TWO LABORATORY METHODS FOR EVALUATING SKID-RESISTANCE PROPERTIES OF AGGREGATES

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In this paper a description and evaluation of two methods are given for determination of aggregate skid-resistance properties in the laboratory. In the first method, pavement samples manufactured from the aggregate to be evaluated are placed in a circular track and subjected to wear from small-diameter pneumatic tires. No abrasive or water is used, and pavement specimens can usually be brought to terminal polish in about 16 hours. Skid-resistance values are determined by using the British portable tester. In the second method, coarse aggregates are polished dry in a jar mill with a charge of flint pebbles. Pavement samples are made from the polished aggregates and tested for skid resistance by using the British portable tester. Polish rate is determined by exposing a number of samples of the same aggregate for different amounts of time to establish a wear-time curve. Results from the two methods are different in value level but show a linear correlation. Also, aggregates were rated in the same order in both methods. Twenty aggregates were used.

•THE research results reported here are based on a thesis (1) and two reports (2, 3) by the authors on wear and polishing properties of aggregates oriented to the pre-evaluation of aggregates in the laboratory for pavement surface course use. Objectives of the research include development of test procedures including test machines, determination of reasons for differences in performances of different aggregates, and evaluation of specific paving mixtures in the laboratory and the field.

The part of the overall research reported in this paper is the description and evaluation of two methods for determination of aggregate skid resistance in the laboratory. In the first method, pavement samples manufactured from the aggregate to be evaluated are placed in a circular track and subjected to wear from small-diameter pneumatic tires. No abrasive or water is used, and pavement specimens can usually be brought to terminal polish in about 16 hours. Skid-resistance values are determined by using the British portable tester. In the second method, coarse aggregates are polished dry in a jar mill with a charge of flint pebbles. Pavement samples are made from the polished aggregates and tested for skid resistance by using the British portable tester. Polish rate is determined by exposing a number of samples of the same aggregate for different amounts of time to establish a wear-time curve.

CIRCULAR TRACK WEAR METHOD

The Machine

A circular track machine utilizing smooth pneumatic tires (4.10/3.50-5) was constructed (Fig. 1). The machine consists of four wheels that travel over a segmented circular track (Fig. 2) and an electric motor to drive the central shaft. The circular

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Figure 1. Circular track machine.

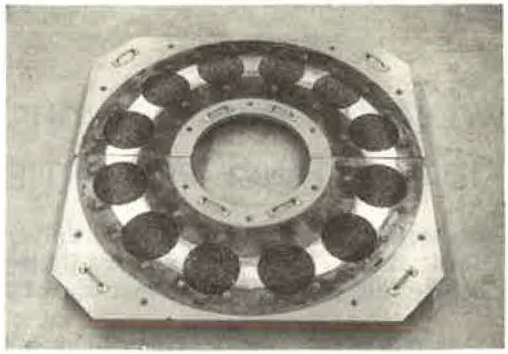

Figure 2. Removable track from circular track machine.

track contains spaces for twelve specimens. Each specimen may be adjusted individually for elevation and level. Track segments must be removed from the machine for friction measurements (Fig. 3).

The tires rotate around the 36-in. diameter track at the rate of 30 rpm generating 7,200 tire-passes per hour. We attempted to obtain accelerated machine polishing action by adjusting the tire setup so that two of the diametrically opposed wheels would toe-in while the other two would toe-out producing a scrubbing action in addition to the rolling action.

The Test Specimen

A circular specimen 6 in. in diameter was used in the wear and polishing machine circular track. Thickness may vary but must be in the range of 1 to 2 in. to be accommodated in the machine specimen holder. This type of specimen can be prepared in the laboratory or may be cored from pavements in service. Bituminous or portland cement concrete specimens can be used with equal facility. Results from bituminous specimens only are reported here.

