

Use of Friction Course Mixes in Ontario

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The dramatic increase in the volume and speed of automotive vehicles in the 1950s and 1960s in Ontario resulted in the need for safer and better quality highways. The increased traffic also created rapid deterioration of frictional and durability characteristics of the road system that was originally designed for lighter traffic. The need to upgrade urban freeways and to rehabilitate other highways led to the development of friction course mixes. In the process of formulating policy for safer and better quality highways, in 1974 a major installation of 18 test sections of bituminous overlays on one of the most heavily trafficked roads in Ontario was undertaken, and a task force was set up to review the performance of friction courses and make recommendations on their use. The developments that led to the adoption of a policy of using friction course mixes in Ontario are outlined. The design, construction, and results of the experimental sections and the findings of the task force on friction course mixes are discussed. The experience gained and the annual program of friction courses are also discussed. One important finding of the experiment is that the most effective way to improve the level of friction on a wearing course is by using harsh, angular, fine aggregates such as traprock or slag screenings and a sufficient proportion of crushed good-quality coarse aggregate in the bituminous mixes to maintain the micro- and macrotecture of a surface. These characteristics can best be provided by open friction course and dense friction course mixtures. Friction courses are accepted by the Ontario Ministry of Transportation and Communications as the most suitable surface course mixtures for freeways and accident "black spots." The volume of friction course mixes laid each year verifies this commitment.

Advances in automobile technology in the 1950s resulted in the need for safer and better riding quality roads to accommodate high-speed transportation. The dramatic increase in the volume of traffic on the roads that was brought about by the postwar increase in the ownership of automobiles and the change to the transportation of goods and commodities by truck challenged the highway engineer to construct and maintain better highways.

Such need clearly existed on a major multilane urban commuter freeway in metropolitan Toronto, the Highway 401 Toronto Bypass. The rehabilitation and upgrading of this section of freeway initiated the search for better techniques for improving driving qualities and for a hot-mix resurfacing system that would produce a long-wearing surface with good friction properties under high volumes of traffic.

The developments that led to the use of open friction course (OFC) and dense friction course (DFC) on a major installation of 18 test sections are outlined, and the findings of a task force on the performance of these friction courses are presented. In

addition, the annual OFC and DFC program and the rehabilitation techniques are discussed.

BACKGROUND

Use of OFC and DFC was sparked by the need to rehabilitate Highway 401. Planned, constructed, and reconstructed in stages during the past 40 years, Highway 401 (Figure 1), or the MacDonald-Cartier Freeway as it is also called, has become the main artery across southern Ontario. It runs from the Ontario-Quebec boundary on the east to the Ontario-Michigan boundary on the west, for a total distance of 820 km (510 mi). Commencing in 1947, sections of this major route were constructed to bypass major centers. It runs with Highway 427 for 50+ km (30 mi) through metropolitan Toronto and is the main east-west commuter route serving a population of 3 million people. The average annual daily traffic (AADT) for the busiest location is 238,400, and there are 1,800 vehicles per lane per hour at peak periods on several sections.

Construction of Highway 401 as an Urban Freeway

In the vicinity of Toronto, Highway 401 was first constructed as a four-lane divided freeway through largely agricultural land. Construction began in 1952, and by 1958 the basic four-lane divided controlled-access highway was completed. It was built as a conventional flexible pavement with gravel shoulders, core-type construction, and a wide depressed median.

By 1960 the bypass was being taxed beyond capacity because, within a relatively short period of time after completion, numerous residential subdivisions and industrial areas had been constructed adjacent to the freeway. A major increase in car and traffic volume resulted (Table 1).

The reconstruction of the original facility as a multilane, urban commuter, concrete pavement in the vicinity of Toronto took place between 1963 and 1973 when the original four-lane asphalt pavement was widened to a twelve-lane system of collector and express lanes. Concrete pavement was chosen for the highway because it was assumed to have the best potential for providing a long service life under the anticipated heavy traffic conditions.

Performance of the Concrete Pavement

It was originally expected that the portland cement concrete pavement would be maintenance free for 25 years. However, within less than 10 years after construction it was evident that rehabilitation would be required sooner than expected because of emerging problems. The main and earliest problem to develop was the marked increase in the multicar wet weather

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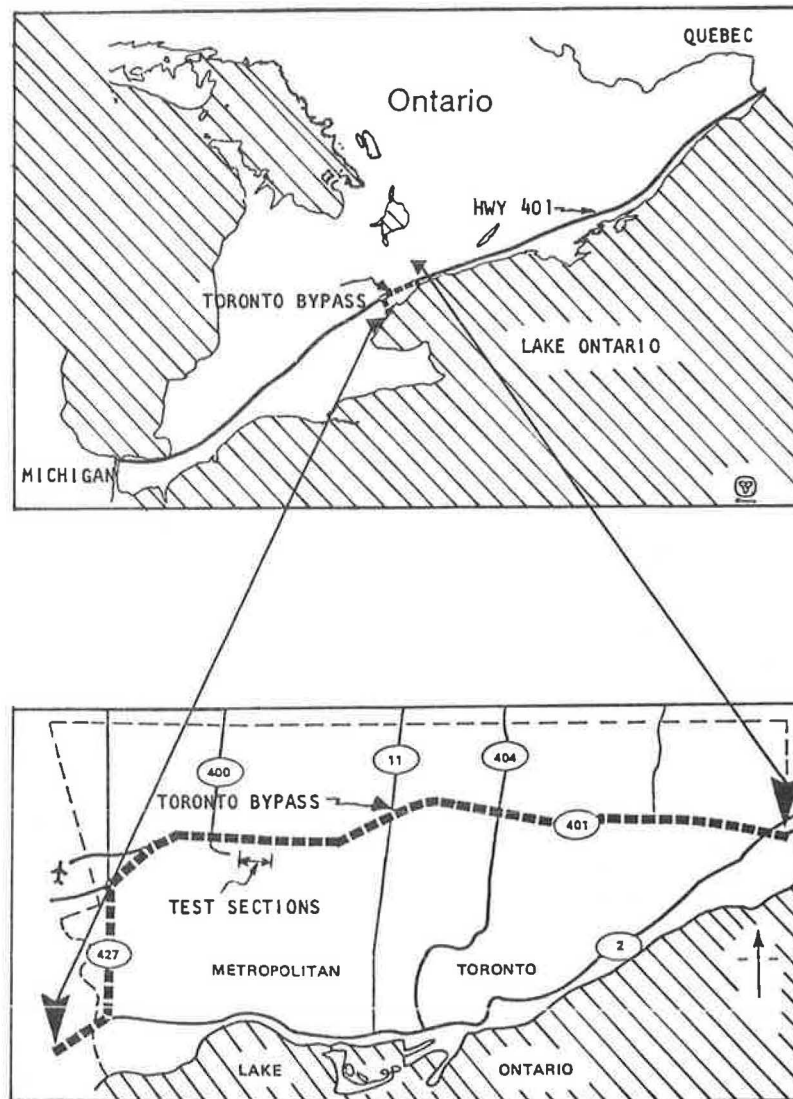


FIGURE 1 Location of test sections (1).

accident rate. The ministry tried grooving the existing concrete pavements to improve their frictional properties. That technique, although somewhat effective for a while, created excessive tire noise that was unacceptable to both the driving public and nearby residents. Problems were also encountered with the performance of the joints: transverse cracking began to appear between the joints, and spalled areas of varying depth developed at quite a number of joints and cracks.

