

# Effects of Sample Preparation and Air-Void Measurement on Asphalt Concrete Properties

JOHN HARVEY, JORGE B. SOUSA, JOHN A. DEACON, AND  
CARL L. MONISMITH

A compaction study focusing on the extent to which laboratory compaction methods (gyratory, kneading, and rolling-wheel) affect fundamental mixture properties important to pavement performance has been carried out as part of a project by the Strategic Highway Research Program. The work has shown that besides compaction method, other aspects of specimen preparation significantly affect test results and their interpretation. Of particular importance were the method to measure air void content and the effect of surface condition (cut or as-molded) on both air void measurements and mechanical behavior. Air void content was significantly underestimated by standard procedures that leave the outer surface of the specimen unsealed during submersion. However, difficulties with the standard paraffin wax procedure, coupled with the need to compare dry specimens with partially saturated ones, led to the adoption of a new procedure. By using a surface-dry specimen (wetted and then surface dried) encased in parafilm (a stretchable, waterproof membrane), a consistent measurement of air void content was obtained. Further, it is evident that the surface of the specimen, cut or uncut, influences the measured air voids. Thus, air voids are not uniformly distributed within specimens, a factor that can significantly bias test results. The fact that surface type was found to influence the mechanics of mixture behavior under direct shear loading casts doubt on the accuracy of comparing tests results from field cores and laboratory-compacted specimens when the latter are tested in the as-molded or uncut condition. To obtain reliable and consistent results, it is recommended that laboratory testing be limited to specimens with cut surfaces and that air void measurements use the wet-with-parafilm technique.

The results of a compaction study carried out by the University of California at Berkeley as part of the Strategic Highway Research Program (SHRP) Project A-003A, Performance Related Testing and Measuring of Asphalt-Aggregate Interactions and Mixtures, demonstrate that asphalt-concrete performance in all types of laboratory testing is highly dependent on the air void content of the specimens (1,2). The direct effect of air voids on mixture performance is clearly shown by the shear creep response of kneading (Figure 1) and gyratory (Figure 2) specimens.

The laboratory work for this study revealed that standard methods of air void measurement present significant problems in comparison of specimens compacted by the various methods included in the study. Significant differences in measured

air void contents and in mechanical behavior were observed between uncut specimens (tested as compacted in the mold) and cut specimens (sawed or cored from a larger compacted mass).

Data presented here provide insight into these problems, and recommendations are made for resolving them. Although not included as part of the original study plan for the project, data were collected to examine the issues of air void measurement (Table 1) and effects of cut surfaces. Useful evidence was collected about relationships between measured air voids and specimen preparation method and about the effects of cut surfaces on measured air voids. Shear creep tests were also performed to examine the effects of cut surfaces on specimen performance under loading.

## SPECIMEN PREPARATION

Two aggregates with different characteristics were used in the study: Watsonville granite, a completely crushed, nonstripping aggregate with rough surface texture; and Texas Gulf Coast chert, an incompletely crushed, stripping aggregate with a smoother surface texture. The Watsonville granite is softer than the Texas chert and much easier to cut with a masonry saw. The chert is prone to chipping during cutting and coring. Two asphalts were used: Boscan AC-30 and California Valley AR4000.

Two levels of asphalt content were investigated. For each asphalt-aggregate mixture, the lower asphalt content was determined using a modification of standard Hveem procedures (ASTM D1560). The higher asphalt content was set at 0.6 or 0.7 percent more (by weight of aggregate) than was found using the Hveem procedures, which corresponds to approximately the optimum asphalt content found by the U.S. Army Corps of Engineers (Marshall) 75-blow procedure (ASTM D1559).

Three compaction methods were used in the study: Texas gyratory compaction (adapted from Texas Method Tex-206-F and ASTM D4013), kneading compaction (ASTM D1561), and rolling-wheel compaction (procedure not yet standardized). Specimen preparation details are included in a report by Sousa et al. (1).

Briquets (4 × 2.5 in.) prepared by gyratory or kneading compaction had compacted or as-molded surfaces that were not cut by coring or sawing. Cylinders (4 × 8 in.) prepared

J. Harvey, J. B. Sousa, and C. L. Monismith, Institute of Transportation Studies, University of California, Berkeley, Calif. 94720. J. A. Deacon, Kentucky Transportation Center, University of Kentucky, Lexington, Ky. 40506-0043.

