and 7.5-in.) diameter molds.

Mixing Viscosities:

- 1.7 (optimal) and 6 Poise (high) for conventional binders (virgin asphalt), and
- 177°C (350°F) (optimal) and 149°C (300°F) (high viscosity) mix temperatures for rubberized asphalt binder.

Compaction Viscosities:

- 1.7 (low), 6 (optimal), and 20 Poise (high) for conventional binders (virgin asphalt); and
- 149°C (300°F) (optimal) and 135°C (275°F) (high viscosity) compaction temperatures for rubberized asphalt binder.

EXAMINATION OF AGGREGATE AND AIR-VOID STRUCTURE

The investigation was performed by the Danish National Roads Laboratory (DNRL), using image analysis of plane sections of specimens prepared at UCB using gyratory and rolling wheel compaction. DNRL takes vertical and horizontal plane sections, impregnates them with epoxy, to fill all air voids, applies ultra-violet light to make the epoxy stand out from the asphalt-concrete, and then uses a computer image-scanning and analysis system to measure the percentage of the scanned section that is air voids. In addition to revealing air-void content, such images of the plane sections also allow qualitative examination of the degree of aggregate orientation within a specimen (*4*).

A set of 36 specimens was prepared at UCB and sent to DNRL as part of this project. Specimens were prepared following a balanced full-factorial design with no replicates, using Pleasanton gravel, Watsonville granite, and Maryland limestone aggregates; gyratory and rolling wheel compaction; three compaction temperatures (low, optimum, and high viscosities); and two air-void contents (approximately 4 and 8 percent). DNRL evaluated the extent of aggregate orientation, average air-void section size, and air-void structure homogeneity (*5*).

Aggregate Orientation

The following conclusions were drawn from the investigation regarding aggregate orientation:

- Pronounced orientation of the aggregate was found in mixes containing Maryland aggregate that had been compacted with a rolling wheel. Air voids were oriented and flattened for the Maryland limestone mixes under rolling wheel compaction.
- Less aggregate orientation was observed for the Pleasanton gravel and Watsonville granite mixes compacted with the rolling wheel than was observed for the Maryland limestone mixes.
- Among the mixes compacted using gyratory compaction, only the flaky Maryland limestone mixes showed signs of aggregate orientation. The Maryland limestone mixes compacted using the gyratory compactor showed less orientation than the same mixes compacted using the rolling wheel compactor.

DNRL's analysis confirms the hypothesis that a greater degree of aggregate orientation results from rolling wheel compaction, as compared with that produced by the Texas gyratory compactor. The minimal aggregate orientation observed in the very flaky and enlongated Maryland limestone mixes compacted using the gyratory compactor may have been caused as much by rodding when being placed in the mold, as by the gyratory action that followed. Reducing the angle of inclination used for gyration, as is done by some machines, may result in a compaction method closer to static compaction (although the specimen is spinning), considering that the side-to-side motion caused by the inclination angle is responsible for the shear forces imparted to the mix.

These findings support the hypothesis that Texas gyratory specimens' lower resistance to permanent deformation under repetitive shear loads (*1*) is at least partly related to the lack of a strong, oriented aggregate structure. It is not known how much the static leveling load placed on gyratory specimens after gyration affects aggregate-to-aggregate contact and, therefore, permanent shear deformation resistance.

The rolling wheel specimens' greater resistance is a result of aggregate orientation and interparticle contact caused by the forces induced by the rolling alone because, unlike gyratory and kneading methods, rolling wheel compaction does not include any static leveling load that might increase particle-to-particle contact by crushing aggregates together.

Aggregate orientation and aggregate-to-aggregate contact caused by kneading action are the primary reasons California kneading specimens have greater resistance (*1*), not the leveling load.

Air-Void Structure Homogeneity and Air-Void Section Size

DNRL evaluated the homogeneity of the aggregate structures both among as-compacted gyratory specimens and cut and cored rolling wheel specimens.

Homogeneity of air voids in vertical and horizontal directions was evaluated on the basis of image analysis and examination of the plane sections under ultraviolet light. Aggregate orientation and segregation phenomena, as well as the influence of mold walls on the aggregate structure, (as-compacted gyratory specimens only), were evaluated and described for each specimen.

Average air-void section size within specimens differed for the three aggregates, irrespective of their air-void content, compaction temperature, or method of compaction.

Aggregate	*Gyratory*	*Rolling Wheel*
Maryland	0.32–0.62 mm^2 (496–961 × 10^{-6} in.^{2})	0.24–0.97 mm^2 (372–1504 × 10^{-6} in.^{2})
Pleasanton	0.14–0.42(217–651)	0.11–0.38 (171–589)
Watsonville	0.08–0.23 (124–357)	0.04–0.25 (62–388)

The more flaky and difficult to compact Maryland limestone specimens had the largest air-voids. Larger air-void sizes also were found in most specimens with higher air-void contents and with increasing compaction temperatures. It is obvious that less compaction would result in larger air-voids as well as higher air-void contents, because the aggregates and binder are not subjected to much orientation and particle arrangement.