During the 10-year period after the construction of the first

section of concrete pavement there was a marked increase in traffic volume above that anticipated as well as a dramatic increase in allowable truck weights and axle loadings (Table 1).

DEVELOPMENT OF POLICY ON SURFACE COURSE MIXES

The low-friction condition was created because the original burlap drag and broom textured concrete pavement surface was severely polished by the heavy traffic and studded tires (banned after 1971). The texture depth was reduced to about one-tenth of what is desirable. The friction value as determined by the ASTM brake-force trailer at 100 km/hr (62 mph) varied between 19 and 22.

Bituminous Mix Test Sections

In an effort to determine the best rehabilitation methods for restoring the driving qualities of the concrete pavement, the

TABLE 1 TRAFFIC VOLUMES AND TRUCK WEIGHTS

Year	AADT	Gross Vehicle Weight (tonnes)	Legal Axle Weight (tonnes)
1963	77,000	32.0	8.6
1976	199,000	63.5	10.6

ministry designed and placed 18 bituminous overlay test sections in 1974. Dense- and open-graded hot mixes, sand-asphalt mixes, and mastic mixes both with and without asbestos were used. The emphasis in the evaluation of the test sections was on long-term frictional characteristics and improvement of ride quality. Another consideration was that the rehabilitation method chosen should be low cost. The main points of the experiment are described next.

Test Location and Traffic

The test sections were on the westbound core lane between Allen Expressway and Jane Street (Figure 1). The traffic count had increased dramatically from 111,000 AADT in 1967 to 179,000 in 1974 and 260,600 in 1985. Truck traffic averaged about 17 percent.

Layout of Test Sections

The 18 test sections were each 137 m (448 ft) long and 11.3 m (37 ft) wide. Sections 1-10 and 17 were 38 mm (1½ in.) thick overlays whereas Sections 11-16 were only 25 mm (1 in.) and Section 18 consisted of two lifts of 38 mm (1½ in.) each.

Mix Design and Composition

Because a surface with good frictional properties must possess sufficient microtexture or harshness (evaluated per ASTM D 3319) and suitable macrotexture or stone projections (measured by the ASTM E 770 method) (2), the mixtures were designed to have various degrees of micro- and macrotextures. The test sections included both dense- and open-graded types of mixes with a variety of coarse and fine aggregates including traprock, steel slag, and blast furnace slag (Table 2).

Test Sections 1-10 consisted of HL-1 mixes in which the coarse aggregate content was progressively increased to obtain a greater macrotexture [i.e., more stone particles at the surface (Figure 2)]. The standard HL-1 mix is a dense-graded mixture with good-quality coarse aggregate [50 percent retained on No. 4 (4.75-mm) sieve] and local fine aggregate. The modified HL-1 mixes tested are mixtures with good-quality fine aggregate (i.e., DFC by definition), or a blend thereof, instead of just local natural sand.

Mixes in Sections 11 and 12 were sand-asphalt mixes with traprock screenings that contained small percentages of coarse aggregates and asbestos fiber filler for greater flexibility and impermeability.

Sections 13 and 14 were open-graded mixes designed to have high permeability [e.g., >10⁻⁵ cm², test method of Saylak et al. (3)] characteristics that facilitate rapid drainage of surface

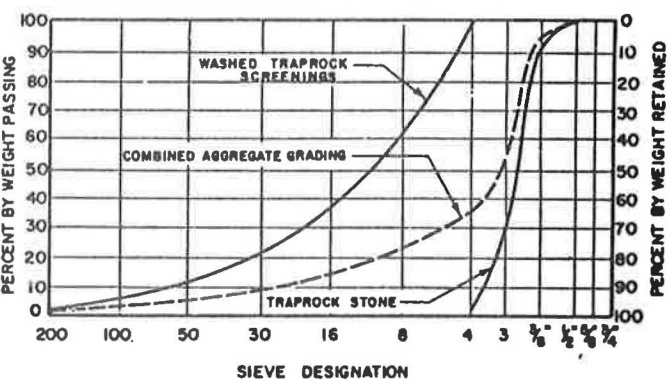
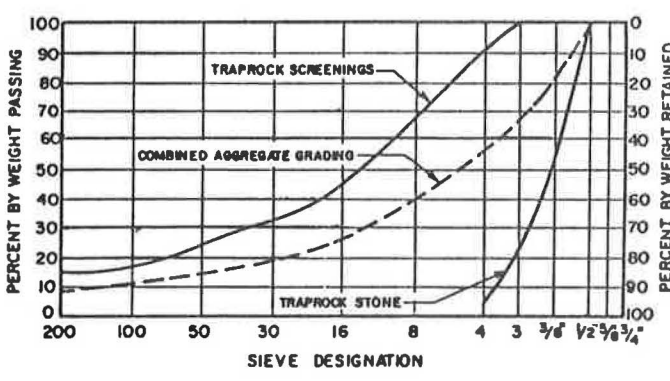
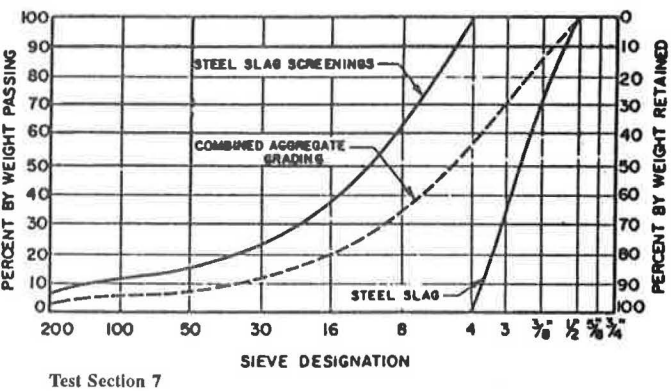
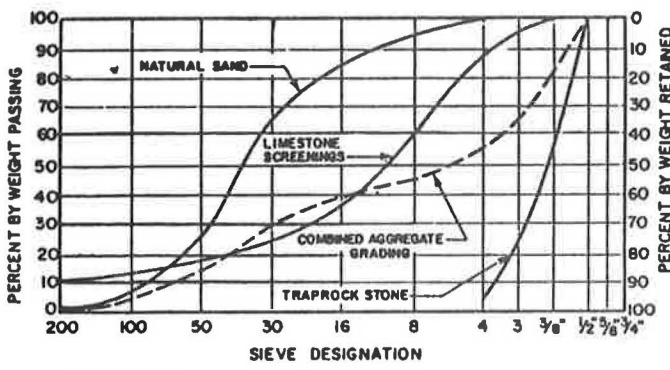


FIGURE 2 Gradations of four of the trial mixes (2).