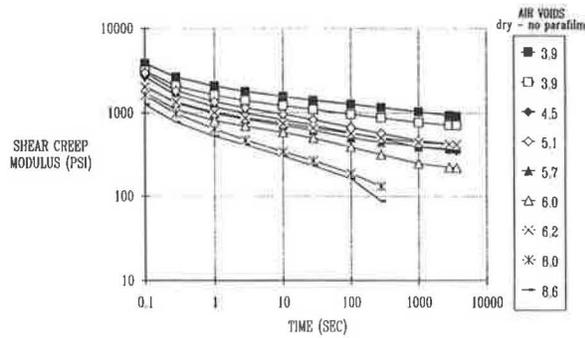


FIGURE 1 Effect of air-void content on shear creep modulus (kneading compaction).

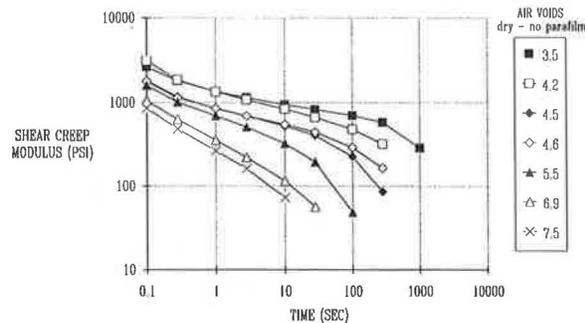


FIGURE 2 Effect of air-void content on shear creep modulus (gyratory compaction).

by kneading compaction had uncut surfaces at the sides and cut surfaces at the ends. Fatigue beams (3 × 3 × 15 in.) prepared by kneading compaction, cylinders prepared by gyratory compaction, and all specimens prepared by rolling-wheel compaction were cut or cored from larger compacted masses and had cut surfaces, that is, surfaces that resulted from removal of all material that touched the compaction mold.

## AIR VOID MEASUREMENT

### Objectives

The objectives of air void measurement procedures are summarized as follows:

1. To measure the degree of mixture compaction resulting from the application of mechanical energy to the mixture in order to expel air or reorient the aggregate into a denser arrangement;
2. To measure the voids in the aggregate matrix not filled with asphalt;
3. To be fast, simple, and repeatable, and to maintain the original specimen shape so that it can be used for testing; and
4. To allow meaningful comparisons among a variety of specimens with different degrees of compaction, asphalt contents, or fabrication techniques, including field coring.

TABLE 1 SAMPLE SIZE FOR STUDY OF AIR VOID MEASUREMENT

Compaction	Specimen Size (Inches) and Shape	Texas Chert (RL)		Watsonville Granite (RB)		Other
		Valley (AAG-1)	Boscan (AAK-1)	Valley (AAG-1)	Boscan (AAK-1)	
Gyratory	4 × 2.5 (Briquet)			29		
	4 × 8 (Cylinder)			12		
Kneading	4 × 2.5 (Briquet)	12	6	38	15	8
	4 × 8 (Cylinder)	2	9	15	5	
	3 × 3 × 15 (Uncut Beam)	27	7	20	17	
	3 × 3 × 15 (Cut Beam)	12	1	30	71	
	1.5 × 1.5 × 15 (Beam)	105	34	165	143	
Rolling Wheel	4 × 2.5 (Briquet)			11		
	4 × 8 (Cylinder)			18		
Total Number of Specimens 805						

### Methods

Bulk specific gravities for air void measurement of specimens prepared early in the compaction study (4- × 2.5-in. briquets using kneading and gyratory compaction) were calculated by weighing the specimens in air and in water, without the use of paraffin wax or other surface coating. The air void content was calculated using the following equation:

$$AV = \left(1 - \frac{G_b}{G_{mm}}\right) \times 100 \quad (1)$$

where

- AV = air void content in percent,
- $G_b$  = bulk specific gravity, and
- $G_{mm}$  = maximum specific gravity determined by the Rice method (ASTM D2041).

The standard method for sealing specimens using paraffin wax (ASTM D1188) was not used because testing after air void measurement requires complete removal of the paraffin wax, a difficult and time-consuming process. These specimens were neither cut nor cored and therefore contained no trapped water. This procedure was later referred to as dry-no-paraffin (dnp) (1).