Greater homogeneity of air voids was found in specimens with higher air-void contents, indicating that applying compaction energy results in some portions of the specimen having more air voids than others. In the as-compacted gyratory specimens larger air-voids were found along the mold surface, both at the top and bottom, and at the sides. The effect was found to be greater at the top and bottom of the specimens than around the horizontal perimeter. The outer 10 mm to 20 mm (0.4 in. to 0.8 in.) were affected by the mold surface at the top and bottom of the specimens, and the outer 2 mm to 5 mm (0.1 in. to 0.2 in.) were affected around the circumference of the as-compacted gyratory specimens.

Further evidence of the effects of the mold wall on the aggregate at the circumference of a 15-cm (6-in.) diameter Texas gyratory specimen with as-compacted surfaces can be seen in Figure 1. The low air-void content specimen accidently was placed in axial tension while at 60°C (140°F), which separated it into two pieces. The aggregate at the periphery is crushed, and the interior of the specimen broke at the asphalt interface, indicating that an annulus of broken aggregate, or aggregate with no asphalt film between them, exists near the mold wall of at least some as-compacted gyratory specimens. The crushing or grinding together probably is caused by the specimens' inability to become oriented by the gyratory compactor's low shear stresses while under axial compressive stress.

The rolling wheel specimens, which were cored and cut from a larger compacted mass, did not show the effect of mold surfaces on air-void distribution.

Segregation occurs much more frequently in gyratory specimens than in rolling wheel specimens. The effect usually occurs in discrete areas and less frequently in specimens compacted at higher temperatures.

FIGURE 1 Gyratory specimen broken by axial tension, showing aggregates crushed during compaction around mold wall.

EFFECTS OF COMPACTION METHOD AND CUT AND UNCUT SURFACES ON AIR-VOID CONTENT MEASUREMENT

The following questions exist regarding the testing of specimens with as-compacted surfaces versus specimens with cut or cored surfaces:

- What is the relative ability to accurately and repeatably measure air-void content?
- What is the presence of air-void content gradients?
- Is aggregate structure the same in the interior and near the mold wall for specimens with as-compacted surfaces? and
- What are the interactions of two air-void content measurement methods with cut and uncut aggregates?

The difficulties of measuring air voids using parafilm, a waxy elastic paper (*6,7*), and other methods in specimens with uncut surfaces have been documented elsewhere (*7*). Most of these problems have to do with bridging the parafilm or membrane over gaps in the uncut surface, or determining which portions of a rough uncut surface are air voids and which are gaps in the specimen surface caused by rough aggregates.

In addition, it is often difficult to separate the effects of a measurement technique from the additional problem of air-void content gradients between different areas of a compacted specimen. Asphalt-aggregate mixes compacted in the field usually have increasing air-void contents from the top of the lift to the bottom. The reason for air-void gradients can be easily explained by the distribution of forces under a field compaction wheel, which decrease with depth. Laboratory-compacted specimens also often have air-void content gradients, which can be explained primarily by the distribution of stresses during compaction and the effects of the mold wall on aggregate structure.

Rolling wheel specimens would be expected to have increasing air-void contents from the top to the bottom of the lift, as do field-compacted specimens. Kneading compaction would be expected to have a similar gradient, possibly more pronounced than that of the rolling wheel because of the large localized shear force placed on the aggregates near the surface. The presence of cracked aggregates near the surface of kneading specimens, caused by high shear stresses directly under and at the edges of the kneading foot, have been noted previously (*4*). Air-void contents are expected to be fairly homogenous in the horizontal plane for rolling wheel and kneading specimens, except near the mold walls, assuming uniform distribution of passes or tamps over the entire specimen. The aggregate structure and air-void content near the mold wall are expected to be different than that of the interior because aggregate in those areas would become oriented parallel to the wall.

Gyratory specimens are subjected to a high axial compressive stress, a side-to-side shear stress, and a torsional shear stress. The combined effects of these stresses are more difficult to visualize than are the effects of stresses on the rolling wheel and kneading specimens, and they would depend on the relative magnitudes. During kneading and rolling wheel compaction, the material is able to move out from under the shearing force of the compactor, whereas in the gyratory compactor complete confinement of the material prevents this from occurring, and aggregate is primarily forced down.

Under high axial compressive stresses and many gyrations, it is expected that the interior of the specimen becomes better compacted. The torsional shear stress, and the inability of aggregate to become oriented, is thought to reduce compaction near the vertical walls of the specimen. In lightly compacted specimens, torsional shear stress probably produces most of the compaction. It is likely to produce a lower air-void content around the perimeter than in the interior of the specimen. Our observations confirm those of other researchers: large aggregates near the surface have a tendency to "pop out," because tension is introduced by the mold wall.

As is the case with the other compaction methods, aggregate near the mold surface has a tendency to become aligned with the mold wall. The tendency was observed by DNRL upon examining a limited number of kneading and gyratory specimens (*4*).

Air-Void Content Measurement Problems

In order to investigate differences in air-void content measurements for as-compacted and cut surfaces and the possible existence of air-void content gradients, a variety of rolling wheel and gyratory specimens were subjected to air-void content measurements at various stages of coring and cutting.

