Abridgment

Construction of Open-Graded Asphalt Friction Courses by Using Asphalt Cement and Asphalt Emulsion

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Both the microtexture and the macrotexture of pavement influence the level of skid resistance available to a tire rotating on the roadway surface (1). To increase the level of friction, several state highway departments have constructed open-graded asphalt friction course (AFC) layers as wearing surfaces (2, 3, 4, 5, 6). Much information on AFC mix design, in which asphalt cement is used as the binding agent, has been published by the Federal Highway Administration (FHWA) (7, 8) and by the American Association of State Highway and Transportation Officials (AASHTO) (9).

In Indiana, hot asphalt emulsion pavement mixtures have been used in the surface courses of highway pavements. This paper reviews the mix design methods, construction procedures, and performance of two AFC projects in which asphalt emulsion was used instead of asphalt cement as the binding agent in most of the AFC material.

IN-43 EXPERIMENTAL PROJECT

Mixtures for Test Sections

The Indiana State Highway Commission (ISHC) constructed an experimental AFC project on a 1.6-km (1-mile) section of IN-43 in White County in June 1974. The four different AFC mixtures that were placed used three coarse aggregates and two types of asphalt. A fifth section, a control section, used an ISHC standard emulsified asphalt hot sand mix.

Limestone, gravel, and slag coarse aggregates were used. The gradation of each met the requirements for ISHC 11 material, which is similar to AASHTO 2.36-mm (no. 8) grading. Coarse aggregate made up 90 percent of the AFC mix by weight of aggregate, and natural sand (ISHC 14-2) and mineral filler (ISHC 16 limestone dust) each made up 5 percent of the total aggregate weight. The gradations of the aggregates used are given below (corresponding U.S. sieve sizes are 0.50 and 0.375 in and nos. 4, 8, 16, 30, 50, 100, and 200):

	Percentage Passing by Weight of Aggregate		
Sieve Size (mm)	Coarse Aggregate	Fine Aggregate	Mineral Filler
12.5	100	–	–
9.5	75-95	100	–
4.75	5-20	98-100	–
2.36	0-5	75-95	–
1.18	–	50-75	–
0.6	–	20-53	100
0.3	–	6-25	–
0.15	–	1-17	–
0.075	0-3	0-3	65-100

Both asphalt cement and asphalt emulsion were used. The asphalt cement was a standard 85-100 penetration grade material. The asphalt emulsion, Indiana grade AE-60 (a high-float material), was manufactured by using a 50-100 penetration base asphalt cement.

Each of the five test sections was about 304.7 m (1000 ft) long and 1.90 cm (0.75 in) thick. The gravel coarse aggregate mix contained 6.5 percent asphalt cement. Slag coarse aggregate was used in two sections, one with 7.8 percent asphalt cement and one with 7.8 percent residual AE-60 asphalt emulsion (the amount of emulsion added to the mix was 11.1 percent, assuming 30 percent water in the emulsion). The limestone coarse aggregate mix incorporated 6.5 percent residual AE-60 asphalt emulsion. The hot sand mix control section, which contained 100 percent ISHC 14-2 natural sand, had a residual asphalt emulsion content of 7.5 percent.

All asphalt contents were determined by using modified Hveem mix design laboratory methods. The actual asphalt content for each mix was chosen based on a combination of stability, void content, and visual appearance according to Colorado (6) and FHWA (7) guidelines.

Construction

All five mixtures were produced in a Stansteel 3.6-Mg (4-ton) batch plant. A 60-s wet cycle time was used for all mixes, and target plant temperatures were 124° C and 110° C (255° F and 230° F) for the asphalt cement and asphalt emulsion mixtures respectively. The hot emulsion sand mix was made at a standard 93° C (200° F) at time of plant discharge.

Because of the small quantities of each mixture that were produced and because of the varying moisture contents in the three coarse aggregate materials, a wide variation occurred in the mix temperature of different mix batches in the plant. These variable temperatures caused the asphalt (particularly the asphalt cement) to drain from the coarse aggregate particles during the haul to the jobsite. In several truckloads, asphalt and mineral filler accumulated 5.1 to 7.6 cm (2 to 3 in) deep on the bottom of the truckbed.

Many fat spots occurred in the mixes when they were placed on the roadway by a conventional asphalt finishing machine. The fat areas were especially prevalent in the gravel and slag coarse aggregate sections that used asphalt cement as the binding agent. Because of the extreme number of spots, it was impractical to remove them, and they were allowed to remain in place.