Rolling-wheel specimens and 4- × 8-in. gyratory cylindrical specimens were cored or cut from larger compacted masses, using water cooling to prevent aging of the asphalt and damage to the specimens caused by frictional heat. This process leaves water in the specimen—in varying amounts depending in part on the internal air voids—which may require many

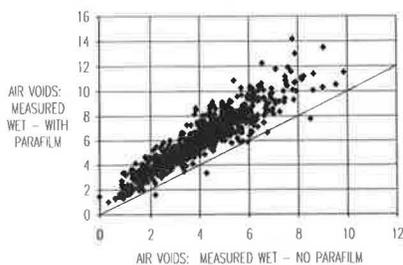
days to remove by drainage and evaporation. Because trapped water is included in the weight-in-air measurement used to calculate  $G_b$  in Equation 1, comparison of air void contents for these cut or cored specimens with those measured using the dry-no-parafilm method was questioned. The standard procedure for removal of water (ASTM D2726) requires heating at 110°C (230°F), a potentially destructive process rendering specimens unsuitable for use. This difficulty was surmounted by developing a method to rapidly determine air voids with prewetted specimens in a surface-dry condition. This procedure, referred to as wet-no-parafilm (wnp), uses a compressed air nozzle to remove water from the specimen surface until no moisture can be seen (1).

At the same time, it was found that permitting water to enter the specimen during submersed weighing resulted in underestimation of air voids, particularly for specimens with higher air void contents. At high air void contents—above approximately 8.5 percent by the dry-no-parafilm method—it was found that air void content as measured by the dry-no-parafilm or wet-no-parafilm methods was extremely insensitive to compactive effort, and visually obvious differences in void content were undetected by the air void measurements. Experimentation was then carried out with an elastic wax paper, parafilm, as a substitute for paraffin wax (3). Measurements of air voids, using the surface-dry condition and parafilm, were found to be sensitive to air void content, applicable to all types of compaction and specimen preparation methods, and convenient for later testing of the specimen. This procedure was referred to as wet-with-parafilm (wwp) (1). The equation used to calculate bulk specific gravity using this method is the same as in the standard paraffin wax procedure (ASTM D1188).

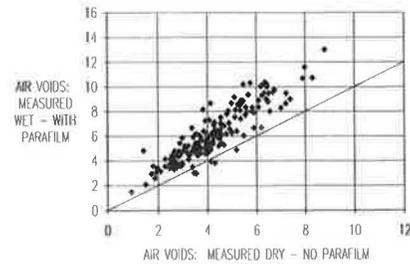
### Quantitative Differences Between Methods

Wet-with-parafilm measurements are compared to wet-no-parafilm measurements in Figure 3 and to dry-no-parafilm measurements in Figure 4. These results show a significant difference caused by the use of parafilm. As shown in Figure 5, dry measurements (dnp) are not significantly different from the surface-dry measurements (wnp). This indicates that the surface-dry condition results in little water remaining within the specimen. These results are summarized in Figure 6, which shows least square regression lines for each relation.

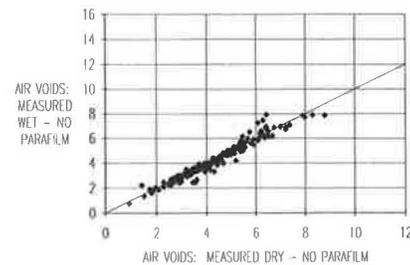
The effect of parafilm on cut and uncut specimens is similar but not identical, as demonstrated by regression lines for the



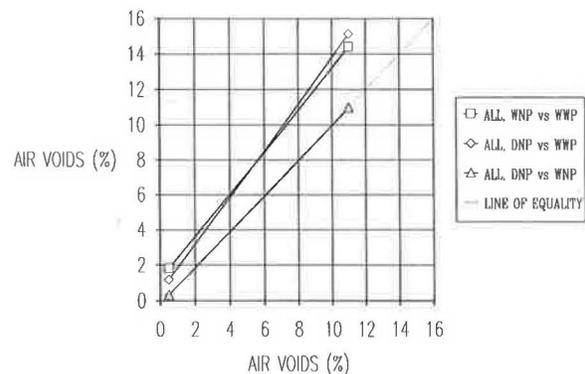
**FIGURE 3** Effect of parafilm on surface-dry measurements of air voids (all specimens).



