Asphalt Overlays of Concrete Pavements: Case Studies in Arkansas

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The rutting problems on two sections of Interstate highway in Arkansas are discussed in this paper. The original asphalt concrete overlays of concrete pavement placed in the late 1970s consisted of a total asphalt thickness of approximately 8½ in. Immediate rutting on one of the overlay jobs led to a reevaluation of Arkansas mix design practices. Modifications made in the mix designs included changing to a 75-blow Marshall design and following AASHTO T245 (Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus) with no alterations. The rutted overlay was milled and surfaced using the new mix design practice. After 6 yr of service, the new overlay is again performing poorly. The other asphalt concrete overlay in another part of the state, however, continues to perform well after 12 yr of service. Other factors not addressed by the Marshall design procedure must therefore have contributed to the difference in pavement performance between the two projects.

Arkansas Interstate highways were completed in their entirety using 8–10 in. of portland cement concrete pavement over various types of bases. Rehabilitation began in the mid-1970s and now 95 mi of the original 542 mi of concrete pavement have been overlaid with asphalt concrete hot mix (ACHM). Construction of the first asphalt overlay on the Interstate highway began in 1974. A typical section of that project consisted of 300 lb/yd^2 of crushed stone bituminous base course, otherwise known as the crack-relief layer, 415 lb/yd^2 of ACHM binder course, and 165 lb/yd^2 of ACHM surface course. This overlay began rutting shortly after construction was complete. The average rut depth was 9/16 in. While the cause of this rutting was under investigation, construction began on a similar overlay of 16 mi of Interstate 40 in East Arkansas. This is the project that will be discussed here.

The I-40 overlay contract was awarded in July 1975 for $6.6 million. Approximately 65 lane-mi of Interstate was overlaid in a four-lane section from Widener to Shearerville. In 1975 the truck volume at this site was 5,180 trucks/day. In 1988 the truck volume had grown to 8,170 trucks/day. While traffic was detoured to an adjacent highway, the westbound lanes were overlaid through the surface course and opened to traffic in July 1977. Work began on the eastbound lanes; while the binder and surface were being placed, the westbound lanes began to rut. By the summer of 1978, rutting had progressed in the westbound lanes to such a state that tractor-trailer rigs were hydroplaning during and after rain showers. After completion of the surface course in the eastbound lanes, the work was suspended. The final course, an open-graded friction course, was not laid.

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MIX DESIGN INVESTIGATION

Needless to say, the Arkansas Highway and Transportation Department (AHTD) was very concerned when these first two Interstate overlays began rutting. Work was undertaken to determine the cause of this problem and the changes necessary to prevent its recurrence. The Asphalt Institute and Federal Highway Administration worked closely with the department in reviewing the then-current Arkansas mix design and pavement construction practices. This review, coupled with research into the rutting problem, led to many modifications in design and construction practices.

Three types of rutting were occurring:

1. Excessive traffic consolidation in the upper ACHM course due to poor compaction during construction.
2. Plastic deformation due to insufficient mix stability and low void content.
3. Deformation due to instability, which was caused by stripping in the mix.

The asphalt surface course placed on Interstate 40 was composed of limestone coarse aggregate and natural sand. A modified Marshall 50-blow mix design of 22 percent natural sand, 5.3 percent asphalt cement, and 1.5 percent air voids was used for the westbound lanes; eastbound lanes used a mix of 30 percent natural sand, 5.0 percent asphalt cement, and 3.5 percent air voids. An initial look at the cores taken from the westbound lanes of Interstate 40 led to doubts about the stability of the crack-relief layer because some binder seemed to have penetrated that layer. However, the occurrence of binder in the crack-relief layer did not correlate well with rut depth. Furthermore, samples taken from the roadway showed that the binder and surface had less than 0.5 percent air voids in the wheelpaths and less than 1.5–2.0 percent air voids between the wheelpaths. This finding indicated that the binder and surface were responsible for this rutting. It was obvious that changes were needed in mix design procedures and construction practices before any more overlays were placed on the highway.

