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Abridgment

Characteristics and Performance of Low-Quality Aggregate in an Experimental Flexible Pavement

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As a major component of pavement structures, aggregates directly affect structural integrity and durability. Under traffic and in rigorous climatic conditions, the quality, properties, and behavior of aggregate play crucial roles in pavement performance and service life. Aggregate degradation, whether caused by chemical interactions such as moisture and freeze-thaw or mechanical causes during construction and/or traffic loading, contributes to pavement distress mechanisms. Complex interactions among load, stresses, strains, and climate, as well as how and where aggregates are used, may influence the extent of the effect of aggregate quality on pavement performance.

Assuming that high-quality materials yield better performance, it is desirable but not always feasible to use quality aggregates in pavement construction. In some regions, supplies of quality aggregate are scarce and the costs of transporting such materials are high. Many other areas have abundant local supplies of lower-quality aggregates and, in some cases, as with certain ash wastes from power plants, so-called inferior materials can be substituted in paving mixtures with little or no adverse effect on pavement performance.

These considerations have stimulated research into low-quality aggregates and their influence on pavement performance. In two such studies recently completed at Ohio State University (1, 2), the characteristics of local low-quality aggregates and their influence on the performance of flexible pavement were evaluated. The first study focused on identifying the mechanisms of aggregate degradation by means of a detailed laboratory evaluation that simulated climate and loading conditions. The second study evaluated the performance of such materials under service conditions.

AGGREGATE QUALITY AND DEGRADATION MECHANISMS

Selection of Materials

The aggregates used in these studies were acquired from local suppliers in central Ohio where the research facilities are located. First, local sources of aggregate were reviewed for the availability of materials, past performance history, and compliance with specifications. Five sources, designated plants 1 through 5, were selected to provide samples of no. 67, no. 57, and no. 8 coarse gravels and sands, which are defined as low quality by state specifications based on content of deleterious material (shale, chert, etc.). These aggregates were used in the laboratory evaluation program; comparable materials were later used to construct an experimental section of flexible pavement for field analysis and laboratory verification.

Laboratory Test Programs

To analyze the properties and performance of local low-quality aggregates, materials obtained from the five sources were subjected to test programs that included environmental simulation, moduli response, indirect tensile strength, and structural simulation of pavement response. Standard procedures were used to determine material properties. Aggregates were oven dried, sieved, and tested for sodium sulfate soundness loss and Los Angeles abrasion loss.

Aggregate quality was expressed in terms of the weight of deleterious materials retained on a 4.75-mm (no. 4) sieve rather than by weight of the total sample. Each aggregate was tested by the Ohio Department of Transportation (DOT) and Ohio State University (OSU) laboratories. The Ohio DOT laboratory used standard procedures. The OSU research team used a subjective but more stringent criterion:

Pieces of aggregate were scraped against the bottom of a stainless-steel pan by using moderate finger pressure, and if the aggregate left a residue it was considered deleterious. The results of these two approaches were only marginally in agreement, but, since the study was largely concerned with qualitative rather than quantitative differences between aggregates, it was felt that the disparity in results would not seriously affect the validity of the findings.

After materials characterization and the assessment of aggregate quality, asphaltic mixes that met specifications for surface and base courses were designed, prepared, and evaluated.

