Evaluation of Open-Graded Asphalt Concrete Mixtures Used in Oregon

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Oregon began using open-graded hot-mix asphalt concrete mixtures on its roadway system in the late 1970s. Because of the excellent performance of these early jobs, open-graded hot-mix asphalt concrete has become the preferred choice for a surface course on many of Oregon's highways. To assess the performance of the open-graded mix, a survey was made of some of the older projects. A total of 17 projects was selected for evaluation: 11 open-graded and 6 dense-graded. The evaluation involves a comparison of the mix properties and their performance, which includes pavement condition survey, rutting resistance, skid resistance, and noise characteristics. The evaluation shows that all the open-graded projects had improved performance when compared with dense-graded projects. Resistance to cracking is improved, resistance to rutting is slightly increased, and skid gradient is improved. Measured noise levels did not show much difference, although the method of noise measurement may not have been capable of differentiating between the two types of mix. This evaluation supports the continuing use of open-graded mixtures on the Oregon roadway system. In addition, it provided an opportunity to develop new and improved guidelines for the use of these mixes.

Oregon began using open-graded hot-mix asphalt concrete mixtures on its roadway system in the late 1970s. Because of the excellent performance of these early jobs, open-graded hot-mix asphalt concrete has gradually become the preferred choice for a surface course on Oregon highways. At present, approximately 900 km center-line (560 mi) of the Oregon roadways are paved with open-graded asphalt concrete.

Open-graded asphalt concrete is characterized by use of a large percentage of coarse aggregate in the mix without a significant portion of fines, as commonly found in dense-graded mixes. In Oregon, the asphalt concrete mixtures are represented by Classes B to F (*1*). Classes E and F are open-graded; whereas Classes B, C, and D are dense-graded. The Class E mix has a nominal maximum size of 19 mm (.75 in.) and is generally used for nonstructural thin overlays [25 mm (1 in.)] to improve skid and hydroplaning resistance. The Class F mix has a nominal maximum size of 25 mm (1 in.) and is generally used for thin overlays [50 mm (2 in.)] and for wearing courses for new pavement construction and structural overlays on all highways [up to 100 mm (4 in.)]. Table 1 shows the broadband limits for three types of mix aggregate gradation most commonly used in Oregon, which are pertinent to this paper.

The F-mix is now being recommended for use on many Oregon roadways, including Interstate highways. To assess the performance of the F-mix, this paper presents an evaluation of some of the older projects constructed with the F-mix. A comparison is also made with pavements having dense-graded asphalt concrete (B or C mix) that were constructed at similar times and locations and have experienced similar traffic applications. In addition, conditions under which open-graded mixes should not be used are identified.

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BACKGROUND

Project Descriptions

To evaluate the overall mixture performance of the F-mix as compared with the B/C mix, 11 projects constructed with F-mix and 6 projects constructed with B/C mix in Oregon were selected for detailed examination. Table 2 provides a list of the selected projects. For the purpose of comparison, these projects were selected on the basis of being located in similar environmental conditions and having similar in-service life. Most of the F-mix projects were constructed from 1984 to 1986 and experienced total traffic applications from 60,000 to more than 2.5 million equivalent single axle loads (ESALs). The dense-graded (B/C mix) projects selected are of a similar age. These pavements have carried from 165,000 to nearly 2.0 million ESALs. Geographical and environmental conditions were also considered in the selection of these projects. An attempt was made to select projects with similar geographic and environmental conditions. It should be pointed out that Oregon has vastly different climatic characteristics, covering AASHTO climatic Regions I, II, and V (*3*). The selected projects were located mostly in AASHTO Regions I and II, where pavements are under wet, no-freeze, or wet, freeze-thaw conditions.

The surface thicknesses for all the projects range from 38 mm (1.5 in.) to 50 mm (2.0 in.) and are included as part of the pavement structure in design and therefore contributes a certain structural capacity. Currently, the same layer coefficient is used for both the F-mix and the B-mix. The surface lift thickness is established on the basis of the nominal maximum aggregate size. The minimum thickness should equal or exceed 1.5 to 2 times the maximum aggregate size. Current practice in Oregon recommends a minimum thickness of 51 mm (2.0 in.) for the F-mix.