The mix design procedure used during the construction of the I-40 overlay was an Arkansas modified Marshall mix design procedure. The maximum theoretical specific gravity was a calculated effective specific gravity based upon bulk and apparent aggregate-specific gravities. The combination of the design procedure and the calculated effective specific gravity resulted in ACHMs that contained a high percentage of asphalt cement by weight of total mixture with questionable void content. These mixes are quite durable but can become plastic due to low voids, and rutting can result.

The aggregates that the contractor proposed to use were required to be hard, tough, durable, and 100 percent crushed particles (coarse aggregate), free from an excess of soft particles. In addition, the aggregates had to be uniformly well graded from coarse to fine and free from an adherent film of clay. When the proposed aggregate complied with these requirements, AHTD inspectors sampled the aggregate stockpiles and submitted samples along with stockpiled aggregate gradation to the central laboratory for design. (Historically, all asphalt concrete hot mixes have been designed in the central laboratory by the Materials and Research Division of the AHTD.) The aggregates were proportioned to develop a trial job-mix gradation, which was within the master range of the specifications. A modified Marshall mix design procedure was used to establish the optimum Marshall properties and, indirectly, the optimum asphalt cement content. This design procedure had been used since 1952.

Summary of Old Mix Design Procedures

- Except for mixes for North Arkansas, where an 85–100-penetration-grade asphalt was used, all mixes were designed using the trial mix gradation with a 60–70-penetration-grade asphalt cement from a standard source. The contractor was allowed (with proper documentation) to switch to another asphalt cement, without a mix redesign, so long as the new asphalt cement was a 60–70-penetration-grade from an approved source.
- Aggregated and asphalt cements were heated to mixing temperature (400°F and 300°F, respectively) on electric hotplates.
- Mixing was accomplished by hand.
- The Marshall specimen molds and Marshall compaction hammer were not heated.
- Air-void content in the compacted Marshall specimen was determined by comparing the specimen's bulk specific gravity with an effective maximum specific gravity of mixture, which was established by averaging the asphalt-cement specific gravity, +No. 4 aggregate bulk specific gravity, and −No. 4 aggregate apparent specific gravity.
- The ACHM mixture was compacted at a temperature above 300°F. The actual mix temperature at the time of compaction was not established.
- The Marshall specimens were extruded, whenever convenient, from the molds by using a hand-held Marshall hammer.
- Marshall stability and flow were obtained according to standard Marshall procedure using regular Marshall equipment.

Summary of Old Construction Procedures

- The asphalt cement was allowed to be heated to a maximum of 300°F before it was introduced into the plant.
- Aggregates were allowed to be heated to 350°F before being introduced into the plant.
- A minimum wet-mixing time of 40 sec was required. The mixture was to be discharged from the plant and delivered to the roadway at a temperature between 285°F and 325°F.
- The finished ACHM surface courses were to be compacted to 92 percent and maximum theoretical specific gravity, determined as described above.
- At least two rollers were required per project, one of which had to be a tandem roller. The rollers were required to weigh at least 8 tons, and at least one had to weigh 10 tons.
- For breakdown rolling of surface courses, a tandem steel wheel or three-wheel roller was required. Intermediate rolling was to be performed by a pneumatic roller, and final rolling by a tandem steel-wheel roller.

Implemented Changes in Mix Design and Construction Practice

Because traffic volume on Arkansas highways is increasing, AHTD developed a new specification in 1977, "Requirements for Asphalt Concrete Hot Mix Binder and Surface Courses," for highways with heavy traffic (especially heavy truck traffic). This new specification used the same gradation meter range as the regular (50-blow Marshall) surfaces and binders, but it further requires that these mixes be 75-blow Marshall and meet the design requirements shown in Table 1.

Aggregate requirements for this new specification remained the same. The stability and flow of the field mixture were to be checked daily by using the same type of Marshall equipment that is used in the central laboratory. Uniformity of the mixture was checked at least daily by performing extractions, in accordance with AASHTO T164.

A heat-stable antistrip was required in both the 75-blow binder and surface courses at a rate of application established in the laboratory by trial mixes. Before being used in ACHMs on highway projects, the effectiveness of each antistrip was to be determined by a boiling water test.

