# Research on Bituminous Concrete Properties With Large-Sized Aggregates of Different Particle Shape

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•A REVIEW of the literature reveals that, with the exception of some surface courses where the maximum size of the aggregate has been limited to about ½ in., the merits of different aggregates in bituminous mixtures have not been thoroughly explored. The technical literature contains little information relative to properties of hot-mixed asphaltic concrete with larger sizes of aggregates, and no single criterion has been established for such mixtures.

The National Crushed Stone Association (NCSA) staff undertook the task of developing a method of test by which mixtures with large-sized aggregates could be evaluated. This research is an attempt to demonstrate the merits of some aggregates with respect to others and assist the engineers and interested agencies in selecting the best-suited materials and developing the most economical designs.

The first step in this program was to adopt a procedure for preparation of specimens of uniform composition and such a size that could be conveniently handled yet accommodate at least a 1½-in. maximum-sized aggregate. Following this, two typical commercial aggregates, a crushed limestone and a washed gravel, were used in the preparation of specimens at three gradations having nominal sizes of ½, 1, and 1½ in. Each gradation of each material was then tested triaxially at several confining pressures and at two different temperatures. The 1-in. stone mix was also tested at different asphalt contents, and tests are under way to evaluate the effect of the asphalt variability for the remaining mixtures. The results, as available up to now, support the hypothesis that angular aggregates are preferable.

## TEST PROCEDURE

For the purpose of studying the effects of different variables on the physical properties of bituminous mixtures, the triaxial method of test used by the Texas Highway Department (1) for soil-aggregate combinations, as well as for dense-graded aggregates, was adopted with some modification. The basic change was close control of temperature during mixing, compaction, and testing.

After considerable experimentation, a combination of drop-hammer compaction and mechanical vibration was selected. The procedure chosen produced densities and void contents similar to the Marshall method as compared with the ½-in. mix. All specimens in this investigation were fabricated in an identical manner, and the method of investigation is described in the following.

Specimens were prepared in 6-in. diameter, split cylindrical molds and compacted in four 2-in. lifts. Seventy-five blows from a 10-lb circular face mechanical hammer, through a free-fall drop of 18 in., were used per lift. The 8-in. specimen, while still in the mold, was placed in the oven to regain any lost heat and then vibrated for 1 minute under a surcharge of 85 lb using a vibrating table (2).

After extraction from the mold, the specimens were measured for density using ASTM Designation D 1075 and were prepared for triaxial compression evaluation at the desired temperature. The triaxial testing was performed using a constant rate of deformation (0.15 in./min). The load was recorded manually at increments of 0.01 in. deformation, and the stress-strain curves were established. Each specimen was tested at a constant, but different, lateral pressure. Lateral pressures of 0, 5, 10, 15, and 20 psi were normally employed.

## MATERIALS

The materials used in this investigation were supplied from commercial sources. The crushed stone was from a commercial limestone deposit and had a bulk specific gravity of 2.72 and Los Angeles abrasion loss of 19 percent. The crushed stone screenings were processed to achieve a relatively good particle shape with a void content of 52 percent (3).

The washed siliceous gravel was from a typical natural deposit. It had about 1½ to 2 percent heavy ferruginous impurities. These were very carefully removed from the specific gravity samples, but some were included with the material from which specimens were prepared and may have influenced the air-void computations somewhat. The clean siliceous gravel had a specific gravity of 2.63 and Los Angeles abrasion loss of 37 percent. This gravel was not processed by crushing, yet it contained a large number of subangular or chipped pieces and could be described as follows:

| Sieve Sizes (in.) | Percent Rounded Particles | Percent Fractured Particles | |
|---|---|---|---|
| | | One Face | Two or More Faces |
| 1½ to 1 in. | 16 | 15 | 69 |
| 1 to ¾ in. | 12 | 23 | 65 |
| ¾ to ½ in. | 21 | 31 | 48 |
| ½ to ⅜ in. | 25 | 30 | 45 |

The fine natural aggregate was a river siliceous sand with well-rounded particles, 48.5 percent voids (3), and specific gravity of 2.60. None of the minus-100 mesh from this material was used, but rather a limestone filler with 80 percent passing the 200 mesh was substituted. The asphalt cement was supplied by the American Oil Company and was of 85-100 pen. paving grade. The Saybolt Furol viscosity of this asphalt was quoted by the manufacturer as being 156 sec at 275 F, and 71 sec at 310 F.