Mix Designs

The mix designs for projects in this study were carried out following the Hveem procedure. The mix design procedures

TABLE 1 Aggregate Gradations for Typical Asphalt Concrete Mixtures Used in Oregon (2)

Sieve Size % Passing		Broadband Limits		
		Dense Graded		Open Graded
SI (mm)	U.S	Class B	Class C	Class F
25	1"	99-100	-	99-100
19	3/4"	90-98	99-100	85-96
12.5	1/2"	75-91	90-100	60-71
6.3	1/4"	50-70	52-80	17-31
2	No. 10	21-41	21-46	7-19
0.43	No. 40	8-24	8-25	-
0.08	No. 200	2-7	3-8	1-6
Asphalt Cement		4-8	4-8	4-8
Mineral Filler				0.0-1.5

TABLE 2 Description of Projects

No	Project Name	Mix Type	Top lift thick (mm)	Project Length (km)	Year Const.	ADT (1985)	Cumulative Traffic to date (7/92) (ESAL)
	a) Open-graded Mixtures						
1	Junction City-Airport Rd	F	51	11.3	1,979	9,800	1,048,000
2	Springfield-Leaburg	F	38	7.5	1,985	3,850	885,000
3	Springfield/Creswell-SPRR O'Xing	F	38	3.7	1,985	6,100	1,563,000
4	Clover Lane-Neil Crk Rd	F	38	4.8	1,985	3,900	226,000
5	Jenny Creek-Parker Mtn. Summit	F	38	8.2	1,986	470*	125,000
6	Day Creek-Truck Scales	F	38	3.2	1,984	1,300	65,000
7	S.Fork Coquille River-Railroad Ave. Sec.	F	38	2.8	1,985	1,100	130,000
8	Antioch Road-Crater Lake Highway	F	38	7.8	1,985	1,600	392,000
9	Lenz Road-Forge Road	F	38	1.6	1,984	3,200	2,534,000
10	Salmon Creek-Salt Cr.	F	51	9.6	1,983	2,400	2,126,000
11	Wild Park Lane-Reeves Creek Sec.	F	38	4.1	1,984	4,000	852,000
	b) Dense-graded Mixtures						
12	Eagle Creek-Salt Cr. Tunnel	B	51	12.3	1,985	2,300	1,612,000
13	Powers Jct.-Shields Cr	C	38	2	1,984	1,050	168,000
14	Powers Jct.-Warner Cr.	C	38	12.3	1,984	2,900	1,954,000
15	Monroe-Crow Creek	C	38	7.7	1,985	4,350	790,000
16	Church St (Monmouth)-S.FK Ash Creek Sec.	C	38	1.9	1,985	5,900	619,000
17	Third and Fourth Street (Corvallis)	C	51	2.7	1,982	10,900	1,064,000

* As of 1992

used for the F-mix and the B/C mix follow the same concepts, except for the Index of Retained Modulus, a modified Lottman conditioning procedure for predicting moisture-induced damage to asphalt concrete. This is not performed on the F-mix, primarily because of its rough surface and open gradation, which make modulus testing (ASTM D-4123) difficult.

Current mix design criteria for both types of mixtures used in Oregon are summarized in Table 3. As noted, the current F-mix designs have slightly increased targets for design air voids when compared with past practice. Hveem stability is no longer performed for F-mixes. However, a draindown test has been added. Draindown results are being compared with the field experience to help fine-tune the criteria. Additional changes made to the mix design procedure include determination of bulk specific gravity by the geometric procedure and use of static compaction instead of Hveem kneading compaction of specimens.

The mix design results for the projects evaluated are summarized in Table 4 and are plotted in Figures 1 through 4. The asphalt contents (percent, by weight of total mix) in the F-mix projects, as shown in Figure 1, are about the same to slightly higher than those in the B/C mix projects. With open-graded mixes, this results in thick asphalt coating on aggregates, which minimizes potential stripping and reduces the rate of oxidation. Typical asphalt contents used in these projects are between 5.2 and 6.0 percent. Asphalt grades used in the early projects were AC-20 and AR-4000, with passing No. 200 of 3.5 to 6.0 percent and mineral filler of 1 percent. Asphalts specified for use in open-graded mixes are used for current projects and will be used for future projects. These asphalts are graded to achieve maximum film thickness and reduce asphalt migration during hauling and laydown.