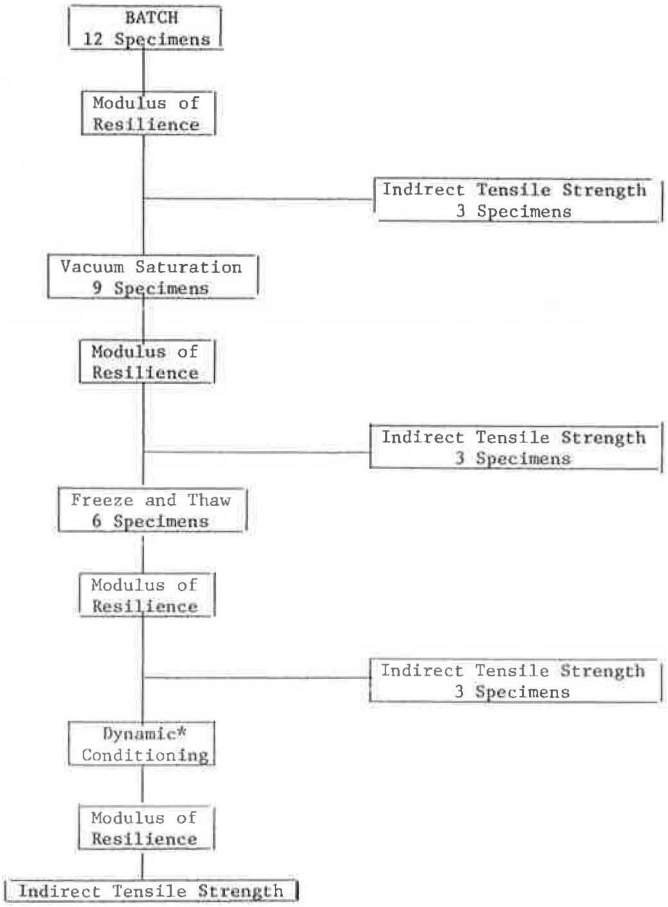
The surface-course mixtures (one for each materials source) were prepared by using no. 8 coarse gravel and sand, one asphalt type (AC-20), and similar gradations. Since low-quality aggregates may be susceptible to moisture damage, the mixes were designed so that air voids were close to a minimum of 4 percent and the percentage of fines passing the 0.075-mm (no. 200) sieve was limited to 4 percent. At least 12 Marshall specimens were prepared for each mix type by using standard procedures. A minimum of three samples were prepared for each mix at three asphalt contents; these were analyzed for Marshall stability and flow, specific gravity of aggregate, loose mix and compacted specimens, and air voids and voids in mineral aggregate.

The base-course mixtures were prepared by using no. 67 coarse gravel and sand from each source, AC-20 asphalt cement, and an asphalt content of 4.7 percent by weight of total mix and were designed to have similar gradations. Two types of mixes were prepared for each source: (a) one set of samples in which the deleterious materials were removed and (b) another set in which the deleterious contents were as established by the OSU quality tests. These samples were prepared as follows.

Sufficient material for 24 Marshall-size specimens from each source was oven dried and sieved, and the fractions were separated and stored. All deleterious materials (shale, chert, etc.) were removed from fractions larger than the percentage passing a 4.75-mm (no. 4) sieve and were stored. For each mix type, 12 specimens were prepared by recombining appropriate fractions to meet gradation limits and replacing deleterious materials with quality aggregate of comparable gradation. A second set of 12 specimens was prepared for each mix type in the same way except that deleterious materials were recombined in proportions established in the earlier tests of aggregate quality. Specific gravity and water absorption were determined for the coarse and fine aggregates and the loose mix by using standard procedures.

The durability of the base-course mixes was evaluated by using a specially designed environmental simulation program, which is shown in Figure 1. The program used a resilient-modulus approach; i.e., each batch of specimens was tested for resilient modulus and indirect tensile strength. As Figure 1 shows, samples were selected at random, subjected to vacuum saturation and freeze-thaw, and then retested for resilient modulus and/or tensile strength. The original program also called for dynamic load tests after environmental conditioning. But the effects of the freeze-thaw conditioning were so damaging that the specimens could not withstand dynamic loading, and this item was dropped from the program.

Figure 1. Flowchart for environmental simulation testing program.



Laboratory Test Results

The gradation of the aggregates studied showed wide variation from one source to another. For example, a no. 57 gravel from plant 1 had 17.67 percent passing the 12.7-mm (0.5-in) sieve, whereas the same type of aggregate from plant 2 showed 51.2 percent passing the same sieve size. Similar variations were noted for gravels no. 8 and no. 67. Los Angeles abrasion tests showed similar plant-to-plant variations. The abrasion values for no. 57 gravel ranged from 24 to 40.2 percent. The values for no. 8 gravel were very similar, however—generally less than 30. Most aggregates did fall within specification limits. These aggregates also met limits for soundness loss but again showed variations according to source. No. 8 gravel from plants 1 and 3 had the highest losses (18.4 and 18.8 percent, respectively); for no. 67 gravel, plant 4 yielded 15.2 percent loss whereas plant 5 yielded 17.5 percent loss; and for no. 57 gravels and sands, plants 1 and 5 showed the highest soundness losses. The contents of deleterious material obtained by the Ohio DOT and OSU laboratories are given in Table 1. Again, the agreement in the results was only marginal and, although it is felt that the findings of the study are valid, this disparity would have to be considered in developing aggregate acceptance standards.