## PROPORTIONING AND AGGREGATE COMBINATIONS

The proportioning of the aggregates was based on the midgrading of ASTM Specification D 1663 for hot-mixed, hot-laid asphaltic concrete. For closer control over uniformity in specimen preparation, each was weighed cumulatively from sized materials in accordance with the distribution given in Table 1. Selection of the asphalt requirement was based on the U.S. Army Corps of Engineers void criteria (4, p. 17), using the Rice method of maximum specific gravity (5), because the commonly used Marshall design (6) does not apply to

TABLE 1

AGGREGATE COMPOSITION OF ASPHALTIC PAVING MIXTURES

| Gradation[a] | Mix B | Mix C | Mix E |
|---|---|---|---|
| Sieve size | | | |
| 1½ in. | 100 | | |
| 1 in. | 80$^b$ | 100 | |
| ¾ in. | 70 | 85$^b$ | 100 |
| ½ in. | 61$^b$ | 70 | 95 |
| ⅜ in. | 54$^b$ | 62$^b$ | 85$^b$ |
| No. 4 | 38 | 42 | 58 |
| No. 8 | 25 | 30 | 40 |
| No. 16 | 19$^b$ | 23$^b$ | 30$^b$ |
| No. 30 | 14$^b$ | 16$^b$ | 20$^b$ |
| No. 50 | 9 | 10 | 12 |
| No. 100 | 4$^b$ | 5$^b$ | 7$^b$ |
| No. 200 | 3 | 4 | 5.5 |

[a] The materials were combined to the midpoint of ASTM Specification D 1663.

[b] The marked figures were obtained through extrapolation.

TABLE 2

SUMMARY OF TRIAXIAL TEST RESULTS FOR CRUSHED STONE MIX C AT DIFFERENT ASPHALT CONTENTS TESTED AT 140 F

| Category | Percent Asphalt | | |
|---|---|---|---|
| | 4.0 | 4.4 | 4.8 |
| Properties of compacted specimens | | | |
| Bulk specific gravity | 2.427 | 2.449 | 2.466 |
| Unit weight, pcf | 151.1 | 152.4 | 153.5 |
| Air voids, percent | 5.0 | 3.6 | 2.4 |
| VMA, percent | 14.2 | 13.8 | 13.5 |
| Voids filled, percent | 65.0 | 73.0 | 83.0 |
| Maximum normal strength[a], psi, at lateral pressure of | | | |
| 0 psi | 90.0 | 82.0 | 97.0 |
| 5 psi | 135.0 | 127.0 | – |
| 10 psi | 180.0 | 167.0 | 160.0 |
| 15 psi | 222.0 | – | 200.0 |
| 20 psi | 240.0 | 247.0 | 265.0 |
| Deformation, percent strain, at maximum normal strength, lateral pressure of | | | |
| 0 psi | 1.1 | 0.7 | 1.1 |
| 5 psi | 1.4 | 1.4 | – |
| 10 psi | 1.8 | 1.7 | 2.0 |
| 15 psi | 1.9 | – | 2.2 |
| 20 psi | 2.1 | 2.4 | 2.6 |

[a] Triaxial strength tests (deformation of 0.15 in./min).

TABLE 3

SUMMARY OF TRIAXIAL TEST RESULTS WITH DIFFERENT AGGREGATES IN MIX C ASPHALTIC CONCRETES TESTED AT 140 F

| Category | Materials Combination | | | |
|---|---|---|---|---|
| | Stone[a] Stone[b] | Stone[a] River Sand[b] | Gravel[a] Stone[b] | Gravel[a] River Sand[b] |
| Properties of compacted specimens | | | | |
| Asphalt, percent | 4.4 | 4.2 | 4.2 | 4.0 |
| Bulk specific gravity | 2.449 | 2.426 | 2.432 | 2.403 |
| Unit weight, pcf | 152.4 | 151.0 | 151.4 | 149.6 |
| Air voids, percent | 3.6 | 4.6 | 2.5 | 3.0 |
| VMA, percent | 13.8 | 13.2 | 12.3 | 11.7 |
| Voids filled, percent | 73.0 | 65.0 | 80.0 | 74.0 |
| Maximum normal strength[c], psi, at lateral pressure of | | | | |
| 0 psi | 82.0 | 62.0 | 50.0 | 35.0 |
| 5 psi | 127.0 | 104.0 | 97.0 | 72.0 |
| 10 psi | 167.0 | 145.0 | 130.0 | 102.0 |
| 15 psi | – | 197.0 | – | 140.0 |
| 20 psi | 247.0 | – | 202.0 | 167.0 |
| Deformation, percent strain, at maximum normal strength, lateral pressure of | | | | |
| 0 psi | 0.7 | 0.9 | 0.9 | 0.7 |
| 5 psi | 1.4 | 1.1 | 1.2 | 1.0 |
| 10 psi | 1.7 | 1.1 | 1.1 | 1.2 |
| 15 psi | – | 1.7 | – | 1.5 |
| 20 psi | 2.4 | – | 1.8 | 1.7 |