Air voids in the F-mix projects studied (Figure 2) were from 9.5 to near 15.6 percent after first compaction versus 2 to 6

TABLE 3 Mix Design Requirements and Criteria (2)

(a) Open-Graded Hot Mix Design Values		
Criteria	Past Value	Current Value
1.Asphalt Film Thickness	Sufficient to thick	Thickvery thick
2.Design Air Voids % (DAV) a) 1st compaction b) 2nd compaction (min.)	 11-13 8	 12-18 n/a
3.Hveem Stability, minimum a) 1st compaction b) 2nd compaction	 26 30	 n/a n/a
4.IRS @ DAV; minimum	75	75
5.Draindown	n/a	45-90%
Note:These mixes used to be designed with 1% portland cement incorporated as a mineral filler to stiffen the hot asphalt during transportation and laydown. The recent switch to the use of PBA-5 and PBA-6 asphalts (Table 5) has virtually eliminated the need for mineral filler.		

b) Dense-Graded Hot Mix Design Values			
Criteria	Heavy	Standard[1]	Light[2]
1.Asphalt Film Thickness	Sufficient to Sufficient-thick		
2.Design Air Voids % (DAV) a) 1st compaction b) 2nd compaction (min.)	 5.5-6.5 2.5	 5-6 2	 4-5 1.5
3.Hveem Stability, minimum a) 1st compaction b) 2nd compaction	 37 37	 35 35	 30 30
4.IRS @ DAV; minimum[3]	75	75	75
5.IRM_R @ Design Asphalt Content[4]	703	703	703
6.P200/AC ratio	0.6-1.2	0.6-1.2	0.6-1.2
7.VMA %, minimum a) "B-Mix" b) "C-Mix"	 14 15	 14 15	 14 15

[1]2,500 ADT or more
[2]Less than 2,500
[3]AASHTO T 167
[4]ASTM D 4123

TABLE 4 Summary of Mix Design Results

No	Project Name	AC Content[1]	Air voids[2]	Specific Gravity[2]	IRS (%)	Stability[2]
	a) Open-graded Mixtures					
1	Junction City-Airport Rd	5.2	12.8	2.3	70	33
2	Springfield-Leaburg	5.7	11.6	2.28	73	30
3	Springfield/Creswell-SPRR O'Xing	5.7	10.6	2.29	86	25
4	Clover Lane-Neil Crk Rd	5.5	12.4	2.3	76	26
5	Jenny Creek-Parker Mtn. Summit	5.6	15.7	2.25	89	26
6	Day Creek-Truck Scales	6	9.4	2.35	88	24
7	S.Fork Coquille River-Railroad Ave. Sec.	6	9.4	2.35	88	24
8	Antioch Road-Crater Lake Highway	6	12	2.29	75	27
9	Lenz Road-Forge Road	N/A	-	-	-	-
10	Salmon Creek-Salt Cr.	N/A	-	-	-	-
11	Wild Park Lane-Reeves Creek Section	5	8.6	2.39	89	36
	b) Dense-graded Mixtures					
12	Eagle Creek-Salt Cr. Tunnel	5.3	4	2.42	89	37
13	Powers Jct.-Shields Cr	5.5	2	2.42	89	33
14	Powers Jct.-Warner Cr.	5.5	2	2.42	89	33
15	Monroe-Crow Creek	5.6	4.5	2.31	81	30
16	Church St (Monmouth)-S.FK Ash Creek Sec.	N/A	-	-	-	-
17	Third and Fourth Street (Corvallis)	N/A	-	-	-	-

[1] % weight of mixture
[2] After 1st compaction. Voids based on Rice Gravity (AASHTO T 209)
N/A = Not Available

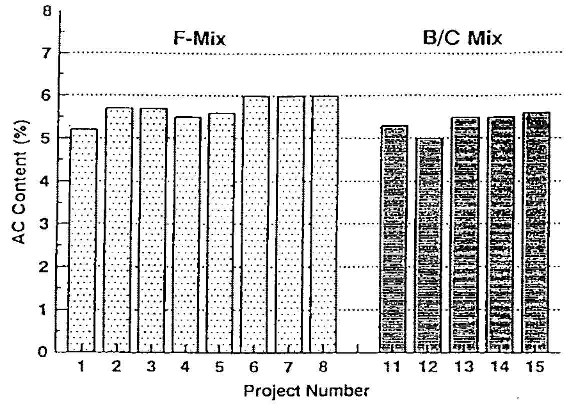

FIGURE 1 Comparison of design asphalt contents by project.