**FIGURE 4** Combined effect of parafilm and wetting on air void measurements.



**FIGURE 5** Effect of wetting on no-parafilm measurements of air voids.



**FIGURE 6** Comparison of dry-no-parafilm, wet-no-parafilm, and wet-with-parafilm measurements of air voids (regression lines).

wet-with-parafilm and wet-no-parafilm methods (both methods used on specimens in both the cut and uncut condition) shown in Figure 7. At higher air void contents, the effect of using parafilm is greater for uncut specimens than for cut specimens. This is because of the generally smoother exteriors of the cut specimens (due to cut aggregate surfaces). At lower air void contents, the effect of using parafilm is greater for cut specimens than for uncut specimens, probably due to smearing of asphalt at the interface between the mold and the specimen surface under heavy compaction.

Specimens prepared using Watsonville granite and Texas chert show no difference between the dry (dnp) and wet (wnp) conditions, as shown in Figure 8. However, the Texas chert specimens with higher air void contents are more sensitive to the use of parafilm than are the Watsonville granite specimens, as shown in Figure 9. This finding is probably the result

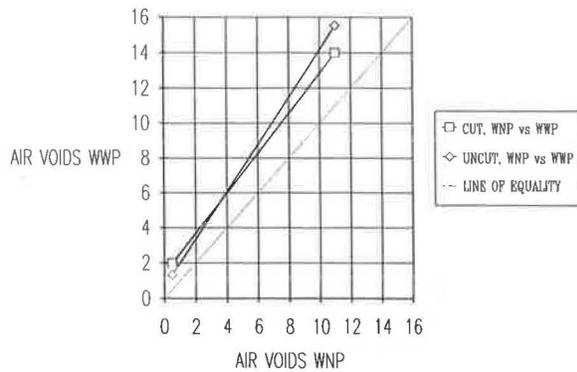


FIGURE 7 Combined effect of cut surfaces and parafilm on air void measurements (regression lines).

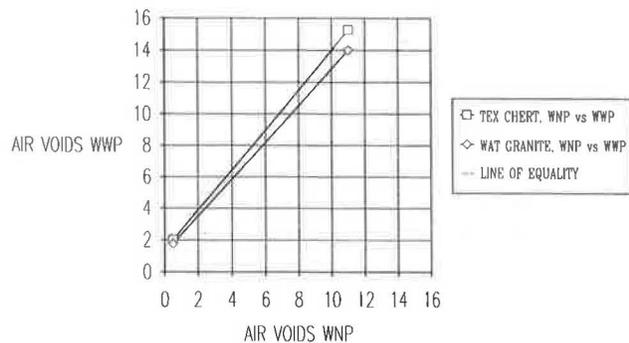


FIGURE 8 Combined effect of wetting and aggregate type on air void measurements (regression lines).

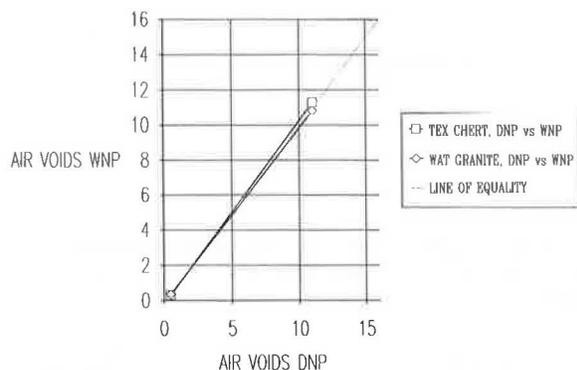


FIGURE 9 Combined effect of parafilm and aggregate type on air void measurements (regression lines).

of the parafilms trapping air in the more irregular, chipped surfaces of the Texas chert specimens.

### Critique of Wet-With-Parafilm Procedure

Although the wet-with-parafilm procedure is better than alternatives, it has some problems. The primary problem is arching of the parafilm over surface irregularities caused by chipping of the aggregates during cutting and coring; the result is that air trapped under the parafilm is improperly considered

as air voids. This problem occurs most frequently with specimens having thin cross sections or many sharp edges, such as 1.5- × 1.5- × 15-in. fatigue beams, and with specimens made with very hard aggregates or low asphalt contents. The same problem occurs with specimens without surface irregularity if careful attention is not given to the removal of air trapped beneath the parafilm.