TABLE 2 COMPOSITION AND DESIGN DATA ON BITUMINOUS MIXES

Test Section	Type of Mix	Composition								Characteristic			
		Coarse Aggregate Retained on No. 4 Sieve		Fine Aggregate Passing No. 4 Sieve		Filler Material		Percentage Retained on No. 4 Sieve ^a	Asphalt (percentage by weight of mix)	Marshall Stability (lbf)	Marshall Flow (in.)	Voids in Mineral Aggregate (percentage by volume)	Voids (percentage by volume)
		Type	Percentage	Type	Percentage	Type	Percentage						
1	HL-1												
	L	TR	45	NS	41			43.8	5.4	1,625	10.3	16.9	2.8
	F			LS	14				5.4	2,614	11.6	17.5	3.7
2	HL-1												
	L	TR	45	NS	41			48.2	5.4	1,625	10.3	17.2	3.0
	F			TRS	14				5.3	2,870	13.4	15.0	0.8
3	HL-1												
	L	TR	45	TRS	55			47.5	4.1	3,185	16.5	12.9	1.2
	F								4.0	3,407	15.3	13.5	2.0
4	HL-1												
	L	TR	55	NS	34			54.1	4.8	1,730	10.2	16.0	2.7
	F			LS	11				4.8	3,027	12.3	14.2	1.2
5	HL-1												
	L	TR	60	NS	28	ASB	2	58.1	5.6	1,800	15.0	14.2	1.0
	F			LS	10				5.7	1,903	22.5	16.0	0.9
6	HL-1												
	L	TR	60	TRS	38	ASB	2	62.3	5.3	2,190	22.7	15.2	1.0
	F								5.4	2,570	18.7	18.6	3.4
7	Modified HL-1												
	L	SL	45	SLS	55			46.8	5.3	3,520	16.0	18.5	2.7
	F								5.2	3,640	13.2	18.7	3.3
8	Modified HL-1												
	L	SL	50	NS	38			47.1	5.7	2,160	12.9	17.3	2.3
	F			LS	12				5.7	2,990	13.7	17.7	1.9
9	Modified HL-1												
	L	BF	45	BFS	55			43.2	8.0	2,830	12.8	24.0	6.9
	F								7.8	3,326	14.9	23.1	6.1
10	Modified HL-1												
	L	BF	40	NS	45			40.5	6.8	1,975	10.4	17.9	2.9
	F			LS	15				6.5	3,155	9.7	17.0	2.2
11	Sand												
	L	TR	14	TRS	84	ASB	2	5.4	7.1	2,084	27.2	17.7	0
	F								7.0	2,175	40.2	19.5	0.2
12	Sand												
	L	TR	9	TRS	89	ASB	2	6.9	7.0	2,650	19.2	16.8	0
	F								7.2	1,885	45.1	20.7	1.1
13	Open graded, F	TR	67	TRS	33			60.5	5.9	1,458	12.7	20.6	4.7
14	Open graded, F	TR	67	TRS	31	ASB	2	71.7	5.8	1,691	11.9	19.6	4.0
15	Open graded, F	TR	30	TRS	70			29.3	5.6	2,678	19.2	16.3	0.7
16	Open graded, F	TR	30	TRS	68	ASB	2	31.4	6.6	2,116	30.5	18.6	0.2
17	Mastic, F	TR	70	TRS	19	MF	9	75.2	7.5	1,887	56.7	21.0	1.0
18 ^b	HL-1												
	L	TR	45	NS	41	ASB	2	47.4	5.4	1,625	10.3	16.9	2.8
	F			LS	14				5.4	2,825	14.5	14.6	0.4

NOTE: Adapted from Ryell et al. (2). L = laboratory mix designs, F = field laboratory tests, TR = traprock, LS = limestone screenings, NS = natural sand (glacial deposit), TRS = traprock screenings, ASB = short-fiber asbestos, SL = steel slag screenings, BF = blast furnace slag, BFS = blast furnace slag screenings, and MF = mineral filler (finely crushed limestone).

^aBased on field and laboratory extraction tests.

^bSame as Section 1 but constructed over a 38-mm-thick bituminous base course.

water into, and laterally through, the surface course layer (i.e., OFC mixes). The mixes used a large proportion (67 percent) of single-sized coarse aggregate and a small amount of washed fine aggregate (Figure 2).

Sections 15 and 16 were also considered OFC mixes but with 30 percent coarse aggregate and washed fine aggregate as in Mixes 13 and 14. Section 17 was a mix called "Mastiphalt," which is a kind of mastic asphalt derived from the German "Gussasphalt" technology and modified so that the material can be mixed and placed with conventional equipment.

Construction

Night paving was necessary because of heavy traffic. The core lanes at the contract location were closed and traffic was diverted to the collector lanes via a transfer lane. Construction was problem free, except that normal mixing time was extended for mixes with asbestos because lumps of asbestos appeared in the mix.

Frictional Performance of Test Sections

The frictional characteristics were measured using the ASTM brake-force trailer. A previous report by Ryell et al. (2) detailed the results obtained up to 1978. Thereafter, some sections had physically deteriorated to the degree that complete resurfacing of all of the test sections was warranted in 1985. Before this work was done, a final evaluation was carried out on the sections and a report is being prepared on the evaluation of the performance of these test sections after 11 years of service. The updated results to 1985 (Figure 3) are summarized next.

- HL-1 and modified HL-1 mixes: Sections 7 (Figure 4) and

9, which are considered DFC mixes (i.e., consisting of steel slag or blast furnace slag coarse and fine aggregates, respectively), had maintained a friction number (FN), formerly skid number, in excess of 31 (4). In comparison, Section 8, which contained steel slag coarse aggregate and a blend of natural sand and limestone screenings as the fine aggregate, and Section 10, with similar fine aggregate and blast furnace slag coarse aggregate, exhibited significantly lower FNs. These fine aggregates had a similar effect on the frictional properties of the HL-1 mixes that contained traprock coarse aggregate, particularly in the driving lane (e.g., Section 3 versus Section 1). Test Sections 3 and 6 that had traprock screenings as the fine aggregate have FNs just on the 31 level.