It has been determined by several investigators (4 through 8) that the skid resistance of a bituminous pavement surface is determined primarily by the type and size of aggregate used in the surface mix. Coarse aggregate particles (greater than ⅛ in.) were found to have the primary influence even when they constituted only a moderate percentage (20 to 30 percent) of the aggregate used in the mix. The mix adopted for this research is an open-graded bituminous mix consisting primarily of aggregate greater than ⅛ in. The advantage of this type of mix is that the surface contains only one aggregate, the one to be evaluated. In addition, this type of mix has been placed on experimental surfaces by the North Carolina State Highway Commission (NCSHC); therefore, an opportunity exists for laboratory-field performance correlation. The composition of this mix is within the range of NCSHC No. 13 stone. The bitumen used for all mixes was obtained by the NCSHC from a single source of 85 to 100 penetration grade asphalt cement. Generally, the asphalt cement content of a mix was kept at the relatively low level of 6

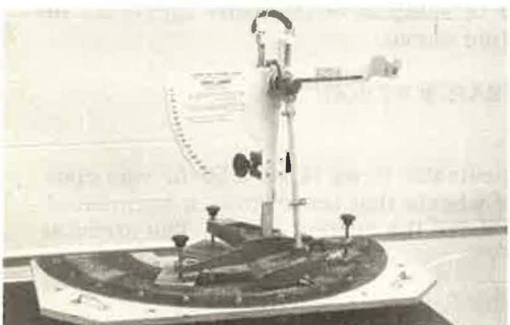

Figure 3. British portable skid-resistance tester.

percent by weight of aggregate (5.66 percent by weight of total mix). The No. 13 stone gradation has been used for all laboratory specimens prepared for this research, unless otherwise stated, and is as follows:

Sieve	Percent Passing
½ in.	100
⅜ in.	95
No. 4	43
No. 10	10
No. 40	4
No. 80	3
No. 200	2

Mounting and Testing

The surface of each specimen was cleaned with trichloroethylene solvent before mounting to remove, as much as possible, the asphalt surface coating and to expose the aggregate surface for acceleration of the test by the time required to wear away this asphalt.

The specimens were tested for initial skid resistance by using the British portable tester, and the track plates were fitted in place in the machine, checked for level, and bolted down. The tires were lowered to the track surface and the machine set in motion. Tire inflation pressure was kept at 20 psi and the tire-pavement contact pressure at 13 psi, resulting in a contact area of approximately 5 sq in. with an average width of 3.2 ± 0.1 in.

No abrasive powder or water was used to assist the wear and polish action. This procedure was adopted as a result of a field investigation of material on the surface of pavements across the state of North Carolina. It was found that very little loose material was on the pavement surface, and most of that found could be identified as rubber asphalt and aggregate dust from the pavement itself. It is well known that pavements are dry most of the time.

Introduction of ½-in. toe of wheel mounting from axle centers accelerated the test so that first reading could be taken after 1 hour instead of 20 hours without toe, and essentially terminal polish could be reached in 16 hours instead of 2 weeks as before. Friction measurements were made at 0, 1, and 2 hours and then every 2 hours up to 16 hours.

Initially, it was hoped that the accelerated test sequence could be limited to 8 hours, and this was the case for the first three series of 12 specimens. Beginning with the fourth series, some specimens did not show essentially terminal polish until after 16 hours' exposure, and the 16-hour test duration was adopted for all remaining series.

At the end of each time interval, the machine was stopped and the specimens were tested for frictional skid resistance by using the British portable tester as shown in Figure 3.

Circular Track Test Results

Three replicate specimens were made from each of the 20 aggregates given in Table 1. Twelve specimens representing four aggregate types were placed in the track for each machine run series.

To provide a standard for comparing one test series with another, it was decided to include three replicate specimens made of a stock aggregate as control specimens with every series to be tested. The stock aggregate selected to be used as control was a quartz-disc muscovite gneiss locally available in any quantity desired, and one that, in preliminary testing, showed reasonably gradual wear and polish. A supply of this aggregate given in Table 1 as GN-1 was stockpiled. Inclusion of the control aggregate specimens reduced machine efficiency to 75 percent of specimen capacity.