[a] Coarse aggregate (+No. 8).
[b] Fine aggregate (–No. 8).
[c] Triaxial strength tests (deformation of 0.15 in./min).

mixtures with large-sized aggregate. A limited correlation for the ½-in. mix indicated that the selected method of specimen preparation yielded slightly greater densities than the 50-blow Marshall method.

Expectations regarding the new design procedure were rewarded. This first series of testing has been most encouraging, and it is hoped that this new method for bituminous concrete design will find wide acceptance because it is applicable to mixtures having maximum aggregate sizes up to and including 1½ in.

## TEST RESULTS AND DISCUSSION

The triaxial strength results were fairly reproducible, although individual test results might vary at times by more than 5 percent because of the large-sized aggregate and the many problems associated with the preparation of a homogeneous specimen. The effect of asphalt variability on mix properties can be observed from a series of triaxial test results (Table 2). As might be expected, the air voids of the mix were affected. Surprisingly, however, the strength tests were not significantly different. A mixture with a 1-in. nominal-sized crushed stone did not lose its stability with void contents less than 3 percent.

Another series of tests (Table 3) sheds some light on the controversial subject of angularity versus strength. For this purpose, mixtures with all stone, stone coarse aggregate with river sand fines, gravel coarse aggregate with stone fines, and gravel coarse aggregate with river sand fines were compared. The gradations in all cases were identical to Mix C (1 in. top size) as given in Table 1. The resulting strengths shown in Figure 1 clearly demonstrate that the crushed stone contributes to the strength of a bituminous concrete when used in the coarse or fine portion of the mix. The best combination undoubtedly is the mix having all crushed particles. The data also indicate that the angularity in the particles of the coarse aggregate (material retained on the No. 8 screen) is more effective than the angularity of the particles of the fine aggregate. This is in slight disagreement with the work of Herrin and Goetz (7), who used double-plunger static compaction on the specimens having a gradation of ½ in. nominal size. The mix investigated by NCSA was of the 1-in. nominal size that had 70 percent coarse aggregate.

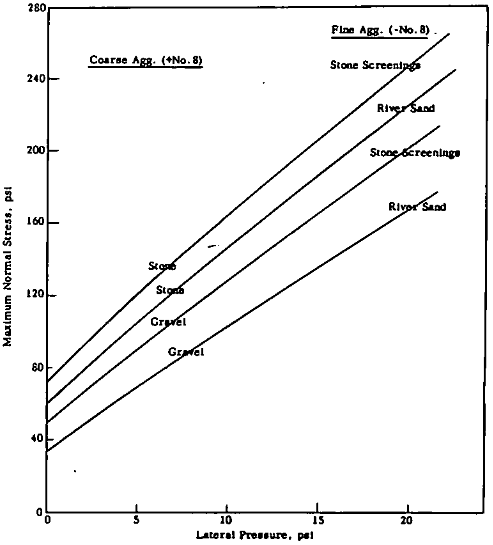

Figure 1. Effect of aggregate particle shape on triaxial compressive strength of asphaltic concrete (1 in. maximum-sized aggregate tested at 140 F).

A complete series of tests on the effects of aggregate particle size is given in Tables 4 and 5 and shown in Figure 2, where at least