- Open-graded mixes: Test Sections 13 and 14 had maintained high FNs with good macrotexture appearance (Figure 5). However, Sections 15 and 16, which contained a reduced proportion of coarse aggregate, had a reasonable initial FN but the level declined to below 30. The interconnected voids in Mixes 13 and 14 appeared to be quite efficient at removing water from the tire-road contact area and thus enhancing the frictional characteristics as well as reducing splash and spray in wet weather. These voids tend to clog up after 4 to 5 years of service, but the permeability is still relatively higher than that of the other mixes (Table 3). It appears that the pumping action of the tires helps to clean out some of the debris.

- Other mixes: The two sand mixes (11 and 12) remained at about FN = 30, but these mixes are considered not quite suitable for high-speed traffic because of the lack of macrotexture on the surface; the lower initial FN-value for Section 12 is because of the higher AC content (Table 2). The mastic mix (Section 17) had the lowest initial friction value of all of the test sections, and after 3 years the values are approaching 20.

- FN versus speed: Figure 6 shows that the OFC (Section 13) has the smallest drop in FN of all of the mixes. The sand mix (Section 11) has the greatest. It is clear that the two DFC mixes consisting of slag materials (Sections 7 and 9) yield the

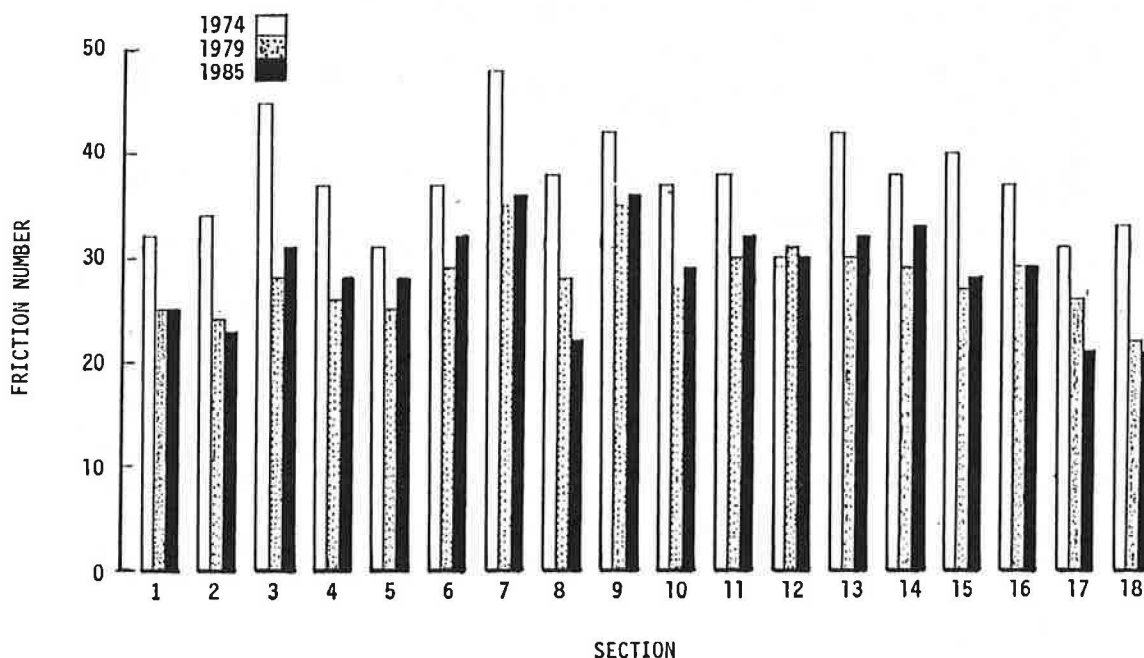


FIGURE 3 Friction number (at 100 km/hr) of the driving lane of test sections.



FIGURE 4 Close-up of wheelpath of driving lane of Section 7 (steel slag coarse aggregate, steel slag screenings fine aggregate) after 11 years of service; friction is excellent, and macro- and microtexture are good.

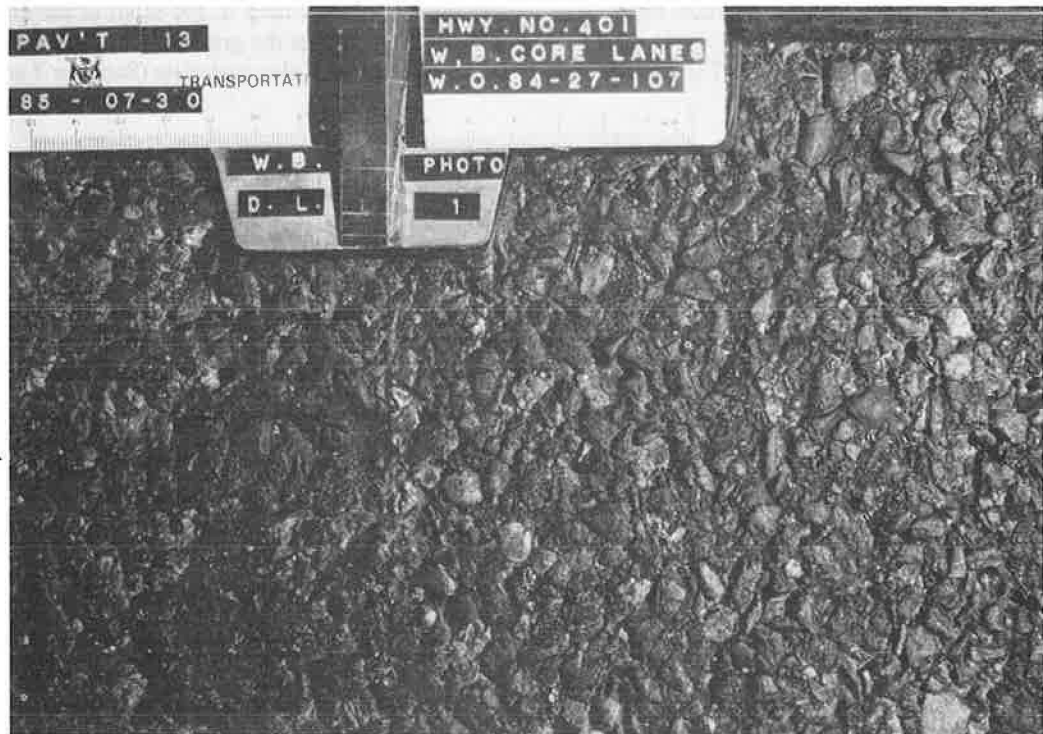


FIGURE 5 Close-up of wheelpath of driving lane of Section 13 (traprock stone coarse aggregate, traprock screenings fine aggregate) after 11 years of service; friction is excellent, and macrotexture is well developed.