The other potential problem with wet-with-parafilm technique is the repeatability with which the surface-dry condition is reached, although a limited comparison with tests from another laboratory showed little problem. Although the general technique used in this study has proven to be suitable, more attention must be given to standardization of the drying equipment and procedure.

### EFFECT OF CUT SURFACES

#### Objectives of Laboratory Specimen Compaction

The objectives of laboratory specimen fabrication are summarized as follows:

1. To fabricate specimens that as closely as possible resemble in-service mixtures, that is, those produced by mixing, placement, and compaction in the field;
2. To fabricate specimens that, under laboratory testing, exhibit the same behavior as in situ mixtures under similar states of stress; and
3. To be as efficient as possible in the use of labor, time, equipment, and material.

#### Effects of Compaction Method

Slight visual differences were observed between the top and bottom surfaces of all laboratory-prepared specimens. The lower surface was usually rougher, that is, both the aggregate particles and the surface voids were larger. The top of the specimen, which had been in contact with the compacting surface, usually had a smoother surface composed of finer particles. The lateral surfaces of most molded specimens were a smooth matrix of asphalt and the finer fractions of aggregate; there was little honeycombing, and larger particles had migrated inward. Lateral surfaces of specimens with high asphalt contents often contained excess asphalt, especially when compacted to low air void contents.

During compaction, the mold walls constrain the reorientation of surface particles. However, in the interior, the shearing action of the compactor reorients the larger particles, producing a structure that significantly affects engineering properties of the compacted mixture. If the quantities of asphalt and fine particles are limited or the compaction effort is modest, gaps between the larger particles at the surface remain unfilled. The net result is that the aggregate structure at the surface is different from that in the interior.

Some segregation of larger from finer particles often occurs during placement of the hot mixture in the mold. Segregation becomes more pronounced as the size of the compacted specimen or the compactive effort decreases, because the size of the larger aggregates in comparison with the mold dimensions,

or the lack of shearing energy, does not permit the movement of fines to the interstices between the larger aggregates.

Gyratory specimens are subjected to a torsional shear force on their lateral surfaces caused by rotation of the compaction apparatus base plate, while the compaction ram resists rotation at the top surface. This produces surface forces on the specimen, which often results in large aggregates' separating themselves from the surface when the specimen is extruded from the compaction mold. When the large particles are rounded, thin layers of finer material between the large particles and the specimen surface also frequently separate from the specimen after extrusion. The effects of the torsional surface forces in gyratory compaction are recognized in the procedure for the Texas gyratory compactor (Texas Method Tex-206-F and ASTM D4013), which stipulates that large aggregate particles should be pulled away from the mold wall with a large bent spoon before compaction. The mold will rotate if the torsional shear force exceeds the friction between the mixture and the mold wall, smearing excess asphalt and fine material across the lateral surface of the specimen.

Cutting or coring the specimen from a larger compacted mass removes portions of the specimen that have been subjected to these forces and effects. The specimen with cut surfaces has a more homogeneous aggregate and air void structure and does not have a smeared asphalt coating that may otherwise be present at the compacted surface.

The major drawbacks of cut specimens include (a) the need for care during sawing and coring to obtain the required geometric shapes that are free of ripples or other surface imperfections, and (b) possible problems with the exposure of mixtures to water during the sawing and coring process. However, problems with water-sensitive mixtures are encountered with all air void measurements that involve wetting the specimen, and they can usually be solved by timely testing.

### Effects on Air Void Determination

The effects of surface condition (cut or uncut) on air void measurements depend on the properties of the mixture (including, for example, asphalt content and aggregate angularity) and the compaction method (gyratory, kneading, or rolling-wheel).

1. The difference between air voids measured with cut surfaces and those measured with uncut surfaces depends on the degree of nonuniformity in the air voids and aggregate structure between the surface and the interior of the specimen: this is a function of the compaction method, the compaction effort, and the aggregate angularity and the asphalt content of the mixture.

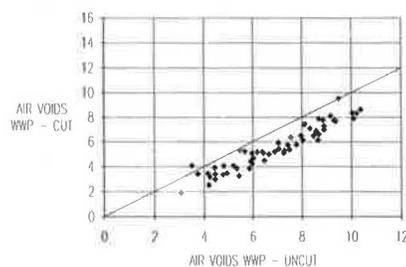
2. If the specimen has a large surface area in relation to its volume, the difference between the measured air voids is greater with cut versus uncut surfaces. Thus large specimens, such as 3- × 3- × 15-in. beams and 4- × 8-in. cylinders, will have less difference in the measured air voids than 2.5- × 4-in. briquets compacted using the same method.