Gyratory Specimens

Gyratory specimens compacted to a 17.5-cm (7-in.) diameter and 10-cm (4-in.) height, and measured dry (never exposed to water from coring or cutting), had similar air-void contents after first being submerged in water and then brought to the surface dry condition, which involves removal of all surface water with a 207 kPa (30 psi) air nozzle (*7*), as indicated in Table 1. The large mold and ram are standard features with the large Texas gyratory compactor used by the Texas Department of Transportation. After specimens were cored to a 15-cm (6-in.) diameter, and their top and bottom were trimmed 5 mm to arrive at the cored and cut surface condition, they generally had an air-void content 1 to 2 percent lower than they did before. Measured using parafilm, this drop in air-void content can be attributed partly to the change in surface types, which reduced bridging of the parafilm over surface irregularities, and partly to the removal of the outside 1-in. of the specimen. It is in the outer portion of the specimen removed by coring that the aggregate particles are generally vertically oriented along the mold wall, instead of horizontally oriented as they are in the interior of the specimen.

After cutting the remaining top and bottom portions (Face A and Face B) to arrive at a 5-cm (2-in.) height, no similar drop in measured air-void content occurred when measured with parafilm, as data in Table 1 indicate. Note that the measurements without-parafilm (unsealed condition) remain essentially the same. Upper and lower faces of the specimens have higher air-void contents than the interiors, indicating that they are less compacted. After coring to a 10-cm (4-in.) diameter, the measured air-void contents generally remained the same. The compacted specimen with a 15-cm (6-in.) diameter and 22.5-cm (9-in.) height showed an increase in measured air-voids when cut to a 5-cm (2-in.) height [while maintaining an uncut 15-cm (6-in.) diameter], with the upper and lower surfaces having lower air-void contents than the interior. When cored to 10 cm (4 in.), the specimen had a lower air-void content in its interior.

Statistical *t*-tests were made of the null hypothesis that the sample means are the same for a 5 percent single-tail level of significance for several paired data samples in Table 1. The null hypothesis was acceptable for the dry-with parafilm (dwp, Column A), and wet-with parafilm (wwp, Column B), as-compacted measurements. The null hypothesis was rejected for the wet-with parafilm as-compacted specimens and for the wet-with parafilm cored and trimmed measurements (Columns B and C). It was also rejected for the wet-with parafilm as-compacted and wet-with parafilm cored and cut measurements (Columns B and D).

TABLE 1 Comparison of Air-Void Content Measurements for Gyratory Specimens at Different Stages of Coring and Cutting

Comparison of Air-Void Content Measurements
Different Stages of Coring and Cutting

		as compacted (uncored and uncut)				cored to 6 in. and trimmed		cored to 6 in. and cut to 2 in.						cored to 4 in.	
								center		face a		face b			
Specimen	Agg	dwp	dnp	wwp	wnp	wwp	wnp	wwp	wnp	wwp	wnp	wwp	wnp	wwp	wnp
Texas Gyratory Compactor															
Stages of Cutting and Coring (compacted as 7 x 4 inches)															
t-Test Column:		A		B		C		D							
FMG20-2	M	7.0	4.7	6.9	4.8	5.5	4.8	5.4	4.3	7.4	5.1	8.3	6.0	6.0	4.7
FMG20-1	M	7.1	5.0	7.1	5.1	6.4	4.9	5.7	4.4	9.3	5.6	8.0	5.3	6.4	4.7
FMG10	M	7.3	5.1	6.5	5.4	6.1	5.1	5.5	4.6	11.8	6.2	8.7	5.4	5.8	4.5
FMG00-1	M	7.8	5.0	8.0	5.2	6.0	5.1	6.0	4.4	7.7	5.9	10.6	6.4	5.5	4.4
FPG11-1	P	2.2	1.1	2.3	1.1	0.9	0.5	1.4	0.7	2.4	0.7	2.1	0.7	2.3	1.2
FPG00	P	4.9	2.9	5.0	2.9	3.6	2.5	3.2	2.4	5.2	3.0	5.2	3.1	3.6	2.9
V0W0-G1	W	5.7	3.6	5.2	3.6	4.3	3.3	4.8	3.9	5.6	3.7	4.7	3.1	5.3	4.5
V0W1-G1	W	6.9	4.2	7.1	4.6			5.3	4.2	7.8	3.5		4.6	6.6	4.6
average		*5.5*	*3.4*	*5.5*	*3.5*	*3.7*	*2.9*	*4.1*	*3.1*	*5.7*	*3.4*	*5.6*	*3.6*	*4.7*	*3.5*
Stages of Cutting and Coring (compacted 6 x 9 inches, cut 6 x 2 inches, uncored perimeter)															
VWOSU-5C	W*	3.8	2.3	3.8	2.5	na	na	5.1	3.5	3.2	1.6	2.2	1.5	4.2	2.6

W* is Watsonville granite with a 1/2 in. top size gradation similiar to high fines gradation

Key: M - Maryland limestone P - Pleasanton gravel W - Watsonville granite
dwp - dry with parafilm; dnp - dry no parafilm; wwp - wet with parafilm; wnp - wet no parafilm

The sum of the results in Table 1 indicates that air-void contents measured on as-compacted gyratory specimens cannot be compared with those with cut and cored surfaces because of the effects of the uncut aggregates on parafilm measurements, and the different aggregate structure present near the mold wall. The results indicate that there is little horizontal air-void content gradient in the specimens once they have had the outer as-compacted ring of material removed. There also appears to be little vertical air-void content gradient.