Two steel-wheel rollers, a three-wheel and a tandem, were initially used to compact the AFC mixtures. Much crushing of the aggregate occurred during the rolling operation, especially under the three-wheel roller. Compaction was finally accomplished by using only one or two passes of the tandem roller. Some pickup of the mix occurred when the roller passed over a fat spot in the pavement surface.

Performance

The performance of the four AFC test sections and one sand mix test section has been monitored visually since 1974. Test data on mix performance have not been gathered because of the variations that existed at the time of construction, particularly the spots of excess asphalt on the AFC surfaces. In early 1978, the fat spots were still quite visible. Some raveling of the coarse aggregate has occurred in all test sections, but more coarse aggregate has been lost from the two sections that used asphalt cement (gravel and slag coarse aggregate) than from the two sections that used asphalt emulsion (slag and limestone coarse aggregate).

Based on visual observations only, the AFC test sections can be ranked as follows in order of quality of performance from best to worst: (a) slag and emulsion, (b) limestone and emulsion, (c) slag and asphalt cement, and (d) gravel and asphalt cement. The performance of each mix, however, seems to be directly related to the condition of each mix at the time of initial placement.

I-64 PROJECT

Mix Design

In the fall of 1975, an AFC surface course mixture was placed on a 5.72-km (3.56-mile) long section of I-64 in Crawford County, Indiana, at IN-37. The material was placed 1.90 cm (0.75 in) thick on top of 40.6 cm (16 in) of full-depth asphalt concrete. Hot emulsion sand mix was placed as the wearing course on an additional 4.98 km (8.10 miles) of the project at a rate of 1.58 cm (0.625 in).

A 90 percent mechanically crushed gravel that met an AASHTO 2.36-mm (no. 8) grading was used as the coarse aggregate in the AFC mix. This material, barged and trucked over 160.9 km (100 miles) to the paving site, was used for 90 percent of the mix. Natural sand (ISHC 14-2) and a limestone dust mineral filler (ISHC 16) each made up 5 percent of the total weight of the aggregate blend. The specification limits for the mixture are given below (corresponding U.S. sieve sizes are 0.50 and 0.375 in and nos. 4, 8, 16, 30, 50, 100, and 200):

	Percentage Passing by Weight of Aggregate	
Sieve Size (mm)	Specification Limits	Typical Grading
12.5	100	100
9.5	88-100	92
4.75	19-37	37
2.36	9-19	13
1.18	7-13	9
0.6	6-12	7
0.3	5-10	5
0.15	4-8	4
0.075	3-6	3

Grade AE-60 asphalt emulsion was used in the AFC material. The laboratory asphalt content of the mix was determined by the centrifuge kerosene equivalent test.

Different residual asphalt contents, mix temperatures, and methods of compaction were used in several trial mix designs made by both ISHC and FHWA. An optimum asphalt content of 6.2 percent residual asphalt emulsion (8.9 percent emulsion, by weight of mix, added to the plant pug mill) was selected for the project. Mixture temperature was set at 110° C (230° F).

Construction

The AFC mixture was produced in a 4.5-Mg (5-ton) Cedarapid asphalt batch plant. Because of the volume of water in the emulsion and the size of the plant's asphalt weigh bucket, only 3.6 Mg (4 tons) of AFC were mixed in one batch. A 2-s dry mix, 70-s wet mix, and 82-s total mix cycle was used. DC-200 silicone was added to the AE-60 asphalt emulsion. The mixture was discharged into the haul vehicles at a temperature between 104° C and 116° C (220° F and 240° F).

The mixture, which was hauled an average distance of 11.3 km (7 miles), was spread with a Blaw-Knox PF-180 paver. At the time of laydown, mix temperatures ranged between 102° C and 104° C (215° F and 220° F) except at the start of paving. No unusual placement problems occurred. The mix flowed from under the paver screed with no pulling or tearing. Compaction was accomplished in four passes over each point in the pavement surface with a Tampo RS-188A double-drum vibratory roller. The roller operated in the static mode without vibration. No nuclear density readings or compaction cores were taken on the AFC layer.

Temperature variations occurred in the first few loads of mix delivered because of starting difficulties at the plant. Some minor drainage of asphalt emulsion from the aggregate occurred in these loads during the truck haul. Several small areas of excess asphalt appeared in the placed mix; these were left in place. Once the plant temperature was stabilized, no further problems were encountered with asphalt drainage.