### TABLE 4

### SUMMARY OF TRIAXIAL TEST RESULTS FOR STONE AND GRAVEL ASPHALTIC CONCRETE MIXTURES TESTED AT 140 F

| Category | Stone | | | Gravel | | |
|---|---|---|---|---|---|---|
| | Mix B | Mix C | Mix E | Mix B | Mix C | Mix E |
| Properties of compacted specimens | | | | | | |
| Asphalt, percent | 3.9 | 4.0 | 5.2 | 3.8 | 4.0 | 5.0 |
| Bulk specific gravity | 2.430 | 2.427 | 2.420 | 2.392 | 2.403 | 2.378 |
| Unit weight, pcf | 151.3 | 151.1 | 150.6 | 148.9 | 149.6 | 148.0 |
| Air voids, percent | 4.9 | 5.0 | 3.4 | 3.8 | 3.0 | 2.8 |
| VMA, percent | 14.0 | 14.2 | 15.5 | 11.9 | 11.7 | 13.4 |
| Voids filled, percent | 65.0 | 65.0 | 79.0 | 68.0 | 74.0 | 79.0 |
| Maximum normal strength[a], psi, at lateral pressure of | | | | | | |
| 0 psi | 80.0 | 90.0 | 92.0 | 35.0 | 35.0 | 30.0 |
| 5 psi | 125.0 | 135.0 | 142.0 | 67.0 | 72.0 | 60.0 |
| 10 psi | 173.0 | 180.0 | 174.0 | 98.0 | 102.0 | 94.0 |
| 15 psi | 215.0 | 222.0 | 226.0 | 134.0 | 140.0 | 130.0 |
| 20 psi | 248.0 | 240.0 | 256.0 | 165.0 | 167.0 | 150.0 |
| Deformation, percent strain, at maximum normal strength, lateral pressure of | | | | | | |
| 0 psi | 1.1 | 1.1 | 1.1 | 0.8 | 0.7 | 0.8 |
| 5 psi | 1.3 | 1.4 | 1.2 | 1.2 | 1.0 | 1.1 |
| 10 psi | 2.3 | 1.8 | 1.9 | 1.3 | 1.2 | 1.6 |
| 15 psi | 2.2 | 1.9 | 2.4 | 1.4 | 1.5 | 1.7 |
| 20 psi | 2.3 | 2.1 | 2.3 | 1.6 | 1.7 | 2.0 |

[a] Triaxial strength tests (deformation of 0.15 in./min).

### TABLE 5

### SUMMARY OF TRIAXIAL TEST RESULTS FOR STONE AND GRAVEL ASPHALTIC CONCRETE MIXTURES TESTED AT 72 F

| Category | Stone | | | Gravel | | |
|---|---|---|---|---|---|---|
| | Mix B | Mix C | Mix E | Mix B | Mix C | Mix E |
| Properties of compacted specimens | | | | | | |
| Asphalt, percent | 4.2 | 4.2 | 5.2 | 3.8 | 3.8 | 5.0 |
| Bulk specific gravity | 2.443 | 2.442 | 2.429 | 2.401 | 2.386 | 2.372 |
| Unit weight, pcf | 152.0 | 152.0 | 151.1 | 149.4 | 148.5 | 147.6 |
| Air voids, percent | 4.0 | 4.2 | 3.0 | 3.0 | 3.7 | 2.9 |
| VMA, percent | 13.8 | 13.8 | 15.5 | 11.6 | 12.1 | 13.6 |
| Voids filled, percent | 71.0 | 70.0 | 81.0 | 74.0 | 70.0 | 78.0 |
| Maximum normal strength[a], psi, at lateral pressure of | | | | | | |
| 0 psi | 250.0 | 270.0 | 290.0 | 251.0 | 245.0 | 210.0 |
| 5 psi | 260.0 | 312.0 | 302.0 | 262.0 | 248.0 | 226.0 |
| 10 psi | 270.0 | 298.0 | 336.0 | 280.0 | 255.0 | 250.0 |
| 15 psi | 305.0 | 327.0 | 356.0 | 305.0 | 295.0 | 270.0 |
| 20 psi | 365.0 | 344.0 | 386.0 | 307.0 | 305.0 | 286.0 |
| Deformation, percent strain, at maximum normal strength, lateral pressure of | | | | | | |
| 0 psi | 1.1 | 1.2 | 1.3 | 1.1 | 0.9 | 1.3 |
| 5 psi | 1.6 | 1.1 | 1.4 | 0.9 | 1.0 | 1.5 |
| 10 psi | 1.2 | 1.3 | 1.4 | 1.1 | 1.0 | 1.5 |
| 15 psi | 1.6 | 1.2 | 1.8 | 1.3 | 1.0 | 1.8 |
| 20 psi | 1.3 | 1.7 | 2.3 | 1.3 | 1.0 | 1.9 |

[a] Triaxial strength tests (deformation of 0.15 in./min).