A second set of 27 gyratory specimens, compacted as 15-cm (6-in.) diameter by 15-cm height cylinders with generally high air-void contents, was also evaluated for air-void gradients (*8*). This set included both modified and conventional binders, with Watsonville granite and Texas chert aggregates. Air-void contents were measured by SHRP A-004 (without parafilm), UCB (without parafilm), and UCB (with parafilm); and average air-void contents were 6.8 percent, 6.7 percent, and 12.1 percent, respectively. It was observed that when air-void contents of completely as-compacted specimens were measured without parafilm they were substantially lower than when using parafilm.

After cutting the top and bottom but not coring to create three specimens, 15 cm (6 in.) in diameter and 5 cm (2 in.) high, air-void contents were measured by UCB (without parafilm) and UCB (with parafilm); and average air-void contents were 8.9 percent and 11.9 percent, respectively. It was observed that the parafilm air-void contents remain consistently high and the without-parafilm air-void contents increase compared with the air-void contents of the as-compacted original specimens.

This indicates, first of all, that when parafilm is not used many air-voids are connected to the surface, allowing water to enter the specimen and resulting in unrealistically low air-void content measurements. The fact that the high parafilm measurements are similar both before and after cutting indicates that the bridging of the parafilm is not responsible. The fact that the without-parafilm air-void contents are also higher after cutting indicates that in lightly compacted specimens the top and bottom have lower air-void contents than does their center. This confirms other data presented here and elsewhere (*7*) indicating that heavily compacted gyratory specimens have higher air-void contents at the periphery than within the interior, whereas the opposite holds true for lightly compacted specimens.

Rolling Wheel Specimens

A similar study of rolling wheel specimens is summarized in Table 2. All rolling wheel specimens were cut and cored from a large compacted mass before use. When cut in half horizontally, the 10-cm in diameter by 5-cm high (4 by 2 in.) cylindrical shear specimens showed little difference in air-void content between their upper and lower portions. Similarly, fatigue beams, 5 cm high by 7.5 cm wide by 37.5 cm long (2 by 2.5 by 15 in.), showed little or no difference in air-void content between upper and lower halves. Cylindrical shear specimens (5-cm tall) also showed little or no change in air-void content from the 15-cm diameter specimens and the 10-cm diameter specimens cored out of them.

Statistical *t*-tests were made of the null hypothesis that the sample means are the same for a 5 percent single-tail level of significance for several paired data samples in Table 2. The null hypothesis was accepted for the Face A and Face B measurements (Columns A and B), as well as for the measurements of specimens cored to 15 cm (6 in.) and 10 cm (4 in.) (Columns C and D).

The results indicate that there is little or no vertical or horizontal air-void content gradient in UCB rolling wheel specimens compacted in 7.5 cm (3 in.) lifts.

Comparison of Measured Air-Void Contents for Different Specimens

Air-void content data for as-compacted and cut and cored specimens measured with and without parafilm (unsealed) are plotted in Figures 2 and 3. The permanent deformation cylinder specimens were prepared for a balanced full-factorial experiment design with the following variables and factor levels: Boscan, California Valley, and rubberized asphalt binders; Pleasanton gravel and Watsonville granite aggregates; low and normal fines contents; 4 and 8 percent target air-void contents (measured with parafilm); high and optimal mixing viscosities; and high and optimal compaction viscosities.

Differences in air-void content between the as-compacted specimens and the same specimens cut and cored to their final dimensions as measured using parafilm exist for cylindrical shapes compacted using gyratory and kneading compaction, as shown in Figure 2. The as-compacted specimen usually has a higher air-void content because of the different aggregate structure near the surface, and bridging of the parafilm over the large aggregates and other irregularities at the surface.

Differences in measured air-void content are not only found when parafilm is used. Specimens measured without-parafilm (unsealed condition) in both the as-compacted and cut and cored condition also showed marked differences, as are represented in Figure 3 for cylindrical shear specimens compacted using gyratory and kneading compaction. Well compacted specimens have lower measured air-void contents when cut and cored, which can probably be attributed to the asphalt film that often forms at the surface of these specimens during compaction. Asphalt is forced out of the aggregate matrix by compaction and bleeds to the surfaces. For most specimens with asphalt contents designed by the Hveem Method (as were those described here), there is not much flushed asphalt; however, flushed asphalt is observable and probably plays a role in sealing the outside of the as-compacted specimen to water. For well compacted specimens, the periphery probably has a higher air-void content; aggregate must become oriented vertically to fit the mold wall at the same time it is being pushed to orient horizontally by the shear forces of compaction. The result is a specimen with more air-voids near the surface, partially sealed with asphalt to prevent water from entering. In general, there is a higher measured air-void content for as-compacted specimens.

Poorly compacted specimens do not flush much asphalt to the surface, and differences in aggregate structure between the interior and periphery are probably not as pronounced. Therefore, there is less difference in measured air-void content between as-compacted and cut and cored specimens, as indicated in Figure 3. If a specimen is not sealed with parafilm, higher air-void contents cannot be measured because water is able to pass into the surface-connected pores.