The results of Marshall tests on surface-course mix samples are shown in Figure 2. The mix stability and density of material from plant 2 were relatively insensitive to asphalt content, as was the stability of plant 4 mixes. At optimum asphalt contents, the air voids contents of all five mixes were very close to the lower design limit. To meet air voids requirements, the optimum asphalt contents would have to be reduced,

Table 1. Deleterious material in low-quality aggregates.

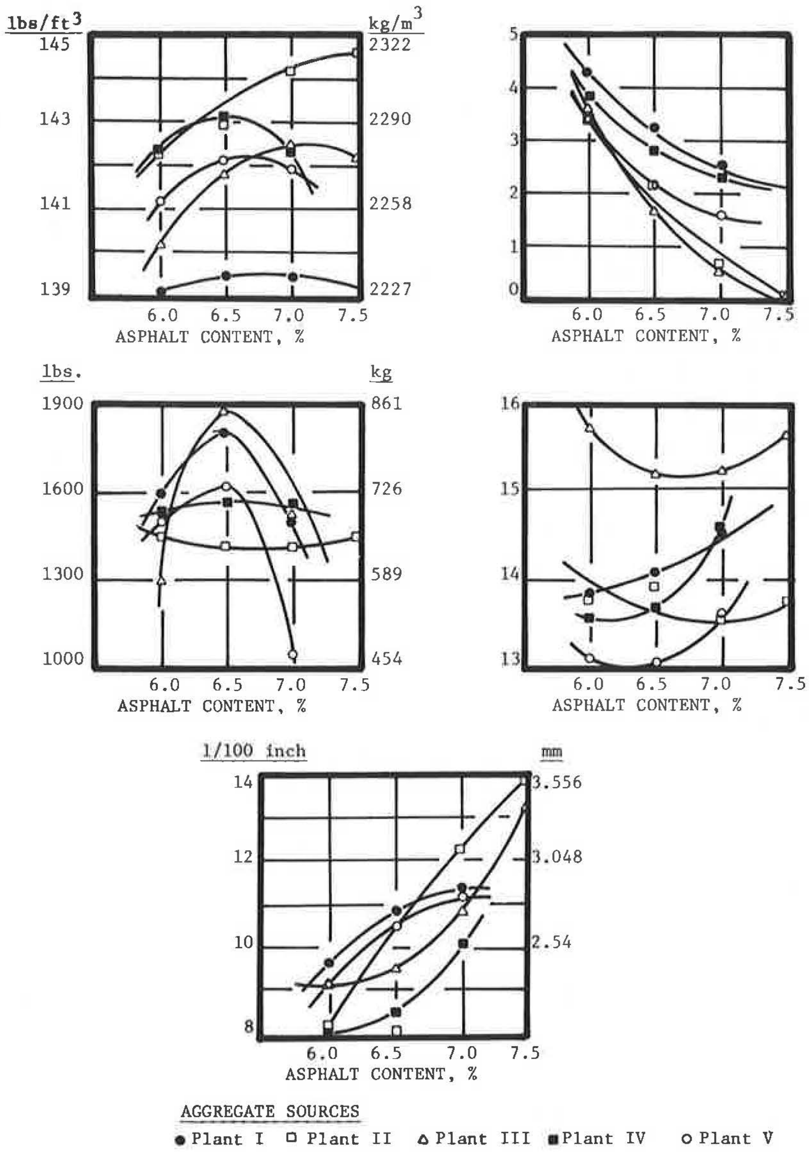
		Deleterious Content (%)					
		Shale and Shaly Material		Chert and Other Material		Total	
Type of Aggregate	Material Source (plant no.)	Ohio DOT[a]	OSU[b]	Ohio DOT[a]	OSU[b]	Ohio DOT[a]	OSU[b]
No. 8 gravel	1	2.8	1.70	0.2	2.10	3.0	3.80
	2	2.6	0.48	0.2	1.05	2.8	1.53
	3	1.3	4.02	0.1	0.54	1.4	4.56
	4	NA	2.57	NA	5.16	NA	7.73
	5	NA	4.08	NA	3.09	NA	7.17
No. 57 gravel	1	2.0	3.39	0.3	4.17	2.3	7.56
	2	0.5	0.32	0.1	3.60	0.6	3.92
	3	2.4	3.15	0.1	3.67	2.5	6.82
	3	2.1	NA	0.1	NA	2.2	NA
	3	3.5	NA	0.2	NA	3.7	NA
	4	1.1	0.71	0.1	2.54	1.2	3.25
	5	3.1	1.89	0.2	4.84	3.3	6.73
	5	3.6	NA	0.1	NA	3.7	NA
	5	2.4	NA	0.2	NA	2.6	NA
No. 67 gravel	1	2.0	5.94	Trace	10.42	2.0	16.36
	2	0.9	1.56	0.3	4.09	1.2	5.65
	3	3.6	5.81	0.1	6.10	3.7	11.91
	3	3.0	NA	0.1	NA	3.1	NA
	4	1.1	3.23	0.1	7.31	1.2	10.54
	5	1.9	5.63	0.3	9.77	2.2	15.40
	5	2.1	NA	0.1	NA	2.2	NA
	5	1.6	NA	0.1	NA	1.7	NA