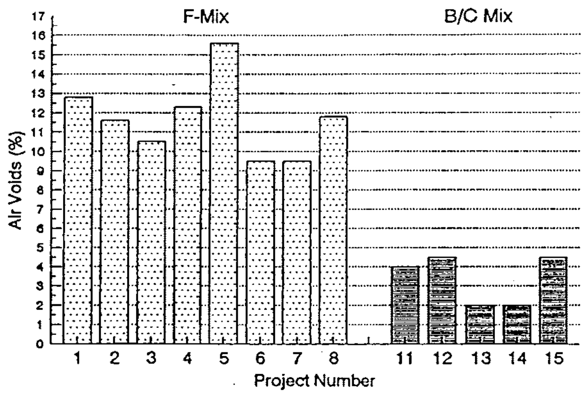

FIGURE 2 Comparison of mix design air voids by project after first compaction (used to represent in-place voids after construction).

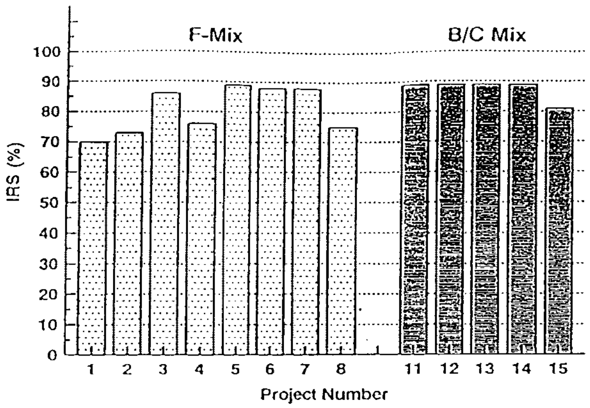

FIGURE 3 Comparison of IRS.

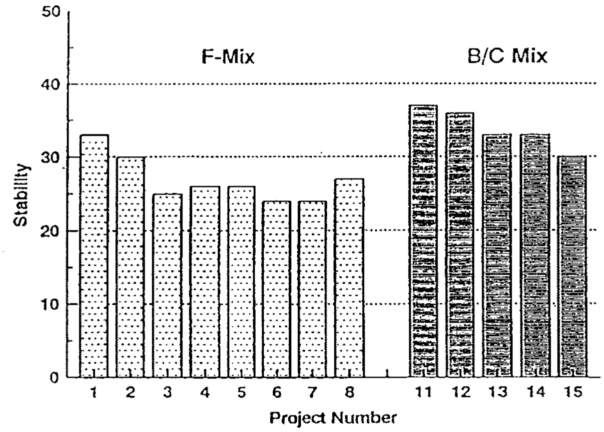

FIGURE 4 Comparison of Hveem stability value after first compaction.

percent for the B/C mix (current criteria call for slightly higher air voids to be used). Current design air voids range from 14 to 18 percent.

The index of retained strength (IRS) for the F-mix projects was slightly lower than those of the B/C mix projects (Figure 3). However, this is believed to be because of difficulties in testing open-graded mixes in an unconfined state and not because of increased stripping potential; stripping has not been a problem in these mixes.

The stability values of those F-mix projects were lower than those of the B/C mix projects (Figure 4). This is also reflected in the mix design requirements and criteria in Table 3. For the projects selected, the stability values (after first and second compaction) generally met or were close to the design requirements. It should be noted that low stabilities do not relate to rutting in the field.

Construction Considerations

The recommended mixing temperature for the F-mix is based on an asphalt viscosity of 700 to 900 cst. For these projects, the maximum mix temperature was 129°C (265°F) at the plant. Minimum allowable temperature during laydown was 96°C (205°F). This is comparable to 163°C (325°F) and 116°C (240°F) for dense-graded mixes. The lower temperatures for the F-mix help promote thick film coatings during mixing and minimize draindown of the asphalt during hauling and laydown. When excessive draindown is present, fat spots in the finished surface occur.