EFFECTS OF COMPACTION AND AS-MOLDED SURFACES ON RSST-CH RESULTS

The possibility of cut and uncut aggregate at a specimen's surface having different mechanical responses to shear loading has been

TABLE 2 Comparison of Air-Void Content Measurements for Rolling Wheel Specimens at Different Stages of Coring and Cutting

Comparison of Air-Void Content Measurements
Different Stages of Coring and Cutting

Rolling Wheel Specimens

Specimen	agg	Whole Specimen AV wwp	Whole Specimen AV wnp	Face A AV wwp	Face A AV wnp	Face B AV wwp	Face B AV wnp
t-Test Column:				A		B	
cut to 4 x 2 in.							
AM0-3-8	M	3.1	1.7	2.6	0.8	2.7	1.8
B1W0-N2-7C	W	4.2	3.0	5.2	2.6	5.6	3.6
B1W0-N2-8T	W	4.6	3.5	5.0	3.4	4.7	3.7
V1T0-N2-7C	T	4.7	3.5	5.1	3.5	4.9	3.4
B1T1-N2-7T	T	7.9	4.8	7.9	5.3	10.1	7.0
V0T1-N1-6T	T	9.9	7.8	11.8	7.4	14.1	9.0
V0W1-N3-8C	W	10.2	8.8	9.8	6.0	8.3	4.6
V0T1-N1-7C	T	11.6	8.3	12.9	7.4	15.0	9.2
VM1-1-6	M	12.6	8.1	13.7	6.9	15.4	7.5
V0W1-N3-9C	W	13.2	6.9	15.2	7.2	13.2	8.6
average		*8.2*	*5.6*	*8.9*	*5.0*	*9.4*	*5.8*

Specimen	agg	Whole Specimen AV wwp	Whole Specimen AV wnp	Top AV wwp	Top AV wnp	Bottom AV wwp	Bottom AV wnp
cut to 2 x 2.5 x 15 in. fatigue beams							
NA2-A5	N	3.4	1.2	3.1	1.4	2.5	0.7
NA1-A3	N	4.8	3.8	4.9	4.0	5.5	3.7
NA1-A4	N	6.1	4.0	6.4	4.9	5.4	3.9
average		*4.8*	*3.0*	*4.8*	*3.5*	*4.5*	*2.8*

Specimen	agg	cut to 6 x 2 in. AV wwp	cut to 6 x 2 in. AV wnp	Cored to 4 x 2 in. AV wwp	Cored to 4 x 2 in. AV wnp
t-Test Column:		C		D	
VP0-C7A	P	1.2	0.6	1.8	1.0
VP0-2-1	P	2.7	1.9	3.0	1.7
VP1-2-1	P	4.4	3.5	4.9	3.6
V0W0-N35-C1	W	4.8	4.0	4.4	3.1
FWR21-3	W	5.1	4.0	4.8	3.9
FWR20-3	W	5.1	4.1	5.8	4.5
VMR20-A2	M	5.3	4.2	6.3	5.0
VMR01-3	M	7.1	5.9	7.2	6.1
V0W1-N5-A	W	9.7	6.6	10.3	7.4
VMR21-A2	M	9.9	7.9	9.9	8.4
VMR21-A1	M	10.1	8.6	10.5	9.0
FPR21-B3	P	12.6	9.6	11.9	9.9
average		*6.5*	*5.1*	*6.7*	*5.3*

Key: M - Maryland limestone N - Nantes limestone P - Pleasanton gravel
T - Texas Gulf Coast Chert W - Watsonville granite

raised also (*7*). Actual effects presumably depend on the aggregate shapes and the relationship of the maximum aggregate size to the specimen size.

To investigate the effects of cut versus as-compacted surfaces on constant height shear testing results, a set of kneading compaction specimens was prepared. The specimens were made using Valley AR-4000 asphalt and Watsonville granite and Pleasanton gravel aggregates. Half were compacted to a shape 10 cm in diameter and 5 cm tall (4 by 2 in.) whereas the other half were compacted to a shape 18.75 cm in diameter and 7.5 cm tall (7.5 by 3 in.) and then cored and cut to the same dimensions as the as-compacted specimens. Specimens were tested at 60°C (140°F) using the repetitive simple shear test-constant height (RSST-CH) (*3,9*) at a stress of 41.4 kPa (6.0 psi).

Permanent deformation results for the cut and as-compacted Pleasanton gravel specimens are plotted in Figure 4. Results for the cut and as-compacted Watsonville granite specimens are plotted in Figure 5. The graphs indicate that the cut specimens following the expected trend of lower air-void content (measured using parafilm) specimens generally perform better than higher air-void content specimens. The peak permanent deformation resistance usually occurs at an air-void content of approximately 3 percent (*9*). The ranking of the as-compacted specimens by number of repetitions to 2 percent permanent shear strain follows the order of air-void contents.