Results of skid-resistance testing on all seven series are reported in terms of average British portable numbers (BPN) versus hours of exposure as given in Table 2. De-

TABLE 1

PHYSICAL PROPERTIES OF THE SAMPLE AGGREGATES

Number	General Classification	Grading C Los Angeles Wear Loss (percent)[a]	Bulk Specific Gravity[a]	Water Absorption (percent)[a]
LS-1	Limestone	18	2.85	0.30
LS-2	Limestone	25	2.87	0.40
LS-3	Limestone	46	2.47	3.35
LS-4	Limestone	29	2.95	0.30
GT-1	Granite	36	2.79	0.31
GT-2	Granite	63	2.67	0.42
GT-3	Granite	51	2.65	0.50
GT-4	Granite	41	2.66	0.50
GN-1	Granite gneiss	29	2.67	0.41
GN-2	Granite gneiss	52	2.68	0.6
GN-3	Granite gneiss	48	2.71	0.55
GL-1	Gravel	42	2.64	0.30
GL-2	Gravel	43	2.78	1.01
SL-1	Slate	17	2.78	0.32
SL-2	Slate	24	2.78	0.33
RH-1	Rhyolite	27	2.67	0.30
TR-1	Traprock (diabase)	15	2.77	0.30
SS-1	Sandstone (arkose)	N.A.	2.66	2.55
SP-1	Expanded glass[b]	23.3	2.05	2.4
SO-1	Expanded slate[b]	40	1.58	3.5

[a] Determined by the Materials Laboratory of the North Carolina State Highway Commission.
[b] Provided by manufacturer.

TABLE 2

BPN DATA CIRCULAR TRACK SPECIMENS

Series	Aggregate	Circular Track Machine Hours[a]																
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	GN-1	56	51	51	48	48	47	48	46	45								
	SP-1	62	54	52	47	49	51	47	48	48								
	SO-1	60	57	52	50	52	53	51	53	53								
	SS-1	62	59	63	64	63	59	60	–	61								
2	GN-1[b]	56	51	51	48	48	47	48	46	45								
	SL-1	51	50	49	48	49	48	46	48	46								
	LS-3	52	47	45	46	44	47	44	45	44								
	LS-2	55	49	46	46	44	45	42	43	42								
3	GN-1	62	51	51	49	49	47	47	45	45								
	GL-1	57	51	48	49	47	46	46	44	43								
	GT-3	59	51	53	51	51	47	48	47	45								
	LS-1	55	44	42	40	41	40	38	38	37								
4	GN-1	58	49	52	51	52	44	45	46	43	41	43	41	42	39	39	39	39
	TR-1	59	48	51	49	49	45	43	45	44	40	41	40	39	38	39	39	37
	SL-2	59	51	56	52	52	48	45	45	45	46	43	44	43	44	43	43	43
	RH-1	59	48	53	51	47	45	45	43	42	42	43	43	40	40	39	38	39
5	GN-1	57	46	48		45		43		44		42		41		44		43
	GN-3	57	47	48		45		44		44		40		41		42		42
	GL-2	55	48	48		46		44		44		44		42		44		44
	GT-2	58	50	49		48		44		44		43		43		44		43
5	GN-1	53		46		46		46		48		44		44		47		47
	GT-1	52		47		47		44		45		43		45		46		45
	GT-4	57		49		48		47		45		45		45		48		46
6	LS-4	51		45		46		44		42		43		42		44		44
7	GN-1	55	50	47		46		46		45		45		44		44		44
	GN-2	57	49	48		46		46		45		45		44		44		42
	RH-1[c]	50	47	45		44		43		43		43		42		42		41
	GT-1[c]	49	48	45		45		46		44		45		42		42		42
	GN-1[d]	56.5	50	49.5	49	47.5	46	46	45.5	45		43.5		43		43		43

Note: Each BPN value is an average of 15 BPT pendulum swings made on three specimens of the same aggregate.

[a] Each hour of machine wear exposure represents 1,800 revolutions and 7,200 tire passes.

[b] Data same as for GN-1 in series 1 because one specimen of three in each of the two series was badly shoved. Other two specimens had similar data; therefore, they were averaged together.

[c] These specimens were cored from NCSHC test pavements with thin overlay open-graded bituminous mixes.

[d] Average of measurements on 19 specimens made from aggregate GN-1 and used for control.

viations from the average BPN were within ±3 numbers for individual specimens of a given aggregate in any measurement with amount of spread decreasing with increased time of exposure. All BPN measurements were made by the same operator.

Discussion of Data Curves

Testing results given in Table 2 have been plotted selectively and are shown in Figures 4 and 5 to illustrate change in BPN versus exposure time in the wear machine for the various aggregates tested. Three curve patterns emerged, and these are shown in Figure 6.