The trial job-mix gradation was established for these mixes as described earlier. The trial job-mix gradation was plotted on .45-power paper for comparison to the maximum density line of the particular ACHM course. Depending upon the relative position of the trial job-mix gradation to the maximum density line, the trial job-mix gradation was adjusted to provide sufficient voids in the mix. As a general rule, AHTD mixes are on the fine side of the maximum density line. Every effort is made to avoid paralleling the job mix gradation to the maximum density line to minimize the chances of producing a low-void, tender mix.

In 1980, a specification ("Special Requirements for Asphalt Concrete Hot Mix Binder and Surface Courses for Heavy Traffic") was developed to replace the 1977 specification. The specification has changed little since 1980 and is included in AHTD's latest standard specification for 1988. These design requirements are shown in Table 2.

Summary of 1980 Mix Design

- Coarse aggregate must be 100 percent crushed on the No. 10 sieve, and at least 70 percent of the particles on the No. 4 sieve must have a minimum of two fractured faces.
- All mix designs must accord with AASHTO T245, i.e.:
  - The ACHM binder and surface courses are 75-blow Marshall per side.
  - Mixing and compaction temperature ranges are established from the temperature-viscosity curve for the

TABLE 1 ARKANSAS ASPHALT MIX REQUIREMENTS, 1977

Test	Requirements for Surface	Binder
Mix Design		
Min. Stability (AASHTO T245)	1400	1400
Flow (0.1 inch)	8-14	8-14
Minimum VMA (%)	15	13
Air Voids (%)	3-5	3-5
Target Air Voids (%)	4	4
Field		
Min. Stability (lbs)	1200	1200
Flow (.01 inch)	8-14	8-14
Air Voids (%)	3-8	3-8

TABLE 2 ARKANSAS ASPHALT MIX REQUIREMENTS, 1980

Test	Requirements for Surface	Binder
Mix Design		
Min. Stability (AASHTO T245)	1500	1500
Flow (.01 inch)	8-16	8-16
Minimum VMA (%)	14	13
Air Voids (%)	3-5	3-6
Field		
Min. Stability (lbs)	1500	1500
Flow (.01 inch)	8-16	8-16
Maximum Air Voids (%)	8	8

asphalt cement to be used. These temperature ranges are reported on every Marshall mix design report that AHTD issues.

— Electronic digital thermometers are used to control the temperatures in the lab.
— Electronically controlled electric ovens are used to heat the aggregate, asphalt cement, and Marshall molds.
— Marshall compaction hammers are heated on hot plates.
— Aggregates and asphalt cement are mechanically mixed.
— Hydraulic jacks are used to extrude specimens from Marshall molds.
— Stability and flow values are electronically recorded by automatic-control Marshall equipment.

- Maximum theoretical specific gravity is determined by the Rice method (AASHTO T209).
- Bulk specific gravities of Marshall specimens are determined by AASHTO T166.
- Asphalt cements must meet the requirements of AASHTO M226, Table II.
- All mixes are checked to determine their sensitivity to moisture by AHTD Test Method 132, "Water Sensitivity for Compacted Mixtures."
- Antistrip agents must be prequalified by passing a boiling water coating test.

Summary of 1980 Construction Procedures

- Baghouse fines, if used, must be accurately metered into the mix.
- Heat-stable antistrip is added in a line at the hot-mix plant in a metered quantity.
- All fuel must be completely burned.
- The recommended temperature ranges shown on the mix design will yield the best results.
- Mixtures must contain no more than 0.75 percent moisture.
- Optimum rolling patterns are to be determined for each

mix at the beginning of paving operations by making a 500-ft test strip.

- Field stability and flow values and target density for acceptance will be determined daily for each lot (a day's run) of mixture produced.
- Density requirements for the compacted pavement for each lot will be based on the average of five cores, which must equal or exceed 96 percent of laboratory density; no one density can be less than 91.0 percent of laboratory density.

ASPHALT MIX PERFORMANCE

Rutting progressed on the I-40 westbound lanes and in 1979, although the mix design procedures and specifications had not completely evolved, AHTD chose to mill and overlay. As an add-on to another overlay project, it was decided to mill ⅘ in., the depth of the ruts, and lay 165 lb/yd^2. This new surface was designed using the old procedure, except that the Marshall compactive effort was at 75 blows rather than 50 blows. After the overlay was complete, the original contract was resumed and completed except for the open-graded friction course in the eastbound lanes.