Permanent deformation results for the as-compacted (uncut) specimens, and the rankings of the uncut specimens do not follow the order of air-void content quite as well as the cut specimens. The presence in some uncut specimens of large aggregates, near the in-

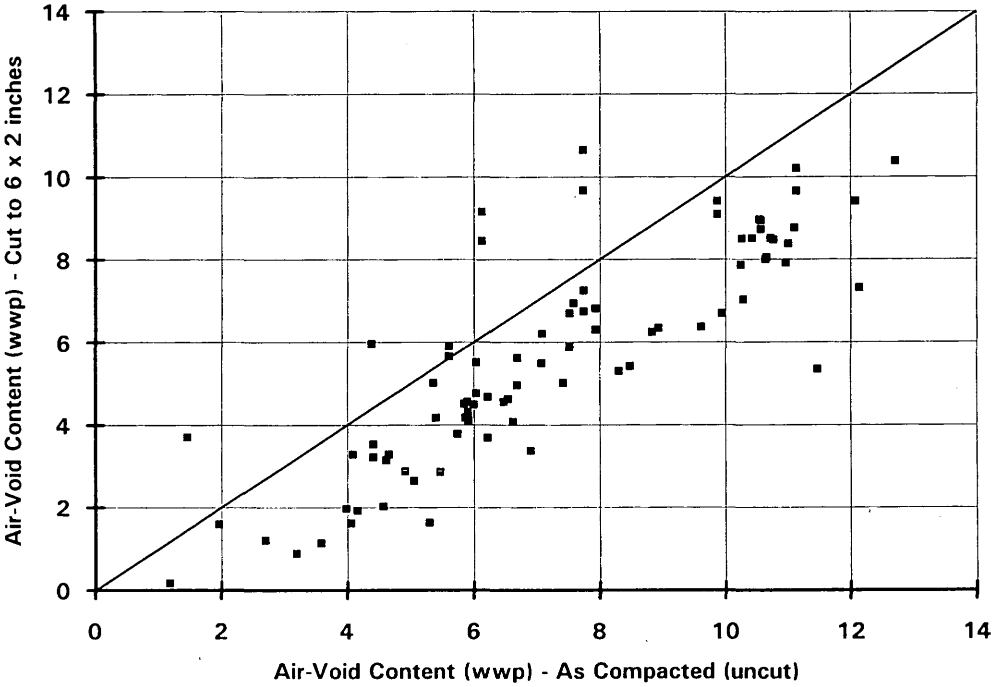

FIGURE 2 Comparison of parafilm air-void contents for permanent deformation specimens, as-compacted versus cut/cored.

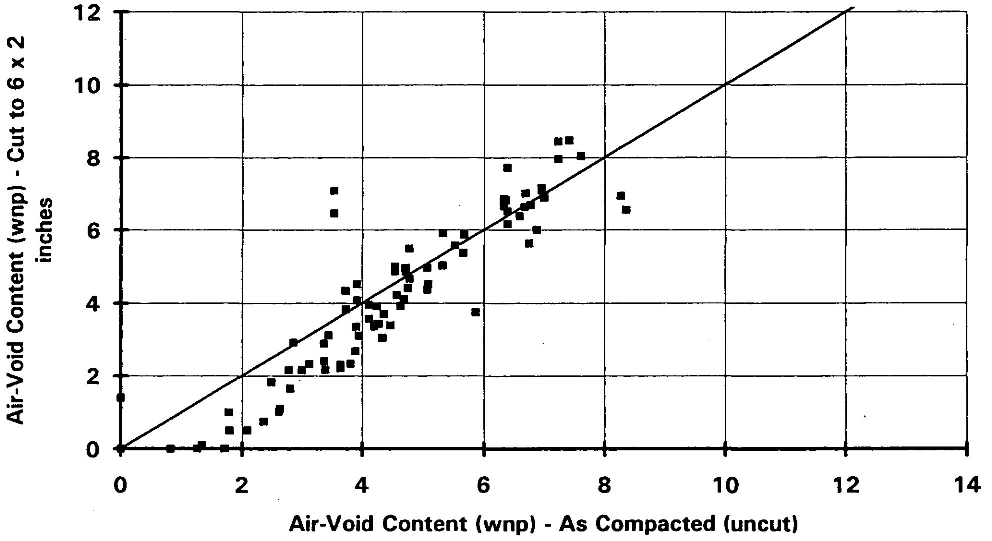

FIGURE 3 Comparison of unsealed (no parafilm) air-void contents for permanent deformation specimens, as-compacted versus cut/cored.

terface with the platens or near the mold wall, and not in others, may be partly responsible for the unexpected rankings of the uncut specimens. Segregation in some specimens may be responsible, as could the inability to precisely measure air-void contents in as-compacted specimens using parafilm.

At low air-void contents, as-compacted and cut and cored Pleasanton gravel specimens with similar air-void contents perform about the same. It can be seen in Table 3 and Figures 4 and 5 for these specimens, the two air-void content measurements show similar air-void contents with parafilm (wwp) and without parafilm (wnp), or unsealed. As air-void contents increase, the as-compacted specimens perform increasingly better compared with the cut and cored specimens of similar air-void content and measured with parafilm. However, when comparing the air-void contents measured without parafilm for these same specimens, the differences in performance are more reasonable.