### TABLE 6

### TRIAXIAL STRENGTH RATIO OF STONE TO GRAVEL MIXES, PERCENT

| Lateral Pressure (psi) | Test Temperature 140 F | | | Test Temperature 72 F | | |
|---|---|---|---|---|---|---|
| | Mix B | Mix C | Mix E | Mix B | Mix C | Mix E |
| 0 | 228 | 257 | 307 | 100 | 110 | 138 |
| 5 | 186 | 188 | 237 | 99 | 126 | 134 |
| 10 | 176 | 176 | 185 | 96 | 117 | 134 |
| 15 | 160 | 159 | 174 | 100 | 111 | 132 |
| 20 | 150 | 144 | 171 | 119 | 113 | 135 |

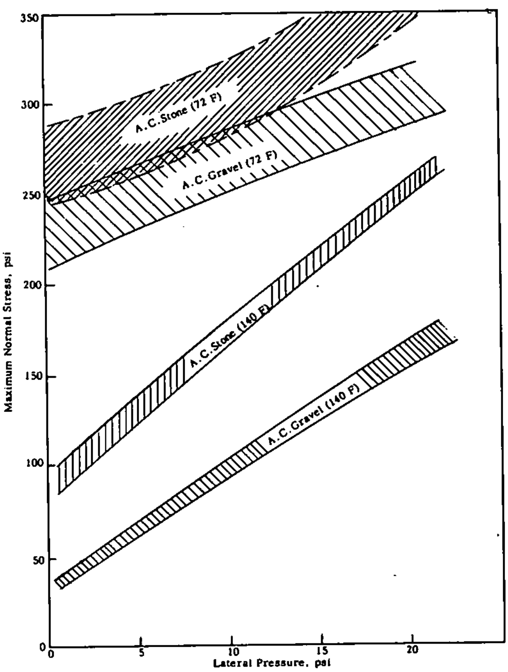

Figure 2. Triaxial compressive strength of asphaltic concrete crushed stone, gravel, and river sand.

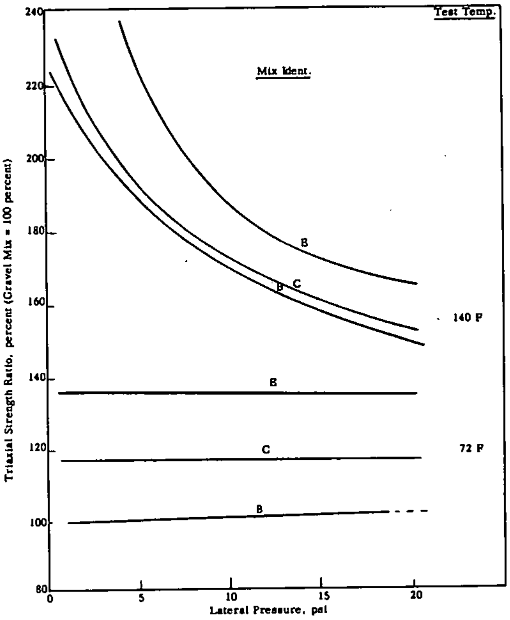

Figure 3. Triaxial strength comparison of asphaltic concrete with crushed stone and gravel.

half of the mixes were repeated. A general conclusion from these tests is that no appreciable contribution to the strength is made by increasing the maximum size of the aggregate, but, looked at from another point of view, it may be said that, as the maximum size is increased, equally strong mixes can be developed using somewhat less asphalt.

A comparison of the strengths of the stone and gravel mixes is given in Table 6 and shown in Figure 3. The tests at 140 F show that the stone mixes developed strengths much greater than those of mixes containing gravel, but the strength ratio is not constant and decreases as the confining pressure increases. The difference in strength at 72 F was not as great, but was approximately constant and approximately as follows:

Mix B (1½ in.)—stone and gravel equal
Mix C (1 in.)—stone better by 15 percent
Mix E (½ in.)—stone better by 34 percent

## CONCLUSIONS

The present status of our research into the merits of different aggregates in hot-mixed, hot-laid asphaltic concrete may be summarized as follows:

1. A method of test has been developed to realistically evaluate bituminous mixtures with large-sized aggregates up to and including those having a 1½-in. maximum size.
2. A small variation in the asphalt content of mixtures with large-sized crushed stone aggregates does not detrimentally affect the strength.
3. Equally stable mixes with less asphalt can be prepared as the aggregate size is increased.
4. Crushed stone asphaltic concrete mixtures, when tested at 140 F and lower lateral pressures, are almost twice as strong as those prepared with natural materials, but the difference is not as great at higher confining pressures or lower temperatures.

5. Although testing at 140 F may not be justified for base course mixes, tests at some intermediate temperature, such as 100 to 110 F, should provide an indication of the beneficial effect of the crushed stone aggregates.

6. Angular aggregates contribute to the strength properties of asphaltic concrete either in the coarse or fine portion of the mix. The best results were achieved with crushed aggregates throughout the mix.

These conclusions are based on tests using the method as described. Although these aggregates are judged to be typical, the results and ratios developed may not necessarily be applicable to all aggregates.

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