TABLE 3 PERMEABILITY RESULTS

Section	Water Permeability (mL/min) at Age (years)				Air Permeability (cm) at 11 years		
	0	2	5	7	Passing Lane	Center Lane	Driving Lane
1	—	1.1	0	0	imp	imp	8.6E-12
2	—	1.7	—	0	imp	imp	2.2E-11
3	70	3.2	2.5	0	6.6E-10	1.3E-9	1.9E-9
4	—	1.2	—	0	imp	imp	imp
5	—	1.9	—	0	6.4E-10	imp	imp
6	—	50	—	3	3.0E-9	6.0E-9	1.3E-9
7	—	4	0	0	10.0E-10	2.6E-10	3.2E-11
8	—	4	—	0	imp	imp	imp
9	vh	30	5.5	0	1.9E-9	2.4E-9	1.5E-10
10	22	2	0	0	imp	imp	imp
11	—	2.8	—	0	1.6E-9	imp	7.1E-11
12	—	2.4	—	0	6.6E-11	3.1E-11	—
13	vh	78	20	7	1.3E-9	1.3E-10	—
14	vh	150	—	13.5	6.6E-9	1.2E-9	1.0E-8
15	6	3	—	0	6.7E-12	imp	imp
16	22	2.5	—	0	1.4E-10	imp	imp
17	—	4.3	—	0	imp	imp	1.0E-9
18	—	2.4	—	0	3.4E-11	imp	imp

NOTE: Dash = results not available, vh = very high permeability, imp = impermeable, and E = $\times 10^7$.

highest FN of all of the mixes although they maintain a friction-speed gradient that is similar to that of the traprock DFC mix (Section 3). The dense-graded mixes (Sections 1 and 4) and the mastic asphalt (Section 17) appear to have an FN-speed gradient that is similar to that of the DFC mixes. A 10 percent increase in stone content (e.g., Section 4 versus Section 1) of the same type of aggregate tends to reduce the FN-speed gradient. The graph clearly suggests that although the FN-

speed gradient is governed by the macrotexture, the level of FN achievable at a given speed is a function of the types of aggregate used, which determine the level of microtexture available in a mix.

• General: Almost all of the mixes provided substantially better friction characteristics than did the existing concrete. The mixes appear to have reached their equilibrium friction level after 2 or 3 years of service (Figures 3 and 7). Also, mixes

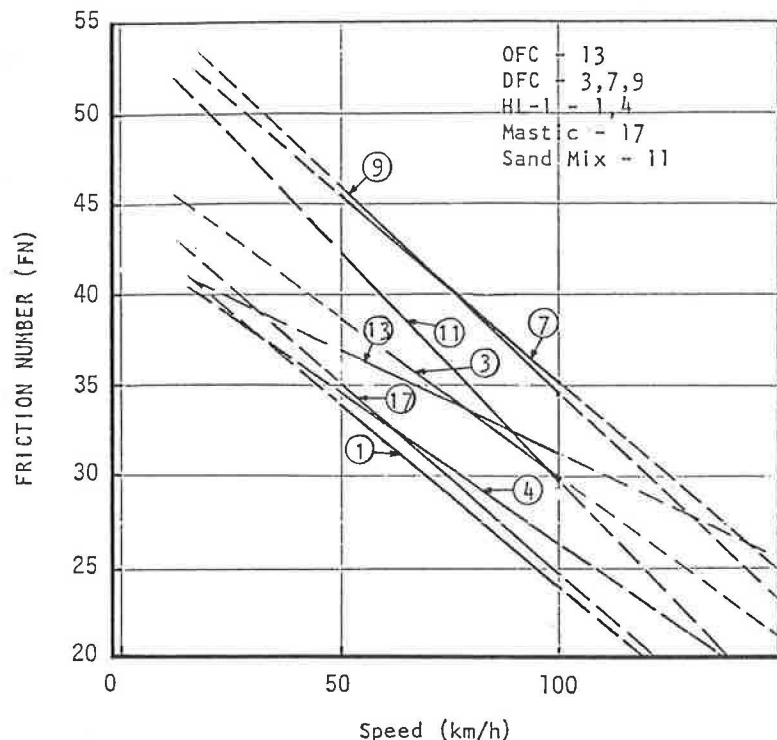


FIGURE 6 Influence of speed on FN of mixes with various degrees of macrotexture after 11 years of service.

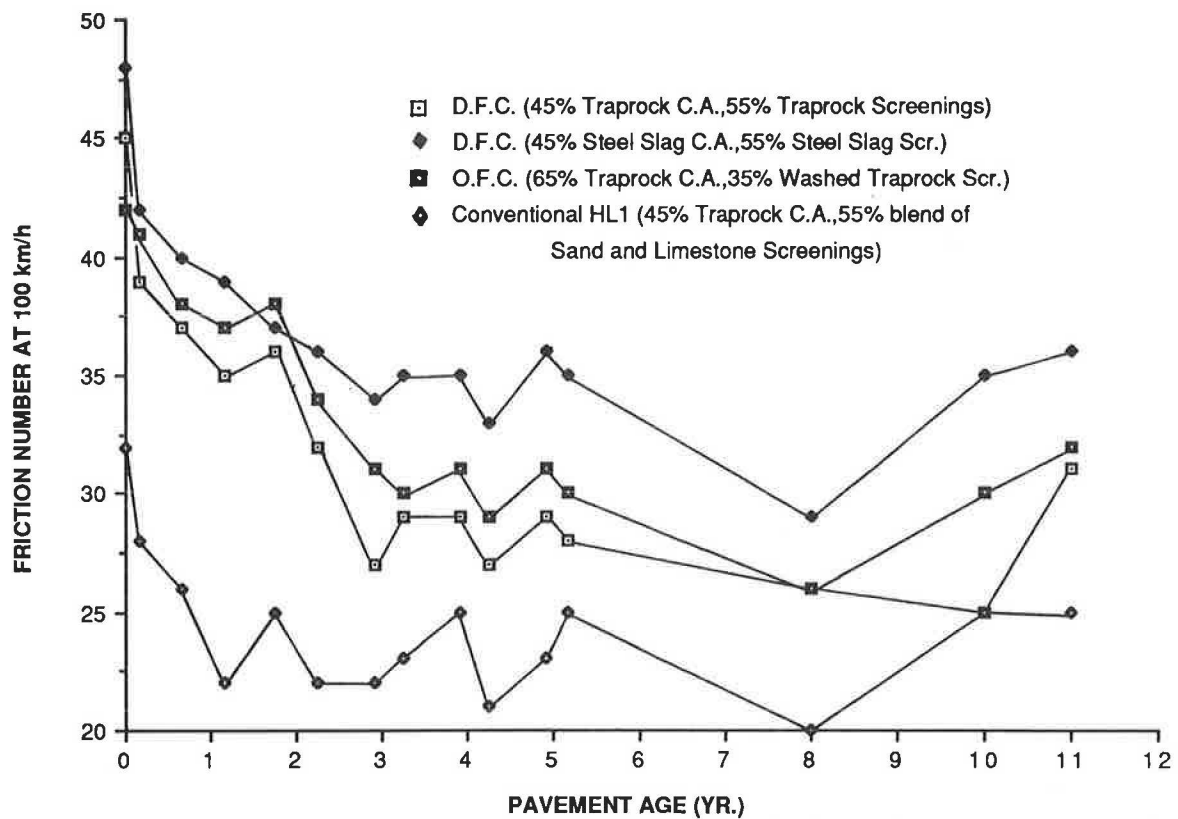


FIGURE 7 Change in FN with time for selected test sections.