Combined results from the air-void content measurement and RSST-CH results indicate that, in combination, problems with mea-

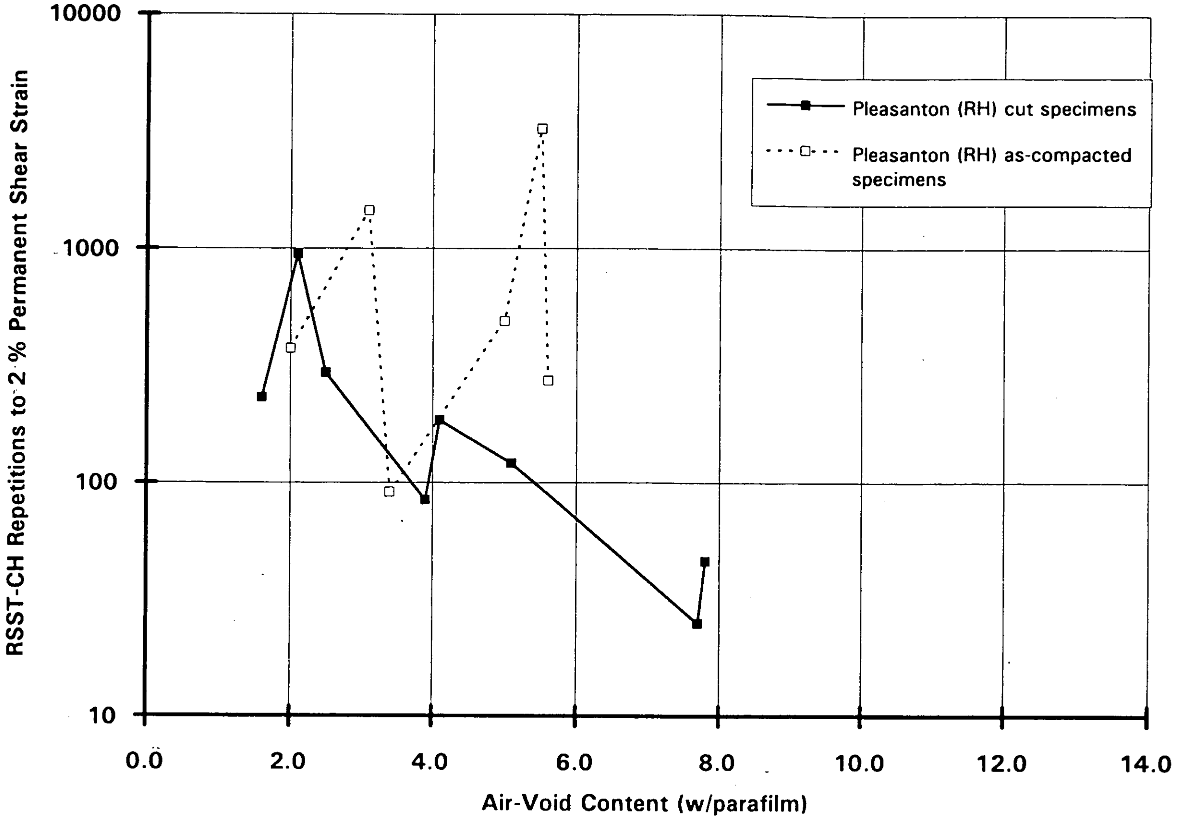

FIGURE 4 Plot of permanent deformation and air-void content for cut/cored and as-compacted Pleasanton gravel specimens.

