Aggregate Voids Characteristics In Asphalt Paving Mixes

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Asphalt paving mixes are comprised of three basic components: mineral aggregate, asphalt and air. Knowledge of the interrelationships existing among these three components, and their respective effects upon the characteristics of the paving mix, is essential to the highway engineer.

The Asphalt Institute is engaged in a comprehensive investigation of the characteristics of asphalt paving mixes. This investigation includes a study of the relative effects of the variable components of the mix upon the properties and characteristics of the compacted asphaltic pavement. A wide variety of aggregate types, gradations and combinations has been subjected to extensive tests by the Marshall, Hveem, Hubbard-Field and Triaxial Test Methods. The resulting data have provided a substantial basis for a study of the aggregate void characteristics in asphalt paving mixes compacted by the specified procedures for these several test methods.

ASPHALT

● THE asphalt cement used in the study was from a single and uniform source. It was an 85-100 penetration grade meeting all specification requirements of The Asphalt Institute.

AGGREGATES

Results presented in this paper are based on a study of seven coarse aggregates obtained from widely separated sources. These coarse aggregates are generally identified as:

1. Maryland gravel, uncrushed
2. Washington gravel, uncrushed
3. Michigan gravel, uncrushed
4. Ohio limestone
5. Carolina granite
6. California granite
7. New York trap rock

The coarse fraction of a given mix was composed entirely of material passing the ¾-in. sieve and retained on the No. 8 sieve, from one of these sources.

The fine aggregate, material passing the No. 8 sieve and retained on the No. 200 sieve, was obtained from a single and uniform source in Maryland. Mineral dust, material passing the No. 200 sieve, was obtained by processing a limestone dust from a single, uniform source. Apparent and bulk specific gravities of all the mineral aggregates and mineral dust are given in Table 1.

GRADATIONS

The study was based upon a wide range of aggregate gradations. Seven basic gradations were used, ranging from mixes in which all aggregate was finer than the No. 8 size to those containing

TABLE 1
SPECIFIC GRAVITY OF MINERAL AGGREGATES AND FILLER

Aggregate	Apparent Specific Gravity	Bulk Specific Gravity
Maryland gravel	2.659	2.632
Washington gravel	2.722	2.697
Michigan gravel	2.753	2.669
Ohio limestone	2.700	2.584
Carolina granite	2.658	2.632
California granite	2.953	2.875
New York trap	2.958	2.911
Maryland sand	2.655	2.632
Limestone mineral dust	2.703	2.703

up to 75 percent of the aggregate of the ¾-in. to No. 8 size. The seven mineral aggregate gradations used for the study are shown in Figure 1.

TEST METHODS

Although the study has included tests on these many combinations of type and gradation of aggregate by the Marshall, Hveem, Triaxial and Hubbard-Field tests, this paper does not include results from the latter two methods. Generally speaking, trends for the aggregate voids characteristics were similar in nature in all four methods. As the Marshall and Hveem test series were somewhat more extensive than the Hubbard-Field and Triaxial series, it was considered that the data derived from the former would be most appropriate for the presentation of this study. The Marshall and Hveem procedures used for these tests are fully described in The Asphalt Institute Manual, "Mix Design Methods for Hot-Mix Asphalt Paving."

Aggregate voids characteristics were also determined for several gradations by a dry rodding procedure and a vibratory method for several gradations of each of two of the coarse aggregates used for the Marshall and Hveem test series. One of the aggregates was the crushed Carolina granite; the other was the uncrushed Maryland gravel. These tests were run on mixes of the dry aggregate without the addition of asphalt.

Test procedures used for the dry-rodding method were those prescribed for "A Tentative Method of Test for Unit Weight of Aggregate," ASTM Designation C 29-55T.[1] The percentage of aggregate voids was calculated directly from the unit weights for the dry mixes using the apparent specific gravity of the composite dry aggregates. Test procedures followed for the vibratory method were those outlined in a paper by J. T. Pauls and J. F. Goode, "A New Vibrating Machine for Determining the Compactibility of Aggregates."[2]

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[1] ASTM standards on Mineral Aggregates and Concrete, American Society for Testing Materials.

[2] The Association of Asphalt Paving Technologists, Vol. 10, January 1939.