Compaction is performed with conventional equipment. However, for the F-mix, a minimum relative density is not specified. The specifications call for a minimum of four coverages with a steel-wheeled roller. Vibratory compaction is not allowed to avoid fracture of aggregate.

A light fog or sand seal is sometimes placed on the F-mix if the full mix design asphalt content cannot be maintained during hauling and laydown. The fog seal generally consists of a CSS-1 emulsified asphalt diluted 50:50 with water. The shot rate varies depending on the actual asphalt content maintained; typical rates are .32 to .64 L/m^2 (.1 to .2 gal/yd^2). This process is intended to replace the needed asphalt in the mix without reducing or eliminating the surface drainage features. However, since incorporation of the new improved asphalt specifications in 1991, the need for fog seals has been eliminated.

Special Considerations

The F-mix is not recommended for all projects. Some situations in which the F-mix is not used are discussed in the following paragraphs.

Long Hauls

Jobs far from the asphalt concrete plant to the project site are not recommended for F-mix because of problems with excessive draindown of the asphalt binder, cooling of the mix, or both. Although success has been obtained with one-way haul distances of up to 112 km (70 mi), the current policy is to stay below 56 km (35 mi). Weather conditions and asphalt grade may also influence the recommended haul distance. When long haul distances are necessary, a remixing stage is added at the paving site. The mix is remixed in a pugmill to break up any chunks of material that may have formed during cooling in the truck.

Inlays

The mixes must be allowed to drain. Drainage is accomplished by daylighting the mix on the shoulder. If adequate drainage outlets are provided, F-mixes may be used for inlays.

Hand Work

The F-mix, because of its coarse texture, is difficult to rake and is not easily placed where an abundance of hand work is necessary. Therefore, it is usually not specified for tapers, road approaches, or in city streets where there are inlets and manholes to work around.

Snow Zones

Some problems with F-mixes have been noted in snow zones where extensive snow plowing is required. The plow blades can catch on the coarse aggregate and pick it from the mat. In these areas, a conventional medium chip seal is normally placed on the mix. The chip seal eliminates the drainage properties of the F-mix.

PERFORMANCE EVALUATION

Condition Survey

Condition surveys for each of the 17 projects were conducted in July 1992 following a procedure developed by the Oregon State Highway Division (OSHD). The condition survey includes various types and severity of pavement distresses, as described in the AASHTO Design Guide (*3*). Each distress type is recorded on the basis of extent and severity, and a deduct score is assigned. The overall pavement structural rating is then calculated by subtracting the distress deduct scores from a perfect score of 100. Pavements with scores of 80 to 100 are classified as very good; 60 to 79 as good; 40 to 59 as fair; 20 to 39 as poor; and less than 19 as very poor. It should be pointed out that the deduct scores used in the OSHD procedure reflect pavement conditions that are more structurally related. The condition surveys show that all the projects are in very good condition. This is in part due to low traffic volumes and the relatively short service life of most projects. However, it should be noted that the Springfield/Creswell-SPRR O'Xing project and the Salmon Creek-Salt Creek project have carried approximately 1.6 to 2.2 million ESALs and the pavements are still in very good condition. The Junction City-Airport Road project was constructed in 1979, and the pavement currently carries average daily traffic (ADT) of more than 14,000 vehicles. At the time of the condition survey (July 1992), the pavement was in very good condition. The rut depth on this project is also very low, less than 6.3 mm (¼ in.). In most areas, the rut was not noticeable. Visual pavement condition survey data collected by Oregon Pavement Management System also provided a consistent overall rating (Table 5).

In general, the rutting performance of the F-mix-surfaced roads is considerably improved over the B/C-mix-surfaced roads (Table 5). This improvement may be due primarily to the large quantity of coarse material in the F-mix.

Overall, the amount of cracking, both load related and thermal, was lower for the F-mix-surfaced roads than for the B/C mix-surfaced roads. All of the F-mix projects in the study except the Junction City project consisted of a single lift overlay of an existing road. Although no quantitative data are available on the condition of these roads before the overlay, most were reported to be in poor condition with significant amounts of cracking. For this reason, the authors believe the F-mixes provide improved cracking resistance over conventional dense mixes.