Performance

Traffic Volumes

In the summer of 1977, approximately 6000 vehicles/d, including 15 to 20 percent trucks, were traveling the test section of I-64. The eastern half of the AFC surface has been under traffic a year longer than the western half because of the location of an interchange in the middle of the job and a delay in the opening of the western half as a result of uncompleted construction beyond the project. Significant differences exist in the two halves of the AFC material; the section that has been under traffic for the extra year shows more damage and poorer performance.

Flushing

The eastern part of the AFC mixture has not performed satisfactorily. Minor flushing occurred in the outside lane at the start of the paving project early in the life of the pavement, primarily because of fluctuations in the initial mix temperature and problems with drainage of asphalt emulsion. This early flushing stabilized during 1976 and remained stable until mid-1977. The remainder of the AFC mixture initially exhibited no flushing or bleeding characteristics.

During the summer of 1977, major flushing occurred in

Table 1. Skid resistance of I-64 surface mixtures.

Date	Test Speed (km/h)	Skid Number: Asphalt Friction Course, Eastbound	Westbound	Average	Emulsion-Sand Mix, Eastbound	Westbound	Average
November 1975	64	39.2	43.4	41.3	50.9	47.3	49.1
June 1977	64	43.5	39.7	41.6	50.5	47.2	48.8
	80	40.6	40.5	40.5	47.7	45.2	46.4
	96	42.5	37.6	40.0	40.4	41.8	41.1

Note: 1 km = 0.62 mile.

both directions in both wheel paths of the travel lanes on the eastern half of the project. No flushing occurred in the wheel paths of the passing lane in either direction. No flushing occurred in any of the AFC mix on the western part of the project even though that section was opened to traffic in late 1976 and was subjected to the same traffic during all of 1977 that caused the flushing on the eastern half.

The flushing in the wheel paths on the eastern portion is not continuous. Although several areas show excessive asphalt for a distance of over 0.81 km (0.5 mile), some locations between the badly flushed locations exhibit only minor or spotty flushing. This flushing has occurred both in the AFC mix placed at the start of paving and in the mix laid at the end of the job (3 d of total paving).

Consolidation and Shoving

Several of the badly flushed AFC areas have consolidated or rutted. In some locations, the depth of rutting is almost 0.95 cm (0.375 in); the average is 0.63 cm (0.25 in). Consolidation has taken place in a layer only 1.9 cm (0.75 in) thick. Visual observation indicates that lateral shoving has occurred: The AFC mix adjacent to the flushed wheel paths is slightly humped up above the surrounding pavement surface. The rutting is directly related to the flushing of the AFC mix.

Skid Numbers

The first skid tests on the I-64 project were conducted in November 1975, about 1 week after the eastern half of the project was opened to traffic. An American Society for Testing and Materials E-17 skid trailer was used. The measured skid numbers (Table 1) were obtained at 64 km/h (40 mph). The skid values for the AFC mixture were lower than those measured on the adjacent hot asphalt emulsion sand mix.

Skid tests were again conducted in June 1977. There was no improvement in the AFC values. The skid measurements were taken on the eastern portion of the project before the extensive flushing in the wheel paths took place. The AFC material exhibits little decrease in skid number with an increase in vehicle speed. The speed gradient of this mix is essentially zero. Although the hot asphalt emulsion sand mix has a greater speed gradient, it also has better levels of skid resistance at all test speeds. The 64-km/h (40-mph) skid numbers for the AFC mixture are slightly less than the average values obtained on densely graded asphalt concrete surface course mixtures in Indiana that use either asphalt cement or asphalt emulsion as the binding agent. To date, the AFC mixture has not demonstrated any benefits in relation to skid resistance.

Discussion of Results

The open-graded asphalt friction course material on the eastern half of the I-64 project deteriorated badly, in terms of rutting and flushing, during the second summer under traffic. The texture of the AFC surface has closed up; this significantly reduces the macrotexture of the surface in the wheel paths of the travel lane. Measured skid numbers are low even in the unflushed areas.

Visual observations made of the AFC material indicate that the mix design procedure used for this type of material is not adequate for use with asphalt emulsion as the binding agent in the mix. The performance of the AFC mix has been less than satisfactory, primarily because of flushing of the mix and rutting of the material under traffic. In addition, the skid numbers of the mix, using crushed gravel coarse aggregate, are below those of Indiana's standard hot asphalt emulsion sand mix or normal, densely graded asphalt concrete mixtures.

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Publication of this paper sponsored by Committee on Flexible Pavement Construction.