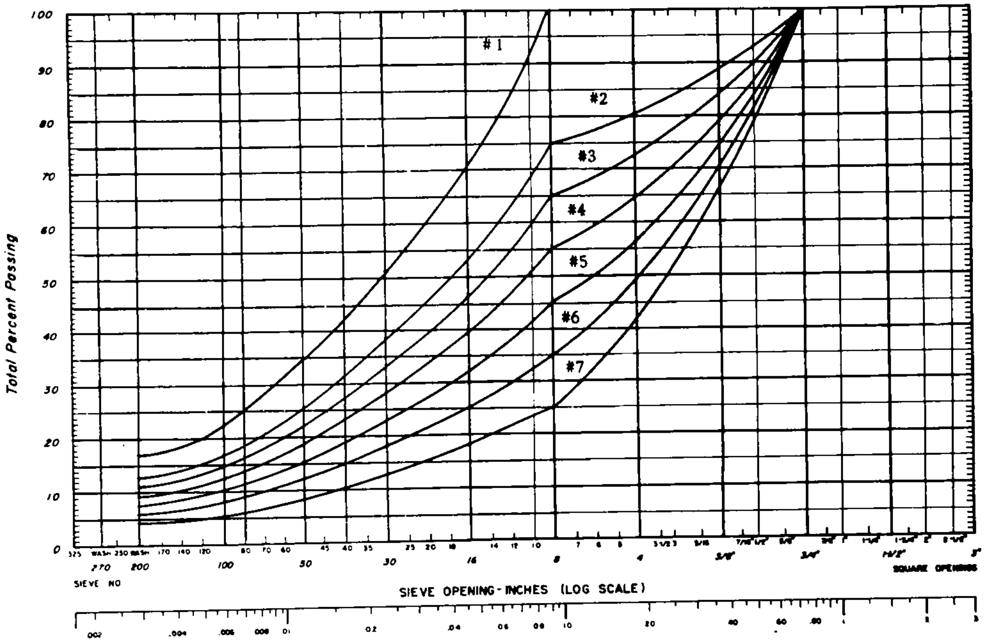

Figure 1. Aggregate gradations.

The voids characteristics of the two mixes determined by the vibratory method were somewhat similar to those for the Marshall and Hveem test series. The Asphalt Institute Laboratory had on hand aggregates and pavement core data from two sections of the New Jersey Turnpike. A final series of tests were made in which aggregate voids were determined by the vibratory method for two mixes to provide a comparison with the aggregate voids of cores removed from the New Jersey Turnpike pavement sections. The gradation of the aggregate mixes used for vibratory tests were identical to the gradations indicated by extraction tests on pavement samples removed from the same location as the cores from which the actual pavement aggregate voids were determined.

PRESENTATION OF DATA

Aggregate voids in compacted paving mixes consist of the volumes occupied by two of the components of the mix, asphalt and air. If the volumes of these two parts are added together and expressed as a percentage of the total volume of the compacted mix, they are commonly termed percent aggregate voids, or percent VMA (voids in the mineral aggregate). The voids in the compacted aggregate framework of a mix are significant because of their relation to both mix stability and the amount of asphalt required in a paving mix. Variables influencing aggregate voids are type and gradation of the mineral aggregate, absorptive characteristics of the mineral aggregate, quantity and type or grade of asphalt, compaction temperatures and compaction procedures.

For a given aggregate, gradation and compaction method aggregate void values normally decrease with increasing asphalt contents to a minimum value and then increase as the increased amount of asphalt prevents aggregate particles from achieving their most intimate contacts. This occurs even though air voids still exist in the mix. The separation of aggregate particles by increased amounts of asphalt, after minimum void values have been reached, affects the strength characteristics of a mix by decreasing its ability to withstand shearing stresses. Stability tests such as the Marshall and Hveem generally indicate stability decreases for asphalt contents greater than that necessary for producing minimum aggregate voids in a mix.

Selection of an optimum asphalt content for a given mix, using the criteria of the Marshall and Hveem methods of mix design, normally results in an asphalt content near, or slightly less than, the amount required to produce minimum aggregate voids. Therefore, the optimum asphalt content appears to be closely related to the voids in the mineral aggregate. Furthermore, the asphalt content is almost directly proportional to the amount of aggregate voids for mineral aggregates having low asphalt absorption.