Two years later, in 1981, the eastbound lanes of the I-40 overlay had rutted enough to warrant rehabilitation. Using the revised 1980 design procedures and specifications, a contract was let to mill 1½ in. of the original surface and lay 165 lb/yd^2 of new surface mix as well as the open-graded friction course. This is the last rehabilitation work that has been done on this section of I-40.

In 1985, the performance of both eastbound and westbound lanes was checked. The westbound lanes, completed in 1979, had rutted to an average depth of ½ in. while the eastbound lanes averaged 5/16-in. rutting. Cores were taken from the westbound lanes to determine the reason for the recurrence of rutting. Cores taken in the wheelpaths showed that the air voids averaged 4.5 percent for the surface overlay, 0.9 percent for the original surface, and 0.2 percent for the binder (see Figure 1). Cores taken between the wheelpaths showed air void contents of 5.0 percent for the overlay, 2.7 percent for the original surface, and 0.7 percent for the binder course. The eastbound lanes were not cored. At this time, 6 yr after the 75-blow Marshall was used for the overlay, with air voids of 4.5 and 5.0 percent, it appeared that AHTD had been successful in its design and construction of an interstate highway overlay.

In 1988 the performance of both lanes was checked again. Because of continued rutting, the eastbound lanes had been milled and could not be measured. Ruts in the eastbound outside lane had an average depth of ½ in., a progression of 3/16 in. since the check in 1985.

Again, cores were taken from both the eastbound and westbound outside lanes. In the westbound lane, cores taken in the wheelpaths showed that the air voids averaged 2.4 percent for the surface overlay, 0.1 percent for the original surface, and 0.4 percent for the binder course (see Figure 2). Cores taken between the wheelpaths showed average air voids at 3.3 percent for the surface overlay, 0.5 percent for the original surface, and 0.5 percent for the binder course.

In the eastbound lane, average air voids in the wheelpaths were 1.2 percent for the overlay and 0.2 percent for the binder (see Figure 3). Between the wheelpaths, the average air voids were 1.6 percent for the overlay and 0.8 percent for the binder.

These rut depths and air void levels show that this section of I-40 now needs another rehabilitation project. The performance of the westbound lane for 9 yr and the eastbound lanes for 7 yr since their overlays in 1979 (westbound) and 1981 (eastbound) indicates that simply milling the ruts and

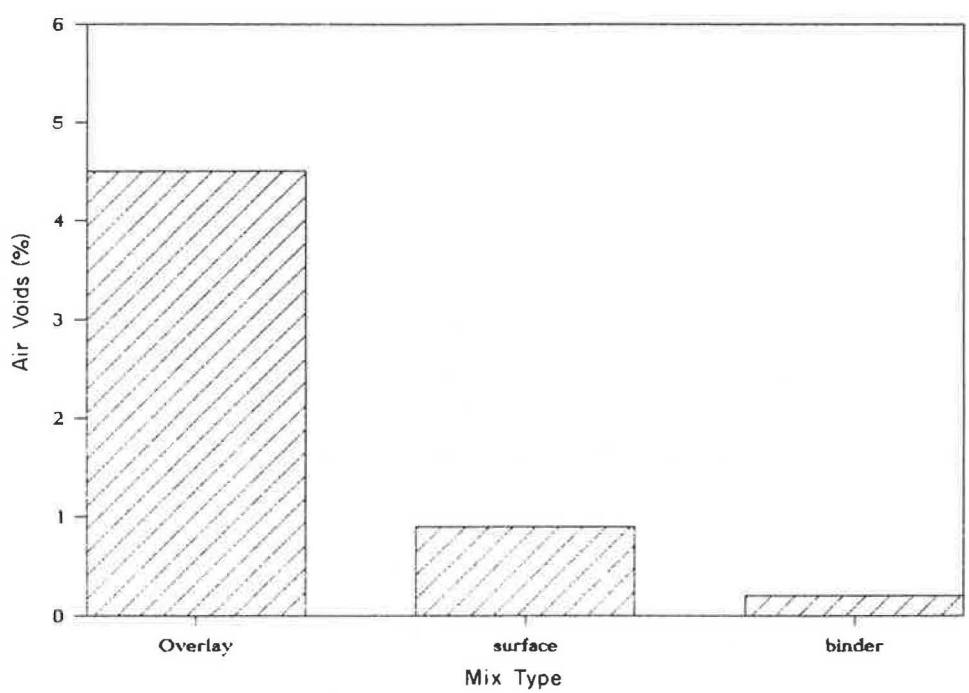

FIGURE 1 Air-void content of westbound I-40 pavement in 1985.