The hyperbolic curve relationship is not unfamiliar in reports by skid-resistance investigators who have undertaken to study the variation in pavement skid-resistance characteristics with increasing vehicle passes (7, 8, 9). What is lacking at this time is a quantitative correlation between number of vehicle passes on actual pavements and the laboratory machine tire passes over the pavement specimens. This correlation will require simultaneous field and laboratory testing on identical paving surfaces. However, the pavement specimens that have been tested in the laboratory exposure (Fig. 5) were brought to an ultimate state of wear and polish approximating that of laboratory specimens, and it has been assumed that the skid numbers measured toward the termination of the machine exposure may represent conditions on pavements subjected to prolonged traffic action.

An examination of the curves shown in Figures 4 and 5 and of the other data given in Table 2 leads to the following observations:

1. All specimens, regardless of aggregate used, showed satisfactory BPN values when surfaces were cleaned before actual exposure began;
2. Most specimens exhibited a rapid loss of BPN, or high rate of polish, during the first 4 to 6 hours of exposure in the CT wear machine, but the loss, representing rate of polish, varied depending on the aggregate;
3. The specimens did polish without the addition of water or abrasive to help the polishing action;
4. The wear machine does separate aggregates by performance for the exposure used;

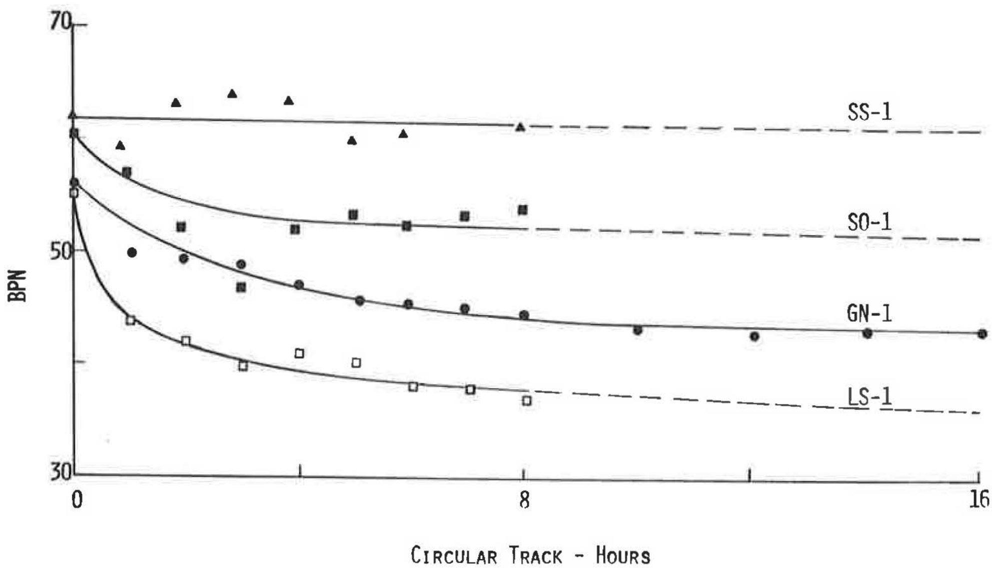

Figure 4. BPN versus circular track polishing time curves for GN-1, SP-1, SO-1, and SS-1.