3. If the asphalt content or the compaction effort is high, asphalt at the surface of the specimen may form a coating, which prohibits the entry of water into the specimen and affects air void measurements.

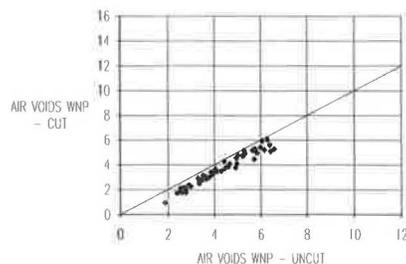
4. For high asphalt contents or high compaction efforts, the sealing action at the surface of the specimen is greater for gyratory specimens because of smearing caused by the torsional shear forces on the lateral surfaces.

An example of the difference between the measured air voids for specimens as compacted and after cutting is shown in Figure 10. In this case 3- × 3- × 15-in. beams of all mixture types, prepared by kneading compaction, were tested using the wet-with-parafilm procedure both after compaction and after trimming of the outer  $\frac{3}{16}$  in. of the surface. The data indicate that the as-compact specimen has approximately 1 to 2 percent higher air voids than the same specimen after cutting. This conclusion is confirmed by testing the same specimens using the wet-no-parafilm method as shown in Figure 11.

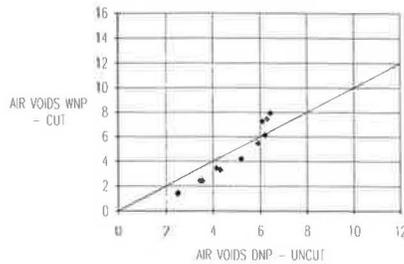
Further evidence of differences between interior and exterior air void contents is shown in Figure 12 for 4- × 8-in. gyratory specimens of identical composition. In this case, specimens were compacted as 6- × 9.5-in. cylinders, then cored and cut to their final dimensions. Comparison of air void measurements using the dry-no-parafilm method for the uncut specimens and the wet-no-parafilm method for the cut specimens—the two methods have previously been shown to produce similar results—indicates that at lower compaction efforts (higher air void contents) the outer portion of the specimen is more densely compacted than the inner portion; at higher compactive efforts (lower air void contents) the reverse is true. At high compactive efforts (low air voids), differences in air voids of up to 3 percent (w/w) have been found between the center third (higher air voids) and top and



**FIGURE 10** Effect of cut surfaces on wet-with-parafilm measurements of air voids in large beams (kneading compaction).



**FIGURE 11** Effect of cut surfaces on wet-no-parafilm measurements of air voids in large beams (kneading compaction).



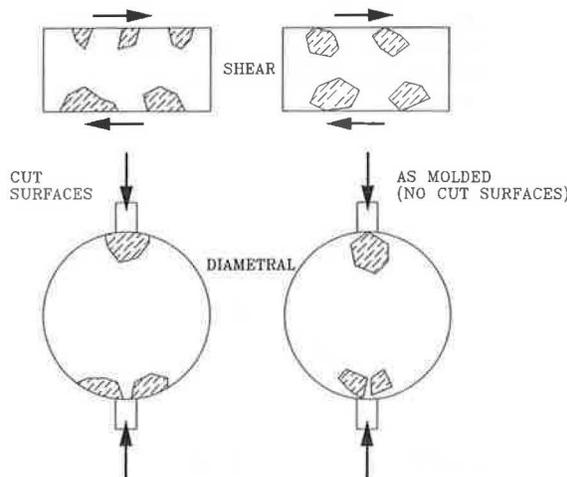
**FIGURE 12** Effect of cut surfaces on no-parafilm measurements of air voids in large cylinders (gyratory compaction).

bottom thirds (lower air voids) of 4- × 8-in. gyratory specimens. This finding also indicates specimen nonuniformity along the vertical axis, despite the fact that the specimens have been compacted in one lift.