that have a high initial friction value tend to take longer to arrive at their equilibrium (e.g., Sections 7, 13, and 3 versus Section 1). In the driving lane that carries 3,700 commercial vehicles per day, the mixes that provide an FN above the value of 30 are (a) dense-graded mixes with both coarse and fine aggregates consisting of traprock, steel slag, or blast furnace slag (DFC) and (b) open-graded mixes with traprock coarse and fine aggregates with high stone contents (OFC).

Durability

The durability of the sections is compared by using the "overall rating" derived by multiplying the length or the area of the appropriate distress by the weighting factors assigned for the severity and type of distress as outlined in the *Manual for Condition Rating of Flexible Pavements* (5). The data in Table 4 indicate that Sections 1, 9, and 17 have overall ratings of 57,

54, and 58, respectively, whereas the other sections have overall ratings between 25 and 37. The friction course mixes (e.g., Sections 3, 7, 9, and 13) performed well relative to the dense-graded mixes, except Section 9 that was built with all blast furnace slag aggregate. The deterioration of Section 9 took the form of raveling and delamination. This is because of the highly absorptive nature of the blast furnace slag aggregate that absorbs the asphalt concrete (AC) and reduces the effective AC available for holding the aggregate in place as well as for adhering the mat to the existing pavement surface. The transverse cracking was reflection cracking from the underlying concrete pavement.

Permeability

Permeability tests were performed on the driving lane wheel-path of each test section using the John Manville outflow

TABLE 4 DURABILITY PERFORMANCE OF TEST SECTIONS

Section	Cracks						Overall Rating
	Transverse	Longitudinal	Raveling	Patching	Delamination	Rutting	
1	4	44	6	0	0	3	57
3	0	1	18	6	4	3	32
4	12	4	6	0	0	3	25
7	16	2	6	9	1	3	37
9	5	7	18	6	14	5	54
11	34	0	0	0	2	0	36
13	6	2	6	14	5	0	33
17	26	5	18	8	2	0	58

permeameter (2). However, by the 11th year, the wheeltrack matrix of all of the sections had closed up to the extent that it required a much longer time (>1 hr) to obtain a water permeability reading. Hence, cores taken from the test sections were tested in the laboratory for permeability using the air permeability method described in the ASTM D 3637.

The results (Table 3) indicate that the OFC test sections (13 and 14) had high initial permeability but that the voids closed up after 7 years of traffic compaction, reducing the permeability to about 10 mL/min [and that of the DFC to zero (Figure 8)]. However, the air permeability of the OFC in the 11th year on the driving lane is still relatively higher than that of the other mixes (e.g., 10^{-8} cm versus $<10^{-9}$ cm, respectively). In general, the lower air permeability in the driving lane confirms the belief that traffic compaction in the driving lane wheeltracks is greater than in the passing lanes because of heavier traffic volume.

Policy on Use of Friction Course Mixes

Because of the performance of these test mixes, a new ministry policy was introduced in 1978 governing the selection of surface course mixes for main highway facilities. The new policy specifies the use of OFC mixes (6) as the surface layer for urban freeways and DFC mixes (7) for other heavily trafficked main highways carrying traffic in excess of 5,000 AADT per lane. The DFC mixes are also used in accident "black spots" with lower traffic volumes. Other factors to be considered are

- Projected traffic volumes,
- Types and percentage of trucks (accident rate), and
- Highway classification.

Special provisions were drawn up for both the OFC (SP 311) and DFC (SP 321) mixes. The OFC consists of from 65 to 70 percent coarse aggregate [retained on No. 4 (4.75-mm) sieve] with 30 to 35 percent washed screenings. Both the coarse and

the fine aggregates have to be obtained from the same source of traprock or steel slag.

The DFC mix consists of 55 percent coarse aggregate [retained on No. 4 (4.75-mm) sieve], and both coarse and fine aggregates have to be selected from the "List of Designated Sources" but do not have to be from the same source. The fine aggregate is unwashed screenings.

Task Force on Performance of Bituminous Friction Course

The commitment of the ministry to constructing more friction course pavements made it essential that the field performance of the new mixes be evaluated and necessary changes be made to optimize performance. A task force was therefore set up with a mandate to review, determine, and recommend the most suitable driving qualities of pavement, with specific emphasis on improving frictional characteristics. The task force considered the following topics:

- General performance,
- Winter performance,
- Frictional characteristics,
- Safety,
- Riding quality,
- Noise levels,
- Performance of zone paint,
- Open friction mixes in other jurisdictions,
- Observations, and
- Recommendations.

The task force evaluated 11 contracts (5 OFC and 6 DFC mixes) between February 1979 and July 1981. The findings of the task force (8) in regard to each of the topics are summarized in the following subsections.

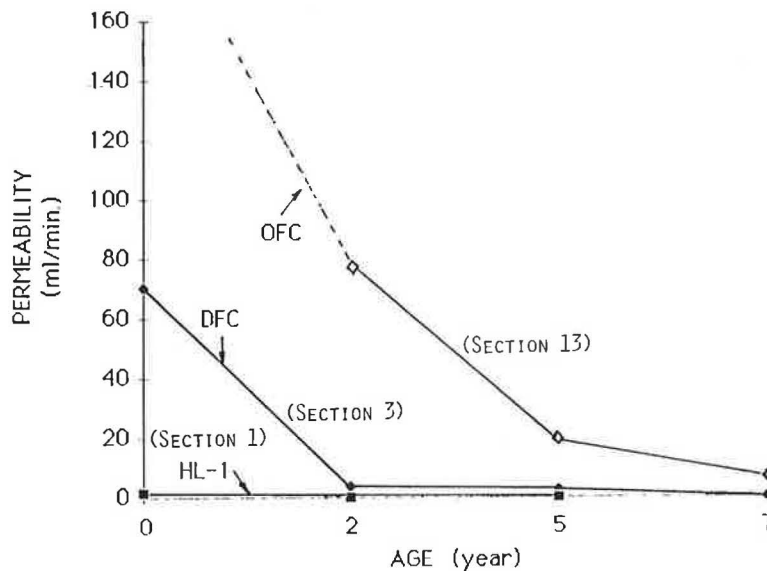


FIGURE 8 Water permeability and age of pavement.