Changes in the relative proportions of coarse and fine aggregate fractions in uniformly graded mixes at, or near their minimum aggregate void contents (at or near optimum asphalt contents), produce decreasing aggregate voids to a minimum value and then increasing aggregate voids. This behavior can be demonstrated by selecting minimum aggregate void values for specimens prepared through a range of asphalt contents for each of several gradations and plotting these minimum aggregate voids against the relative proportions of coarse and fine aggregate.

By this procedure the voids characteristics of different aggregate types of like gradation, through a range of gradations, may be compared to show how aggregate particle shape and surface texture, and compaction methods, influence aggregate voids in paving mixes.

Aggregate voids characteristics developed in this manner are shown in Figure 2 for Hveem test series specimens. The abscissa represents the percentage of fine aggregate and the ordinate the minimum percent aggregate voids in the mixes. Each curve representing a different coarse aggregate type, developed by plotting the minimum percent aggregate voids against the relative proportions of

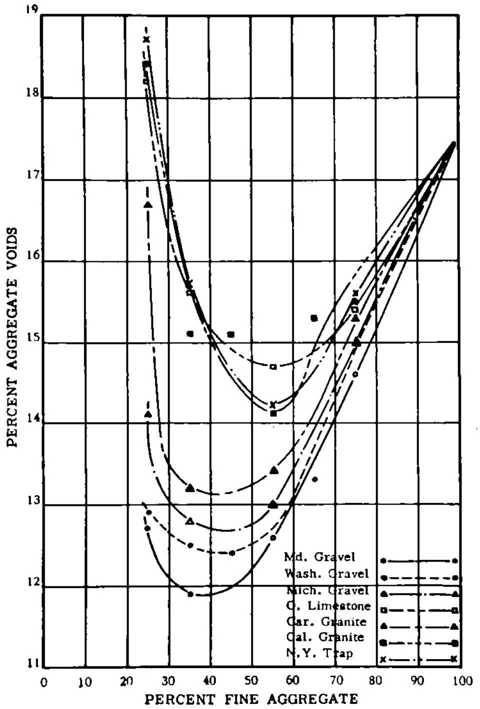

Figure 2. Minimum percent aggregate voids for Hveem compacted specimens.

coarse and fine aggregate, shows decreasing and then increasing minimum aggregate void values as the proportion of fine aggregate is increased to 100 percent.

The uncrushed gravel mix specimens, as a group, indicated lower aggregate voids than the crushed rock mixes through the gradation ranges investigated. The differences in the positions of the aggregate voids curves reflect the combined effect that coarse aggregate type, particle shape and surface texture have on aggregate voids in a mix. The aggregate voids curves indicate that coarse aggregate particle shape, whether the aggregates are crushed or uncrushed, has considerable influence on aggregate voids, particularly when the coarse fractions are greater than 50 percent.

The relative positions of the aggregate voids curves give an indication of asphalt demand for the various coarse aggregates through a range of gradations, assuming nearly equal aggregate asphalt absorption. The curves themselves indicate that the uncrushed gravel aggregate mixes would normally require less asphalt than the crushed rock mixes.

Aggregate voids characteristics for Marshall test series specimens are shown in Figure 3. Minimum percent aggregate voids values were plotted against the percentage of fine aggregate in the mix in the same manner as the Hveem test series. Indications noted for Figure 2 are generally the same for Figure 3.

For a given compaction method the shapes of the individual curves give an indication of how asphalt demand varies with changes in the relative proportion of coarse and fine aggregate. Since the minimum aggregate void contents occur at considerably different relative proportions of coarse and fine aggregate, minimum asphalt requirements with respect to gradation changes would vary considerably with the type of aggregate used.