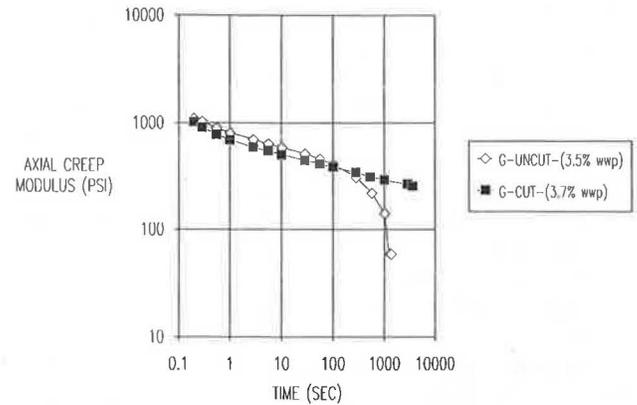
### Effects on Engineering Properties

In some types of tests, cut surfaces may significantly affect the measured response of the mixture. In tests with large shear stress components, the measured values of the strength tend to be larger for specimens with cut surfaces. The cut surfaces of the aggregates rest against the end plates, effectively resisting rotation of the large aggregate particles. Figure 13 shows two examples where this mechanism will produce an effective increase of stiffness modulus, resistance to permanent deformation, and fatigue life. This hypothesis is corroborated by the results of the project compaction study, which show greater modulus, resistance to plastic deformation, and fatigue life for rolling-wheel specimens with cut surfaces, than for kneading specimens with uncut surfaces (1,2).

Further evidence is provided by comparing simple shear test results for uncut 4- × 2.5-in. gyratory specimens with those for similar specimens cored and cut from 6- × 9.5-in. gyratory cylinders. Figure 14 shows the difference between



**FIGURE 13** Boundary effects of cut specimen surfaces in shear and diametral testing.



**FIGURE 14** Effect of cut surfaces on shear creep modulus (gyratory specimens).

the performance of the two types of specimens. The uncut specimens have a larger proportion of aggregates able to move under stress, leading to rapid failure once aggregate interlock has been overcome by the shearing force.

### CONCLUSIONS

Based on the stated objectives of specimens preparation and air void measurement and on the data and observations presented, the following conclusions can be drawn:

1. The surface of a specimen, whether uncut (as-molded) or cut (sawed or cored from a larger compacted mass), significantly affects its mechanical behavior and its measured air void content.
2. In comparison with cut specimens, specimens with uncut surfaces are less homogeneous in their distribution of air voids; during compaction, they experience greater segregation of aggregate and greater migration of fines and asphalt to their surfaces.
3. Cutting the surfaces of laboratory specimens allows more accurate comparison of their properties with those of field cores.
4. Measurement of air void content is critical to understanding specimen performance in testing. The wet-with-parafilm procedure is consistently sensitive and reproducible and easily allows further testing of the specimen after air void determination.

On the basis of these conclusions, it is recommended that laboratory specimens be prepared by coring or cutting from a larger compacted mass and that further study be given to the wet-with-parafilm air void measurement procedure, leading toward standardization.

### ACKNOWLEDGMENTS

The work reported herein was conducted as a part of a project of the Strategic Highway Research Program. This project, "Performance Related Testing and Measuring of Asphalt-

Aggregate Interactions and Mixtures," is being conducted by the Institute of Transportation Studies of the University of California, Berkeley. The authors express their appreciation to Akhtar Tayebali, who first identified the limitations of conventional techniques for air void measurement.

## REFERENCES

1. J. B. Sousa, J. Harvey, L. Painter, J. A. Deacon, and C. L. Monismith. *Evaluation of Laboratory Procedures for Compacting Asphalt-Aggregate Mixtures*. Report TM-UCB-A-003A-90-5. Institute of Transportation Studies, University of California, Berkeley, 1990.

2. J. B. Sousa and J. A. Deacon. Effect of Laboratory Compaction Method on the Permanent Deformation Characteristics of Asphalt-Aggregate Mixtures. Presented at Annual Meeting of Association of Asphalt Paving Technologists, 1991.
3. H. Del Valle. *Procedure—Bulk Specific Gravity of Compacted Bituminous Mixtures Using Parafilm-Coated Specimens*. Chevron Research Company, Richmond, Calif., 1985.

---

*The contents of this paper reflect the views of the authors, who are solely responsible for the facts and accuracy of the data. They do not necessarily reflect the official views or policies of the Strategic Highway Research Program (SHRP) or of SHRP's sponsors and are not necessarily in agreement with other SHRP research activities.*