It should be noted that to date with more than 1,300 centerline km of F-mix pavement placed, no premature failures have occurred. However, problems caused by road kill, draindown, and snow plow damage have been noted. Historic experience in Oregon with dense-graded mixes used over this many miles would have resulted in some problems associated with flushing, rutting, ravelling, or stripping.

Voids and Modulus

Laboratory tests were performed recently on cores obtained from the Junction City-Airport Road project to determine air voids in the field and resilient modulus of the cores. The test results, as summarized in Table 6, show that air voids for this project range from 12.4 percent to 15.4 percent, with an average of 13.5 percent. The average modulus for this project is 3,748 mpa (544 ksi), with a standard deviation of 1,034 mpa (150 ksi). It should be noted that this project has been in service for more than 10 years and has carried more than a million ESALs. Other projects have a relatively short service life and the air voids are expected to be slightly higher. Typical air voids for the F-mix after 5 to 6 years of service are in the range of 12 percent to 16 percent. In newer projects, the void levels have been increased slightly to facilitate better drainage.

TABLE 5 Summary of Pavement Condition Survey (July 1992)

No	Project Name	Mix Type	Pavement Condition Description	Rut Depth mm (in)	Overall Rating
	a) Open-graded				
1	Junction City-Airport Rd	F	Very minor transverse cracking, no bleeding.	6.3 (1/4)	G*
2	Springfield-Leaburg	F	Very minor ravelling, no bleeding.	6.3 (1/4)	G
3	Springfield/Creswell-SPR R O'Xing	F	No cracking, no bleeding.	9.4 (3/8)	G
4	Clover Lane-Neil Crk Rd	F	Very minor alligator cracking and longitudinal cracking, no bleeding.	6.3 (1/4)	G
5	Jenny Creek-Parker Mtn. Summit	F	Minor alligator cracking, no bleeding, very minor ravelling.	9.4 (3/8)	G
6	Day Creek-Truck Scales	F	No cracking, minor bleeding.	9.4 (3/8)	G
7	S.Fork Coquille River-Railroad Ave. Sec.	F	No cracking, no bleeding.	9.4 (3/8)	G
8	Antioch Road-Crater Lake Highway	F	Very minor longitudinal cracking, no bleeding.	6.3 (1/4)	G
9	Lenz Road-Forge Road	F	Very minor longitudinal and transverse cracking, localized minor bleeding.	6.3 (1/4)	G
10	Salmon Creek-Salt Cr.	F	No cracking, no bleeding.	6.3 (1/4)	G
11	Wild Park Lane-Reeves Creek Sec.	F	Very minor alligator cracking, no bleeding.	9.4 (3/8)	G
	b) Dense-graded				
12	Eagle Creek-Salt Cr. Tunnel	B	Minor cracking and bleeding.	6.3 (1/4)	G
13	Powers Jct.-Shields Cr	C	Minor alligator cracking and longitudinal cracking, no bleeding.	15.6 (5/8)	F
14	Powers Jct.-Warner Cr.	C	Very minor longitudinal cracking, no bleeding.	6.3 (1/4)	G
15	Monroe-Crow Creek	C	Very minor alligator cracking, no bleeding.	18.8 (3/4)	G
16	Church St (Monmouth)-S.FK Ash Creek Sec.	C	Very minor alligator cracking, no bleeding.	15.6 (5/8)	F
17	Third and Fourth Street (Corvallis)	C	Localized alligator cracking	11.1 (7/16)	F

* G = Good; F=Fair

TABLE 6 Field Air Voids and Modulus for Junction City Project

Sample I.D.	Air Voids (%)	Resilient Modulus MPa (ksi)[1]
1	12.3	4,947 (718)
2	13.3	2,914 (423)
3	15.4	4,224 (613)
4	13.1	4,479 (650)
5	13.2	2,177 (316)
Average Standard Deviation	13.5	3,748 (544) 1,034 (150)

[1] Determined following ASTM D4123. Tested at room temperature, approximately 23C (73F).