General Performance

On review of the contracts and observations, the pavements were considered to be performing satisfactorily. The OFC mix that had been placed over concrete pavement without sawing and sealing the concrete joints showed reflection cracks that were raveling extensively. All of these cracks were routed and sealed. Reflection cracks on some of the DFC pavements on the other hand were not raveled.

Winter Performance

Visual observations made during the winter of 1978–1979 indicated that

- The OFC mixes appeared to provide the best frictional characteristics.
- There were no problems observed in clearing the OFC surfaces. The “broadcasting” technique of salt application has worked quite effectively to clear the OFC pavements.
- Ice buildup in the DFC mixes has been reported. This problem can be related to the method of spreading deicing salt, (i.e., windrowing versus a recommended broadcasting application). The permeable nature of the DFC mix allows the brine solution to penetrate the pavement before the windrowed deic-

ing salt has a chance to be spread by traffic. It is recommended that broadcasting of deicing salts at a slightly higher application rate for winter snow and ice control be required for both OFC and DFC mixes.

Frictional Characteristics

The task force monitored some 48 sites in southern Ontario that had been laid with the DFC and HL-1 mixes. A friction survey in 1976 showed that mixes with fine aggregate that consists predominantly of natural sand do not provide as good a friction number as do mixes with screenings as fine aggregate (i.e., DFC, Figure 9).

Safety

Collisions on wet pavement decreased by between 42 and 81 percent after rehabilitation. However, alignments had been improved, additional lanes had been added, and lane-change tapers had been lengthened at some locations. Undoubtedly, such improvements contributed to the reduction in the number of accidents on wet pavement.

Riding Quality

The results of the Mays meter readings (in inches of roughness per mile) indicate that the majority of the friction courses fall in

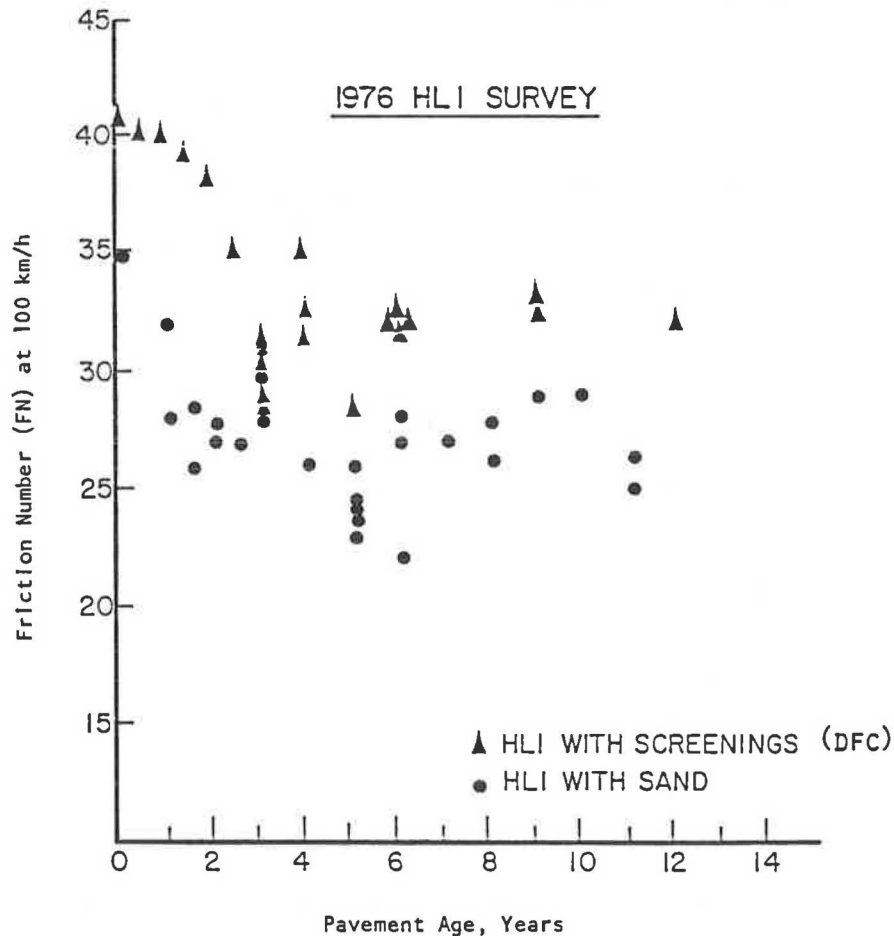


FIGURE 9 Friction survey of HL-1 mixes laid in southern Ontario.

the fair ride range of 80 to 100 in./mi. Two of the contracts are in the good to excellent ride range of less than 80 in./mi.

Noise Levels

Roadside noise measurements indicated that the OFC was 2.1 dB(A) quieter than the standard HL-1 mix.

Performance of Zone Paint

Monitoring of test sections in the core lane of Highway 401 indicates that normal mixes and open and dense friction course mixes have to receive a buildup of traffic paint in order to have a durable appearance. The traffic paint on the bituminous pavements had a minimum of 25 percent remaining with an average of 70 percent, whereas paint on the concrete pavement adjacent to the test sections was on the order of 15 percent remaining, and this was mainly in the grooves. Zone markings on fresh OFC and DFC pavements appear to require the same amount of repainting as do those on standard surface course mixes.

Problems were encountered with adhesive-backed plastic strips not sticking to the OFC mix. It would appear that this material must be placed on the hot mix before compaction so that the mix and the plastic strip can be rolled as one.

Observations

The contracts monitored have not shown any major problems. Small overasphalted areas were observed on some OFC pavements. These areas were caused by asphalt draining down in the mix that was mixed too hot. This problem was eliminated by reducing the mix temperature to below 135°C at discharge.

Recommendations

The task force made the following recommendations:

- The ministry should continue the policy of using OFC and DFC mixes to surface urban freeways and main highways.
- Late fall paving with OFC and DFC mixes should be avoided, and DFC mix should be placed to depths of not less than 30 mm (1.2 in.). Resurfacing should include a leveling course (particularly for DFC mixes) to reduce the chance of thin lifts and subsequent raveling.
- Cheaper local aggregates may be used in OFC mix for shoulders.
- Mix temperatures at discharge into the truck at the plant should be between 122°C (250°F) and 135°C (275°F) (present specification has a maximum of 140°C and placement within 1 hr of discharge) in order to avoid asphalt drainage.
- Tandem paving on multilane facilities should be used wherever practical to reduce joint raveling.
- Dump boxes should be cleared after each discharge onto the paver.
- Maintenance patrollers should be informed of the location

of OFC and DFC surface courses and the need to broadcast deicing salts on these surfaces.