Minimum aggregate void values that result from changes in the relative pro-

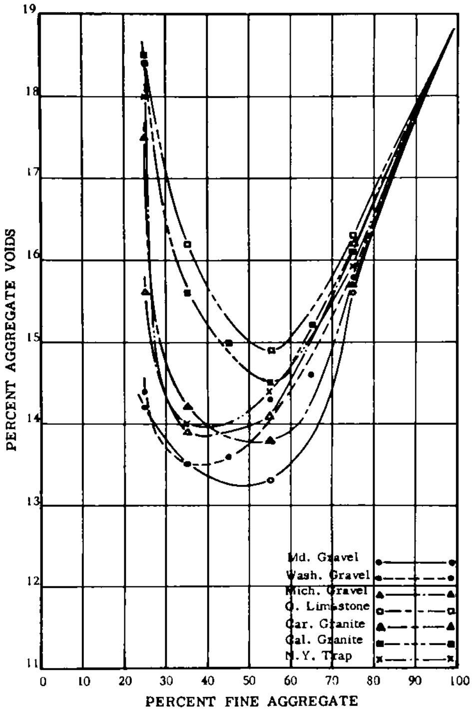

Figure 3. Minimum percent aggregate voids for Marshall compacted specimens.

portions of coarse and fine aggregates represent gradations which produce maximum surface area contacts among the aggregate particles for a given aggregate. Surface area contacts of aggregate are an important factor in mix stability; therefore, mix stability would be related to the minimum aggregate void values. Maximum stability would normally be expected to result at or near the proportions of coarse and fine aggregate that produce minimum aggregate voids in compacted mixes. The aggregate voids curves indicate that minimum aggregate voids values are influenced considerably by both coarse aggregate type and compaction method. The uncrushed gravel mixes would be expected to develop their maximum stabilities with about 10 to 15 percent more coarse aggregate than the crushed rock mixes.

The minimum points on the aggregate voids curves also indicate the relative proportions of coarse and fine aggregate at which a mix would be most sensitive to slight variations in asphalt content. Of all the aggregates used for the study, the Maryland gravel mix would be the most sensitive to slight asphalt content variations when about 55 to 65 percent coarse aggregate was used.

A comparison of the aggregate voids curves developed by the Marshall compaction method, and kneading compaction as accomplished with the Triaxial Institute Kneading Compactor for the Hveem method shows that considerable difference exists between them. Kneading compaction for Hveem compacted specimens generally resulted in lower aggregate voids than Marshall compaction for all aggregate types for all gradations used. Aggregate voids for the two compaction methods differed most for the uncrushed gravel mixes for gradations having more than 50 percent coarse aggregate. This difference was indicated to be as much as 1 to 1½ percent.

Figure 4 shows a comparison of the aggregate voids characteristics for the Marshall and Hveem series of test specimens with aggregate voids characteristics determined by the dry rodding and vibratory methods of test. The ordinate represents percent of aggregate voids and the abscissa, percent of fine aggregate in the mix. Percent aggregate voids for the dry rodding and vibratory methods of test are plotted against the relative proportion of coarse and fine aggregate used in the mix, along with minimum percent aggregate voids that resulted from like mixes for the Marshall and Hveem test series. The aggregate voids determined by the dry rodding and vibratory procedures are given in Table 2.

Aggregate voids determined by the dry rodding method range from about 8 to 13 percent higher than aggregate voids measured in Marshall and Hveem specimens. Differences in aggregate voids determined by these two methods were not constant but varied with changing gradations. Aggregate voids determined by using the vibratory test method were generally 2 to 5 percent lower than those measured in Marshall and Hveem specimens. Differences between them were not constant but also varied with changes in the relative proportions of coarse and fine aggregate used. Aggregate void test results for both the dry rodding and vi-

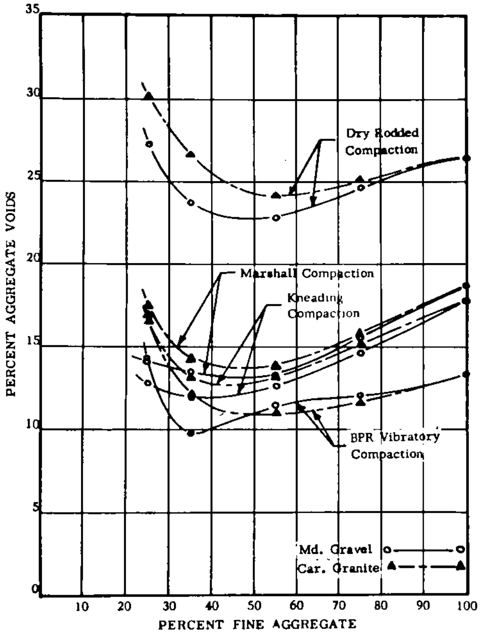

Figure 4. Percent aggregate voids compared for different compaction methods.