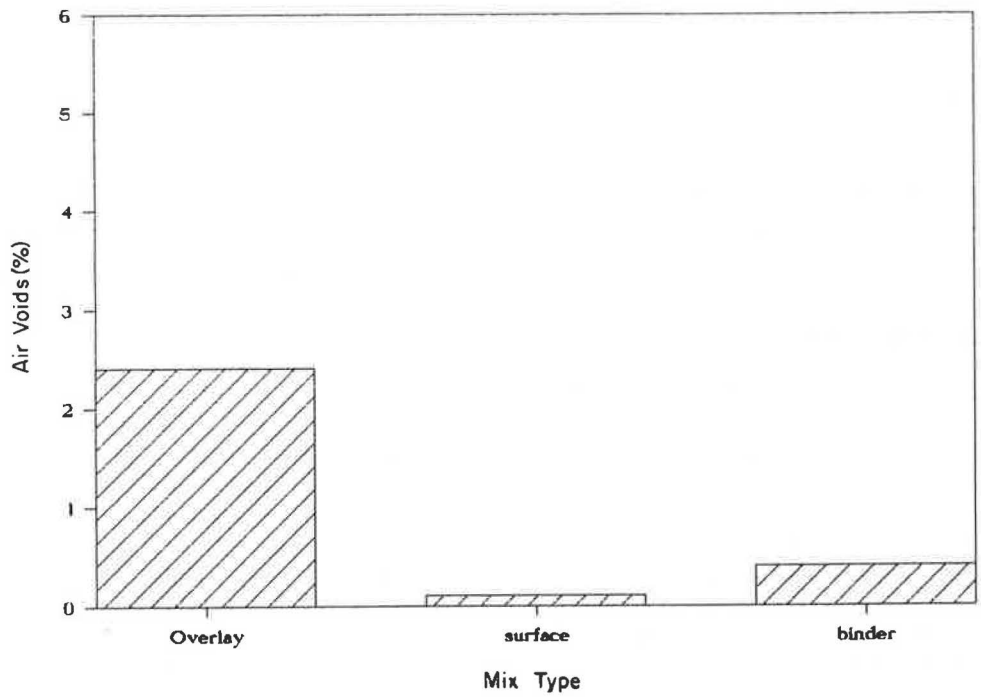

FIGURE 2 Air-void content of westbound I-40 pavement in 1988.