Note: NA = data not available.

[a] Results obtained by Bureau of Testing, Ohio Department of Transportation.

[b] Results obtained by Materials Research Laboratory, Ohio State University.

Figure 2. Marshall mix design curves for surface-course mixtures that contain low-quality aggregate.



thereby reducing mix stability and density. It is probable that degradation and fines production during mix preparation and compaction contributed to the low observed values of air voids and flow. A more detailed investigation might yield data that would lead to a more optimal design. While this study was in progress, however, the state transportation department decided to prohibit the use of low-quality aggregates in surface-course mixtures, and subsequent research efforts focused on base-course mixture performance.

The results of the initial tests of resilient modulus and indirect tensile strength performed on the base-course mixtures are given in detail elsewhere (2). The results indicate that aggregate source and the inclusion or removal of deleterious materials had no significant effect, although the tensile strengths of specimens from which deleterious materials were removed were slightly higher than those of specimens that contained such materials. From a pavement designer's viewpoint, the differences in moduli and strength between the two types of specimens are not significant.

The results of tests on saturated samples led to a similar conclusion. There were no significant differences between materials from different sources, and the effects of including or excluding deleterious materials were only minimal. It was concluded that during initial stages of pavement life, before the structure experiences severe environmental exposure, the moduli and strength are, for all practical purposes, unaffected by the presence or absence of deleterious material in the coarse aggregate.

However, the effects of freeze-thaw conditioning were quite significant and resulted in substantial reduction of moduli and strength for all mixes, regardless of source or deleterious content. A review of data on field cores taken from pavements built with conventional materials showed substantially higher values before and after saturation and freeze-thaw—only a 25-50 percent loss in moduli and strength after environmental conditioning—whereas the samples tested in this study experienced a two-thirds reduction in moduli and strength after conditioning. As mentioned previously, the damage to specimens subjected to freeze-thaw conditioning was so severe that afterwards the samples could not withstand dynamic loading.

Since the removal of deleterious material from coarse aggregate does not ensure that the fine aggregate is satisfactory material, it was considered that deleterious sand might have contributed to the observed poor durability of these mixtures. Accordingly, a mixture in which plant 3 coarse aggregate was used and crushed limestone sand was substituted for the plant 3 sand was prepared and evaluated for resilient modulus. The experimental mixture that contained plant 3 sand and coarse aggregate and from which deleterious material was removed showed a modulus ratio of 0.22; the ratio for the mix that contained plant 3 nondeleterious coarse aggregate and crushed limestone sand was 0.44, nearly double the mix response. This suggests that deleterious material in the fine aggregate may also be detrimental to mixture performance and should be investigated further and be considered in developing specifications.

EXPERIMENTAL FLEXIBLE PAVEMENT PROJECT

Selection of Materials and Site

After the completion of the study described above, an experimental flexible pavement in which low-quality aggregates were used in the base course was designed and constructed near Newark, Ohio, and field and laboratory analyses of its performance were conducted. The Ohio DOT laboratory conducted materials characterization and quality tests on a number of aggregates and selected three classes of experimental mixtures:

1. Type A material used an aggregate that contained less than 2.5 percent deleterious material (using Ohio DOT standard procedures).
2. Type B aggregate had 2.5-3.5 percent deleterious material.
3. Type C aggregate had 3.5-6.0 percent deleterious material.

These three aggregates were incorporated into the base mixes and placed at various stations throughout the project.

Test Program

Dynaflect dynamic deflection measurements were taken on the project subgrade before construction, on the completed base course, and on the completed pavement after the placement of a standard asphaltic surface course. Field cores were also taken—three for each mix type—from the finished pavement after one year's service. The cores were tested for dynamic modulus and then sawed into three Marshall-size sections. The lower sections were tested for tensile strength while the remaining sections underwent the environmental-conditioning program of saturation and freeze-thaw used in the earlier study (Figure 1).