TABLE 2

PERCENT VOIDS IN DRY AGGREGATES BY DRY RODDED METHOD AND VIBRATORY METHOD

Coarse Aggregate Type	% Fine Aggregate	Aggregate Voids	
		% Dry Rodded	BPR Vibratory
Maryland gravel	100	26.4	13.4
	75	24.7	12.1
	55	22.8	11.5
	35	23.7	9.7
	25	27.3	14.3
South Carolina granite	100	26.4	13.4
	75	25.1	11.7
	55	24.2	11.0
	35	26.6	12.1
	25	30.1	16.5

TABLE 3

MIX COMPOSITION AND PERCENT AGGREGATE VOIDS FOR NEW JERSEY TURNPIKE PAVEMENT SECTION NO. 6, STA. 275 + 00

A. Mix composition:
1. Coarse aggregate: trap rock
2. Apparent specific gravity (composite aggregate) : 2.836
3. Gradation:

Sieve Size Sq. Openings	Passing, % By Weight of Dry Aggregate
¾	100.0
⅜	78.1
No. 4	50.6
No. 8	38.8
No. 30	25.6
No. 100	5.0
No. 200	3.0

4. Asphalt content: 5.5 percent

B. Comparison of percent aggregate voids:

	% Aggregate Voids
1. Pavement before traffic	20.2
2. Pavement after 2 years traffic	17.3
3. Bureau of Public Roads vibratory compaction	17.9

bratory test methods indicated that these methods were not wholly reliable guides for predicting minimum aggregate voids produced in Marshall and Hveem specimens. They did not reproduce the same aggregate void contents, and they did not agree as to the relative proportions of coarse and fine aggregates that would produce minimum voids.

The test results for the final series of aggregate void determinations, a comparison of aggregate voids determined by the vibratory method with aggregate voids for the New Jersey Turnpike pavements, are tabulated in Tables 3 and 4. Table 3 is a summary of the pavement mix composition and a comparison of percent aggregate voids determined by the vibratory method, with pavement aggregate voids before and after the pavement was subjected to two years of traffic. The vibratory test method produced percent aggregate voids of 17.9 compared to 17.3 after two years of traffic and 20.2 percent before traffic. These tests indicated close agreement between the aggregate voids resulting from vibratory compaction and actual pavement aggregate voids after two years of traffic for this trap rock aggregate mix. Similar data for a second pavement section with a limestone aggregate mix are tabulated in Table 4. Percent aggregate voids determined by the vibratory method was 12.0 as compared to actual pavement aggregate voids of 15.0 after two years of traffic and 16.9 before traffic. The vibratory method of compaction failed to reproduce aggregate voids found in the pavement for the limestone aggregate mix.

These limited tests indicated that the vibratory compaction method would not be entirely reliable for predicting aggregate voids in hot-mix asphalt paving. This method of test tended to produce lower aggregate voids than those found in pavements and in Marshall and Hveem test specimens, particularly for aggregate gradations having larger fine aggregate fractions.

Aggregate voids in compacted asphalt paving mixes vary in a logical and orderly fashion. Actual values, however, are primarily dependent upon type and gradation of the aggregate, asphalt content and method of compaction.

TABLE 4

MIX COMPOSITION AND PERCENT AGGREGATE VOIDS FOR NEW JERSEY TURNPIKE PAVEMENT SECTION NO. 2 STA. 290 + 00

A. Mix composition:
1. Coarse aggregate: limestone
2. Apparent specific gravity (composite aggregate): 2.765
3. Gradation:

Sieve Size Sq. Openings	Passing, % By Weight of Dry Aggregate
¾	100.0
⅜	80.7
No. 4	52.2
No. 8	46.7
No. 30	28.7
No. 100	8.9
No. 200	4.1

4. Asphalt content: 5.0 percent

B. Comparison of percent aggregate voids:

	% Aggregate Voids
1. Pavement before traffic	16.9
2. Pavement after 2 years traffic	15.0
3. Bureau of Public Roads vibratory compaction	12.0