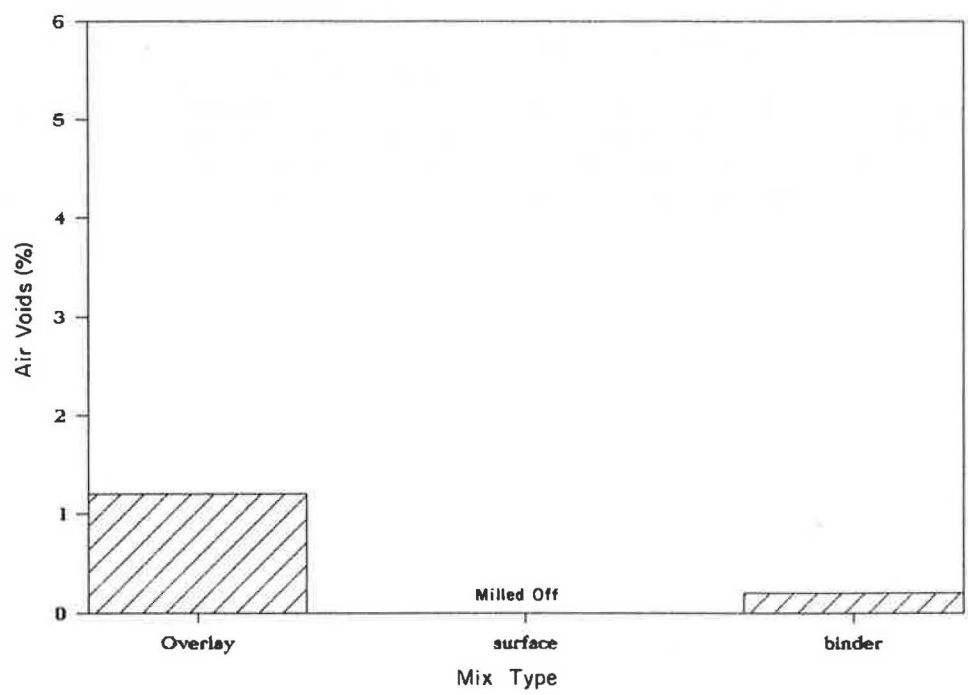

FIGURE 3 Air-void content of eastbound I-40 pavement in 1988.

overlaying with a minimum depth surface course may be a short-term solution, if the pavement layers beneath the overlay are in a plastic state. Results from the 1985 and 1988 core tests show that the 75-blow design procedure and field requirements are definitely an improvement over the older procedures, but they may be insufficient to resist deformation caused by the increasing weight and volume of heavy interstate highway traffic.

The 75-blow design procedure has not adequately defined the ultimate voids in the mixture. In this case, for example, the 75-blow mix design used in the westbound lanes was compacted to 6 percent air voids during construction. The design air-void content was 4.1 percent, and cores taken in 1985 showed that 6 yr of interstate traffic had consolidated the mix to a void content of 4.5 percent. The design air void content closely predicted actual air void content, but, unfortunately,

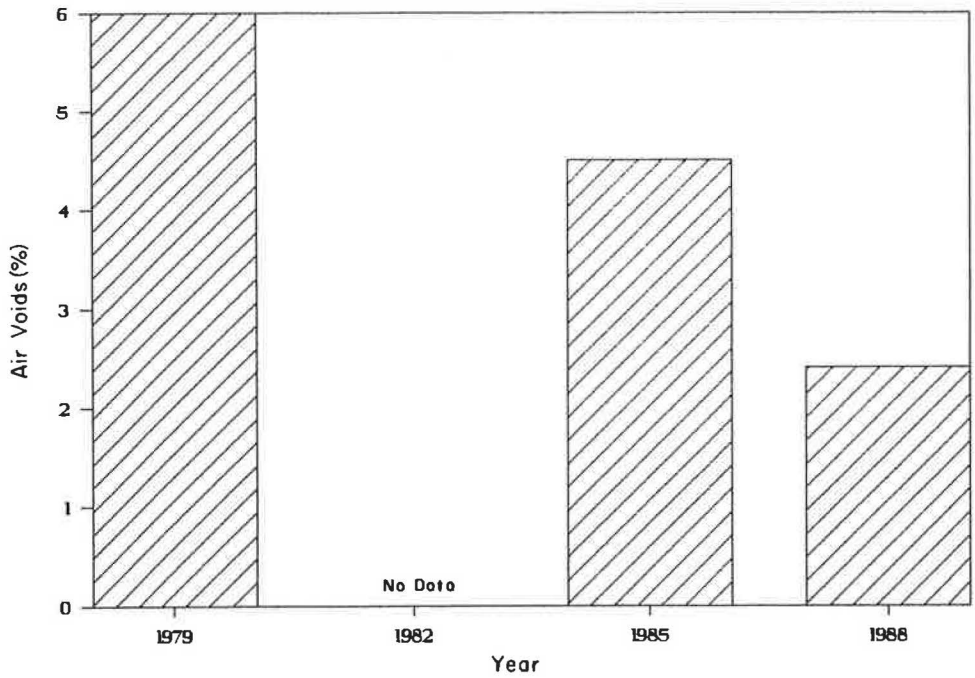

FIGURE 4 Air-void content of westbound I-40 overlay.