Pavement Frictional Properties

One of the expectations of using the F-mix as wearing course is to provide a rougher surface texture and thereby increase the frictional property, especially during wet weather. The frictional property for the evaluated projects was measured using a computer-controlled pavement friction tester owned by OSHD. This computer-controlled pavement friction tester measures average locked wheel (skid) and peak incipient (slip) friction characteristics on paved surfaces and may be used to evaluate changes or deterioration in pavement friction due to weathering, high usage, or aging. The frictional property on these projects was measured at a traveling speed of 64 km (40 mph) and expressed as a friction number (FN) (AASHTO T 242). The test results are summarized in Table 7 and plotted in Figure 5.

The test results from the projects evaluated indicate that the F-mix has a similar or slightly higher FN than the B/C mix (average FN for the F-mix projects is 51, whereas average FN for the B/C mix projects is 48). The Junction City-Airport Road project shows a lower FN than many other projects. This may be because this project has the longest in-service life (it was built in 1979) and has received two fog seals, which may have reduced the frictional results. The other project, S.

TABLE 7 Summary of Friction Test Results

No	Project Name	Mix Type	Friction Number	Year Tested
	a) Open-graded Mixtures			
1	Junction City-Airport Rd	F	44	1,987
2	Springfield-Leaburg	F	53	1,987
3	Springfield/Creswell-SPRR O'Xing	F	55	1,989
4	Clover Lane-Neil Crk Rd	F	49	1,987
5	Jenny Creek-Parker Mtn. Summit	F	54	1,987
6	Day Creek-Truck Scales	F	N/A	-
7	S.Fork Coquille River-Railroad Ave. Sec.	F	43	1,987
8	Antioch Road-Crater Lake Highway	F	51	1,987
9	Lenz Road-Forge Road	F	54	1,988
10	Salmon Creek-Salt Cr.	F	55	1,989
11	Wild Park Lane-Reeves Creek Sec.	F	47	1,987
	b) Dense-graded Mixtures			
11	Eagle Creek-Salt Cr. Tunnel	B	51	1,989
13	Powers Jct.-Shields Cr	C	50	1,987
14	Powers Jct.-Warner Cr.	C	50	1,987
15	Monroe-Crow Creek	C	49	1,987
16	Church St (Monmouth)-S.FK Ash Creek Sec.	C	47	1,987
17	Third and Fourth Street (Corvallis)	C	41	1,987

N/A = Not Available

Fork Coquille River-Railroad Avenue Section, also has a low FN. These FNs are likely a result of the percent of asphalt (6 percent) used, which reduced air voids in the mix and stability of the mix, as can be seen in Table 4.

In addition to the standard friction tests, the speed gradients were determined for some projects. The speed gradients were determined as the slope of the FN versus speed curve from 64 km (40 mph) to 88 km (55 mph). The tests were performed in a conventional manner on dry pavement and then repeated on the same sections during heavy rainfall. The results are summarized in Table 8 and plotted in Figure 6.

The test results from these locations indicate that the F-mix has a slightly improved speed gradient in dry conditions and a much improved gradient during rainy conditions when free water is present on the pavement. These results are due to the coarse texture and free draining nature of the F-mixes.

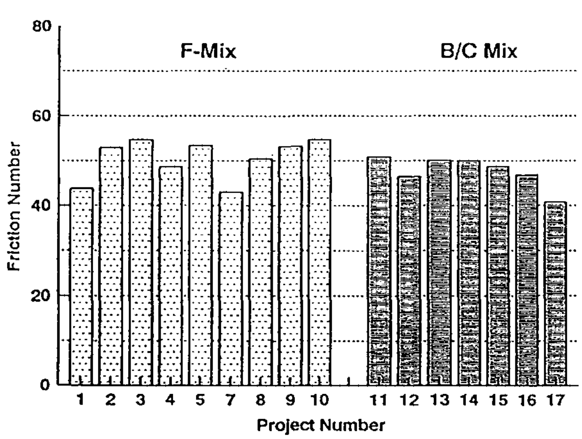

FIGURE 5 Comparison of FNs.