Bulk samples of each class of uncompacted paving mixes were obtained at the time of construction. Seventy-eight Marshall-size specimens were prepared by using standard procedures. After determination of specimen density, the samples were tested for resilient modulus and indirect tensile strength, and a number of randomly chosen samples underwent the same environmental-conditioning program used before.

Test Results

Initial deflections on the subgrade showed considerable variation in maximum deflection and surface curvature index, but measurements on the completed pavement showed a very uniform response (which indicated that subgrade support had improved and that the structure was uniform in thickness and stiffness characteristics). There were no significant differences in deflections on the sections constructed with different classes of materials; this suggested that the initial performance of all three types of mixtures was quite similar and met initial design requirements.

The results of initial resilient-modulus tests on bulk material samples showed unrealistically high moduli: 4248-10 324 MPa (616 000-1 497 000 lbf/in^2). It was felt that the presence of large aggregates in these specimens had distorted the stress field in these tests and yielded the higher moduli. Therefore, several cylinders were prepared from the bulk material, tested for compressive dynamic modulus, and sawed into Marshall-size samples, and the middle section was analyzed for resilient modulus. The dynamic moduli of these samples were within the expected range, but the resilient moduli (obtained from samples with two cut faces, which somewhat reduced the aggregate size) were nearly double the range of the dynamic moduli.

The average resilient moduli for field cores are

Table 2. Effect of environmental conditioning on resilient modulus and indirect tensile strength.

Mix Type	Sample Type	Resilient Modulus (MPa)		Indirect Tensile Strength (MPa)		Ratio (before to after freeze-thaw)	
		Unsaturated	After Freeze-Thaw	Unsaturated	After Freeze-Thaw	Resilient Modulus	Indirect Tensile Strength
A	Laboratory	5261	5379	2896	3841	0.55	0.71
	Field cores	2759	4069	2103	2896	0.76	0.71
B	Laboratory	7723	7186	3793	4303	0.47	0.60
	Field cores	2310	3855	1655	2262	0.72	0.59
C	Laboratory	9242	6131	4745	3821	0.51	0.62
	Field cores	2055	3614	1414	1365	0.69	0.38

Note: 1 MPa = 145 lbf/in^2.

summarized below (1 MPa = 145 lbf/in^2):

Mix Type	Sample No.	Dynamic Modulus (MPa)	Modulus of Resilience (MPa)
A	1	2359	2393
	2	2910	3689
	3	2703	2186
Avg		2655	2758
B	1	2255	2207
	2	2062	2407
Avg		2179	2310
C	1	1952	2000
	2	2076	2110
Avg		2014	2055

From the design viewpoint, the variations in moduli among types A, B, and C mixes are not highly significant. Greater variations can be found among standard mixes with similar aggregate qualities. On the basis of initial performance parameters, it was concluded that there were no significant variations among the three aggregate types that were caused by deleterious material content.

The effects of environmental conditioning on both bulk samples and field cores are summarized in Table 2. As in the earlier study, environmental conditioning (which was much more severe than actual conditions likely to be encountered in Ohio) significantly reduced mixture stiffness and strength. The degree of deterioration in strength increased with increases in the amounts of deleterious materials incorporated into the mixture. Accordingly, type C mixes showed the greatest reduction in moduli and tensile strength under environmental conditioning. Type A mixtures, which had the lowest deleterious content, experienced as much deterioration as type B mixes, which had an intermediate deleterious content. Again, it was suspected that the deleterious content of the fine aggregate might have contributed to the observed performance.

SUMMARY AND CONCLUSIONS

The results of the studies reported in this paper suggest that the presence of deleterious material in either fine or coarse aggregate may be detrimental to pavement performance. Laboratory and field data indicate that, although these materials may perform satisfactorily in the initial stages of pavement life, exposure to saturation and freeze-thaw conditions can result in substantial deterioration in mixture strength and stiffness. It is concluded that such materials should not be used in surface-course mixtures where climatic exposure is greatest. Such materials could be used in base courses if adjustments are made in layer equivalencies to account for lower durability characteristics.

The data also suggest that the presence of deleterious materials in coarse aggregate is not solely responsible for the poor performance exhibited by these mixtures. Deleterious fine aggregate may also adversely affect the durability of mixtures prepared with low-quality aggregates. This possibility is currently being investigated at Ohio State University.

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