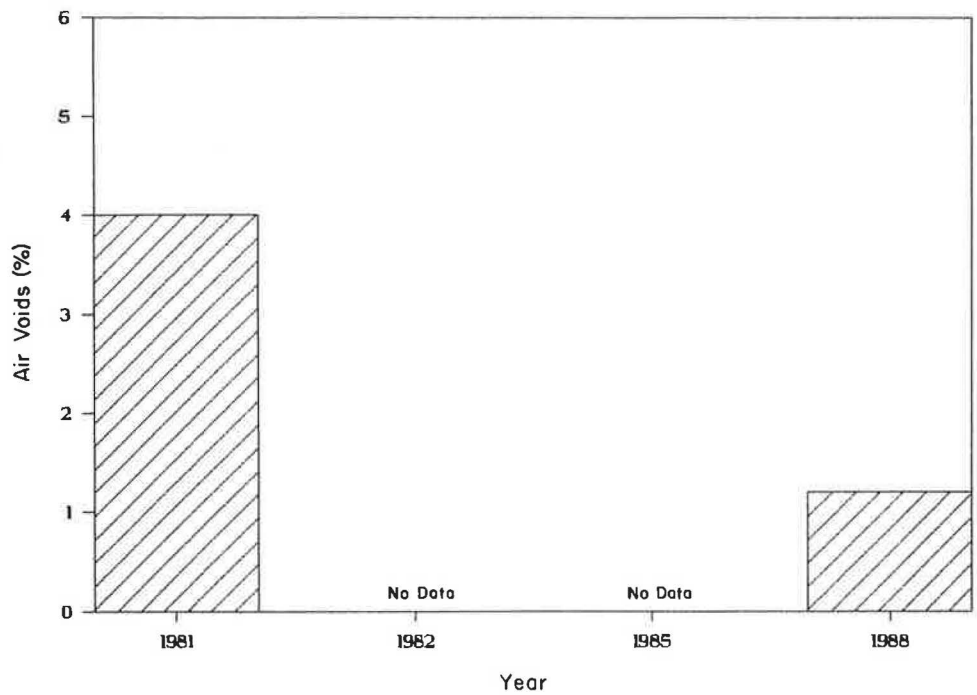

FIGURE 5 Air-void content of eastbound I-40 overlay.

consolidation from traffic did not stop there. By 1988, after 9 yr, the mix had further consolidated to 2.4 percent void content and the mix may be approaching a plastic condition (see Figure 4). The eastbound overlay is in worse condition. It was designed at a void content of 3.4 percent, and the mix was compacted to 4 percent air voids during construction. In 1988, after 7 yr, the average air void level had dropped to 1.2 percent. This mix is definitely in a plastic condition (see Figure 5).

Evaluation of the I-40 overlays shows that improvements in mix design and quality control have helped; however, current procedures for the aggregates available in Eastern Arkansas are still inadequate for interstate highway traffic. A 6-yr life for an overlay on the interstate highway is better than 6 mo, but it is still not the life that had been counted on.

In 1976 and 1977, about the same time that the Interstate 40 overlay was being constructed, two similar projects were under way on Interstate 30 near Little Rock. A typical section

from the projects on I-30 had essentially the same composition as the I-40 overlay, i.e., 300 lb/yd^2 of bituminous crushed-stone base course, 400 lb/yd^2 of ACHM binder course, and 165 lb/yd^2 of ACHM surface course. Both Interstate projects used the same asphalt mix designs, although the I-30 project in Pulaski County was started 1 yr earlier. The surface mix for these jobs was composed of syenite coarse aggregate with 15 percent natural sand and 5 percent limestone dust. The mix design was a 50-blow modified Marshall. Optimum asphalt content was 5.6 percent and the design air void percentage was 3.0.

The two I-30 overlays, with a traffic history similar to that of I-40, have held up very well after 11 yr. Rutting in the wheelpaths is less than ¼ in. Apparently the I-30 50-blow mixes have outperformed the I-40 mixes that were designed with new mix requirements and a 75-blow Marshall mix design.

CONCLUSION

Some design and construction procedures still need to be revised to produce an asphalt hot-mix overlay that will resist today's heavy loads and volume on an interstate highway. Arkansas is reviewing fine aggregate shapes and gradations with the intent of limiting quantities and types of natural sands. A comparison of compactive effort of laboratory specimens with actual compactive effort on the roadway is needed. It is believed that the degree of crushing on some coarse aggregates is insufficient to provide adequate angular shape. Generally, Arkansas is in the process of tightening specification tolerances for aggregate gradations, AC contents, and air voids of the job-produced mix, as well as for rolling and compactive efforts on the roadway.

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