TABLE 8 Friction Speed Gradients

SURFACE TYPE	SPEED GRADIENT DRY	SPEED GRADIENT WET
B-mix	0.34	0.59
F-mix	0.26	0.23
Portland cement concrete	0.45	0.56

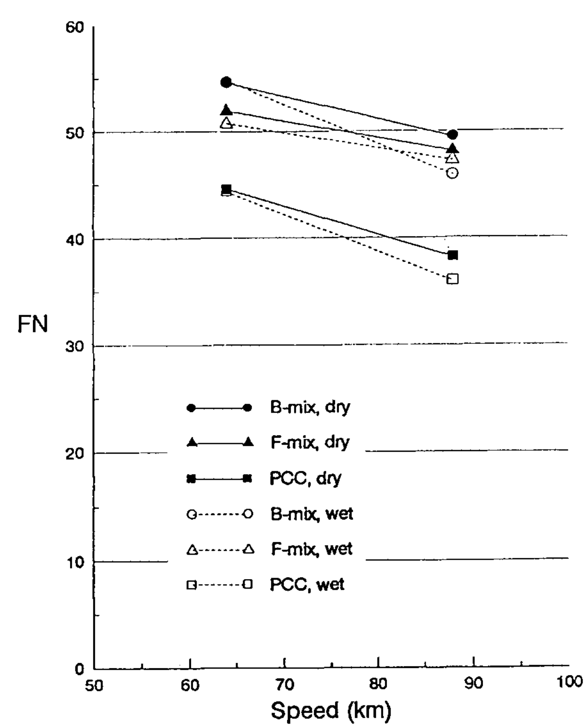

FIGURE 6 Effect of speed and moisture on frictional values.

Splash and Spray

Another advantage of using the open-graded mix as a surface course in Oregon (where it rains frequently) is that the hydroplaning potential and water splash and spray during wet weather are minimized (*5,6*). This feature is obvious when driving on the selected projects during wet weather. Although there are no objective data available related to splash and spray, the observed amount of water splash and spray for the F-mix projects is much less than for the B/C mix projects. Oregon has received numerous comments from motorists noting improved visibility when traveling on F-mix pavements during rainy weather. For Oregon's unique climatic condition, with nearly 6 months of rainy weather, this advantage may greatly reduce the number of vehicle accidents.

Noise Characteristics

Experience has shown that F-mix-surfaced pavements appear to have a different road noise frequency and are considered to be more quiet than B-mix pavements. Some studies (*4–6*) also indicate that the open-graded friction course surface provides reduced tire-pavement noise. To verify this characteristic, a field investigation was conducted to determine the noise level on both mixes. The test was performed by installing a microphone in the rear section of a Ford station wagon and measuring the noise level. Six locations (three F-mix projects and three B-mix projects) were tested. Three noise measurements were taken at each location. For each location, the cruise control of the vehicle was set at 88 km/hr (55 mph). Each noise measurement was taken for 1 min while the automobile covered approximately 1.5 km (0.9 mi) of pavement.

The test results indicate that the noise levels inside the vehicle ranged from Leg 73 to 74 dBA. These results are similar to those for the B-mix pavements. This test measures only total noise level, not noise frequency. The apparent quieter ride experienced on F-mix pavements may be due to the difference in noise pitch and not noise level itself. Also, the total noise level in the vehicle could be dominated by motor, wind, and transmission noise. Future noise studies should measure tire-pavement noise at a fixed location along the roadway.

CONCLUSIONS AND RECOMMENDATIONS

On the basis of this study the following conclusions and recommendations appear to be warranted:

- All projects paved with the open-graded F-mix have performed well. Only minor distress was found in some of the projects evaluated. Rutting resistance is generally improved over the dense-graded B/C mix projects.
- FNs of the F-mix projects are about equal to the B/C mix projects (average FN = 51 for the F-mix projects versus average FN = 48 for the B/C mix projects). Speed gradient is improved for the F-mix versus the B-mix, especially during wet conditions. Hydroplaning potential and water splash and spray during wet weather is reduced.
- The noise level measured from inside a vehicle for the F-mix projects is similar to that measured for the B-mix projects. The apparent quieter ride experienced on the F-mix pavements may be because of the difference in noise pitch and not noise level itself.

Because the performance of the F-mix to date has been very good, the Oregon Department Of Transportation (ODOT) recommends its use wherever possible. However, special considerations must be given for projects with conditions addressed in this study.

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