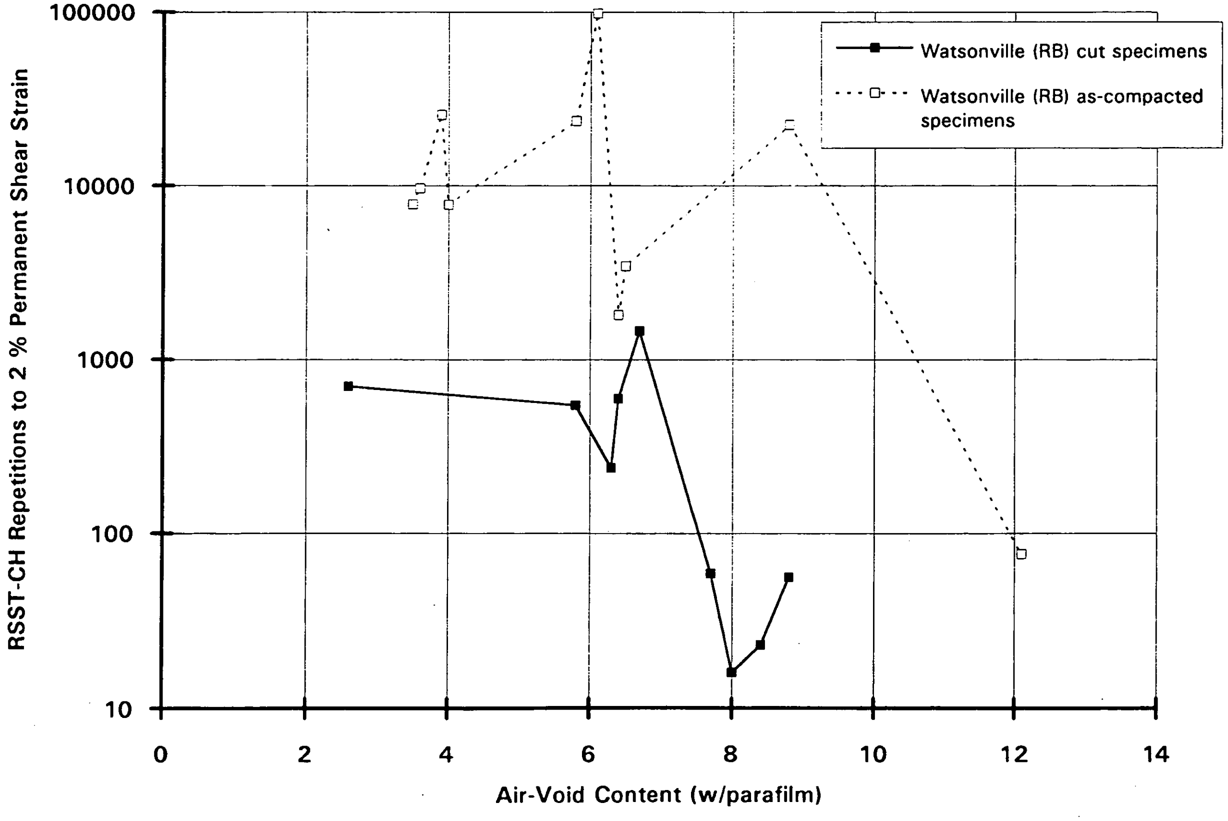

FIGURE 5 Plot of permanent deformation and air-void content for cut/cored and as-compacted Watsonville granite specimens.

TABLE 3 RSST-CH Results for As-Compacted and Cut and Cored Specimens

60 C (140 F)				RSST-CH
Aggregate	Air-Void Content with parafilm	Air-Void Content unsealed	Cut/ As-Compacted	Repetitions to 2 % shear strain
RH	1.6	1.2	Cut	232
RH	2.1	1.8	Cut	953
RH	2.5	2.2	Cut	295
RH	3.9	3.4	Cut	84
RH	4.1	2.5	Cut	185
RH	5.1	3.7	Cut	121
RH	7.7	6.9	Cut	25
RH	7.8	5.7	Cut	46
RH	2.0	1.1	As-Compacted	376
RH	3.1	1.6	As-Compacted	1449
RH	3.4	1.9	As-Compacted	91
RH	5.0	2.2	As-Compacted	490
RH	5.5	3.1	As-Compacted	3245
RH	5.6	2.9	As-Compacted	273
RB	2.6	1.7	Cut	701
RB	5.8	5.2	Cut	544
RB	6.3	5.6	Cut	238
RB	6.4	5.6	Cut	595
RB	6.7	5.9	Cut	1459
RB	7.7	6.1	Cut	59
RB	8.0	7.0	Cut	16
RB	8.4	7.4	Cut	23
RB	8.8	7.6	Cut	56
RB	3.5	1.8	As-Compacted	7782
RB	3.6	2.5	As-Compacted	9655
RB	3.9	2.4	As-Compacted	25506
RB	4.0	2.3	As-Compacted	7773
RB	5.8	3.4	As-Compacted	23526
RB	6.1	2.9	As-Compacted	98238
RB	6.4	3.9	As-Compacted	1798
RB	6.5	4.2	As-Compacted	3443
RB	8.8	4.6	As-Compacted	22416
RB	12.1	7.5	As-Compacted	76

suring air-void contents, and possible differences affected by cut or uncut aggregates at the interface between the platen and the specimen, make comparison of the performance of as-compacted and cut and cored specimens nearly impossible. Specimens cored from the field cannot be compared to laboratory-compacted specimens that either have not been cored and cut from a larger compacted mass or do not have all cut surfaces.

CONCLUSIONS

As-compacted Texas gyratory and kneading specimens appear to have different aggregate and air-void structures near the mold surface than in their interior. Texas gyratory specimens may have little air-void content gradient if the specimen is cored and cut from a larger compacted mass; note that removal of the outer inch is recommended by UCB for specimens with a 2.5-cm (1-in.) maximum aggregate size. The top and bottom 2.5 cm (1 in.) and outer 1.25 cm (0.5 in.) of gyratory specimens are recommended for cutting and coring, based on image analysis by the DNRL.

Rolling wheel specimens cut and cored from larger masses have little air-void content gradient, compacted in 7.5 cm (3 in.) lifts.

RSST-CH results for cut and cored and as-compacted specimens cannot be compared because of difficulty comparing air-void content measurements and the presence of a different air-void and aggregate structure at the outside edge of as-compacted specimens.

For the same reasons, RSST-CH results for laboratory-compacted specimens with as-compacted surfaces cannot be compared with those from field cores.

DNRL's image analysis showed that the rolling wheel compactor produced aggregate orientation in the mixes containing all three aggregates (completely crushed granite; partially crushed gravel; and completely crushed, flaky limestone). The most aggregate orientation was produced in the mixes containing the flaky limestone. Image analysis showed that the Texas gyratory compactor produced aggregate orientation only in the mixes with flaky aggregate and that even for the flaky aggregate it produced less aggregate orientation than did the rolling wheel compactor. Further, DNRL image analysis showed that average sizes of air-voids are dependent primarily on the aggregate used.

The influence of the mold walls on the exterior structure of gyratory compacted samples is seen as segregation of larger aggregate particles entrapping larger air-voids and the crushing of aggregates or removal of the asphalt between them. The segregation phenomenon is most pronounced at the top and bottom surfaces, typically extending 10 mm to 20 mm (0.4 in. to 0.8 in.) inward; it is less pronounced at the vertical mold walls, where the effect typically extends 2 mm to 5 mm (0.08 in. to 0.2 in.) inward. This phenomenon obviously influences the measurement of an air-void content, resulting in one that is too high and not representative of the mix. Crushing of aggregates, or lack of asphalt between aggregates caused by crushing, results in a difference in permanent deformation resistance properties between the interior and the annulus of the specimen.

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