RESURFACING PROGRAM

On the basis of the performance of the Highway 401 test sections, a hot-mix overlay system consisting of a binder course 40 mm (1½ in.) thick followed by an OFC surface course 25 mm (1 in.) thick was selected as the best method of rehabilitating the freeway.

In 1976 the ministry embarked on a program to rehabilitate the 50-km bypass around Toronto. The program is to be completed by 1995. A budget of from \$3 million to \$5 million has been allowed annually for this program. The rehabilitation involves five main areas:

- Additional capacity,
- Repairs to structures,
- Environmental improvements,
- Pavement and shoulder rehabilitation, and
- Construction staging or scheduling of the resurfacing.

On other concrete pavements that carry high volumes of traffic, the normal resurfacing design has been

- 25-mm (1-in.) sand leveling course,
- 50-mm (2-in.) open-graded (porous) binder course,
- 40-mm (1½-in.) binder course, and
- 40-mm (1½-in.) surface course.

These concrete pavements, however, have been allowed to deteriorate to a point where they require more substantial treatment, whereas the rehabilitation treatment, in comparison, on the Toronto bypass consists only of

- 40-mm (1½-in.) binder course and
- 25-mm (1-in.) OFC mix surface course.

It can be seen that the challenge of a high-volume road with many overhead clearance problems has been met with an overlay system that is far less expensive than the normal approach.

Performance of the Rehabilitation System

Pavement Ride

The placing of the new binder and OFC surface course mixes on the two contracts indicates an initial improvement in ride as determined by the Mays meter (Table 5). It is thought that the roughness figures may be improved even more by the use of automatic screed controls with skis on both sides of the paver when laying the hot-mix binder course in the future.

Surface Durability

The surface course OFC shows a small number of flushed areas due to overasphalting (drain down in truck boxes) and some

TABLE 5 ROUGHNESS MEASUREMENT BY MAYS RIDE METER

Contract	Original			New			Change		
	\bar{x}	σ	<i>n</i>	\bar{x}	σ	<i>n</i>	\bar{x}	σ	<i>n</i>
1	110	24	5	73	3	5	-38	17	5
2	141	19	7	72	14	7	-70	14	7

minor winter snowplow scuffing at grade points such as crowns and shoulders, but, all things considered, the durability of the OFC has been exceptionally good to date.

Annual Friction Course Resurfacing Program

The general effect of the OFC mix overlay on improving the driving qualities of the Toronto bypass has been substantial. In addition to the commitment to the overlay program on the bypass, there was a gradual increase in tonnage laid on free-ways from 1978 to 1981 (Table 6). The steady volume of OFC and DFC mixes constructed each year confirms the commitment. The OFC and DFC mixes are specified for use on some 1500 km of main highway across the province (the Ontario Ministry of Transportation and Communications is responsible for 21 500 km of roadway), and most of it is used in southern Ontario. The tonnage is relatively small: less than 20 000

TABLE 6 ANNUAL VOLUME OF FRICTION COURSE MIXES (tonnes)

Year	OFC	DFC
1976	5 080	27 400
1977	40 130	104 800
1978	11 098	104 800
1979	8 147	129 271
1980	7 357	113 698
1981	50 108	112 708
1982	10 531	73 096
1983	18 371	43 829
1984	36 213	76 488
1985	11 138	95 186
Total	198 173	881 276

tonnes of OFC and 100 000 tonnes of DFC compared with an annual average total of about 2.5 million tonnes of hot mix.

In general, there is a misconception about the high cost of the special single-sized ($\frac{3}{8}$ in.) washed coarse aggregate and washed screenings. Also, on the supplier's side, high stone content in the mix poses the problem of having to find an outlet

for the surplus screenings. However, based on coverage per square meter, the cost of OFC (laid 25 mm thick, 24 kg/m²/10 mm) turns out to be about the same as or slightly less than that of the standard dense surface mix (HL-1) for medium-high traffic. Compared with DFC, its cost is about 35 percent lower (Table 7).

The aggregate used before 1982 for the OFC and DFC was mainly traprock. However, factors such as availability and good frictional characteristics of the slag aggregates (both steel and blast furnace slag) led to the increasing use of the slag mixes in later construction.

CONCLUSIONS

OFC and DFC mixes are accepted by the ministry as the most suitable mixtures for treatment of urban freeways and accident black spots where heavy traffic volumes and a large number of commercial vehicles prevail.

The sequence of events that led to the use of OFC and DFC is as follows:

- 1947—Construction of sections of Highway 401 bypass,
- 1952—Initial construction as a four-lane divided highway,
- 1963—Reconstruction of original facility to multilane facility,
 - Widening to a 12-lane system of collector and express lanes,
 - Marked increase in multicar wet weather accidents,
- 1974—Placement of 18 bituminous overlay test sections,
- 1976—Use of OFC and DFC in various contracts begun,
- 1978—Task force set up to review and recommend the use of friction course mixes for future construction,
 - Policy on use of OFC and DFC formalized.

The task force's findings on friction courses follow:

1. General performance is satisfactory with raveled joints at reflection cracks.
2. Winter performance
 - a. OFC provides the best friction properties;
 - b. Salt should be broadcast.

TABLE 7 COMPARATIVE COST (1983) OF FRICTION COURSE MIXES (OFC and DFC) AND STANDARD MIX (HL-1) (1986 cost about \$1.50/tonne higher)

Unit	Cost (\$/Cn)				Percentage Above (below) HL-1		
	HL-1	DFC	OFC	OFC	DFC	OFC	OFC
mm	40	40	40	25	40	40	25
Tonne	34.00	42.00	50.00	50.00	24	47	47
m ²	3.50	4.30	5.15	3.20	23	47	(9)

3. Friction characteristics are superior to those of standard dense mixes.
4. Safety: greater than 40 percent reduction in accidents after rehabilitation.
5. Riding quality is rated good to excellent.
6. Noise level is 2.1 dB(A) quieter than standard dense mixes.
7. Zone painting requires the same quantity as standard dense mixes, but adhesive-backed strips must be rolled in when mix is hot.
8. Construction
 - a. Avoid late fall paving;
 - b. Cheaper local aggregates may be used in OFC mixes for shoulders;
 - c. Discharge temperature at the plant should be between 122°C (250°F) and 135°C (275°F);
 - d. Tandem paving should be used to reduce joint raveling;
 - e. Dump boxes should be cleaned after each discharge.

To be effective in improving the levels of friction, bituminous friction course mixes must contain harsh, angular, fine aggregate such as traprock or slag fines and a sufficient proportion of crushed good-quality coarse aggregate (50 to 70 percent retained on 4.75-mm sieve) to maintain the micro- and macrotexture on the traveled surface. These characteristics can be provided by the open friction course and the dense friction course.

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