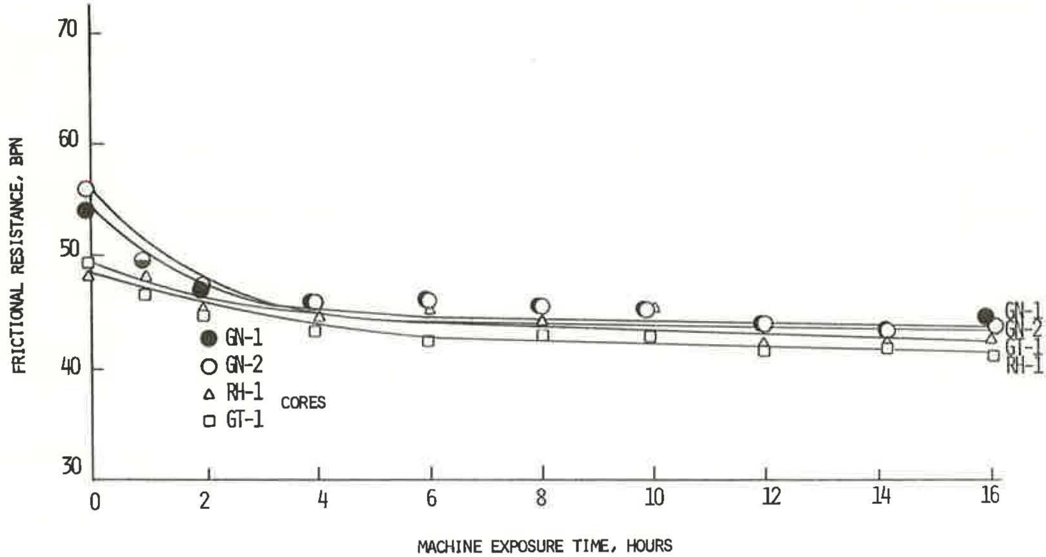

Figure 5. BPN versus circular track polishing time curves for GN-1, GN-2, RH-1, and GT-1.

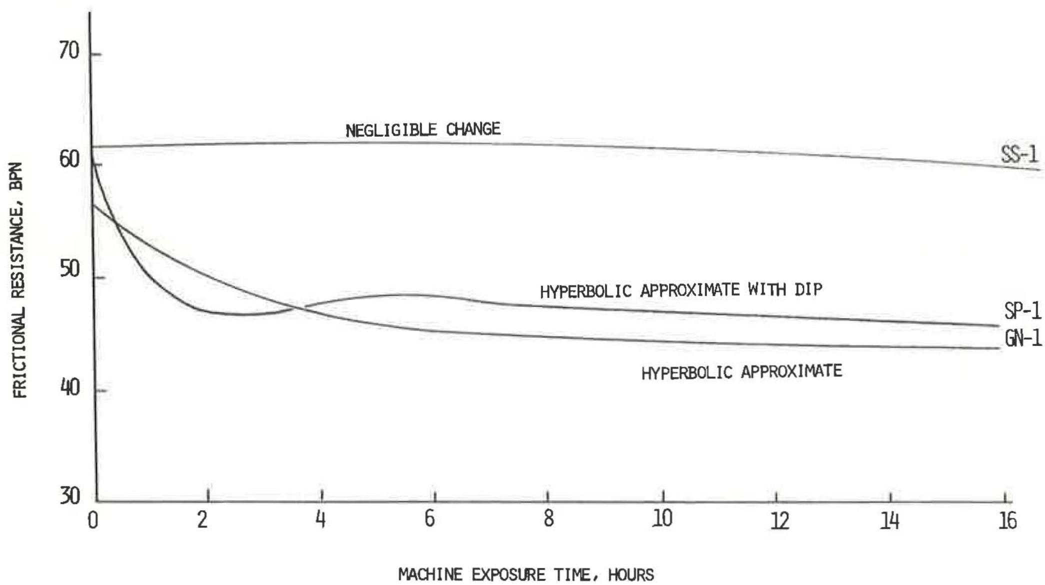

Figure 6. Typical BPN versus wear exposure time curves.

5. Most curves had flattened out by 8 to 12 hours of exposure, indicating very little additional polish or loss of skid resistance with additional exposure;
6. Field and laboratory specimens made with the same aggregate showed similar wear and polishing characteristics in the wear machine exposure; and
7. A dip or loss of BPN followed by recovery is indicated in points for many of the plotted curves.

The reason for this dip in curve is not actually known. It may be speculated that some initial surface polish occurs followed by an actual loss of surface particles or that some asphalt film is being spread and then worn away. The presence of the dip does not appear to influence the final leveling out, or equilibrium position.

Serafin (10) has reported the occurrence of this dip followed by recovery phenomenon on several field bituminous pavements in Michigan, but no detailed explanation is offered.

Rating of Sample Aggregates

To obtain a meaningful comparison between the 20 sample aggregates, we established a standard curve. BPN values obtained for each of the GN-1 specimens used in the seven series were averaged. The result is shown in Figure 7 as the average curve for the GN-1 aggregate. This curve has been used as a standard for comparing the values of all the test series curves by adjusting the GN-1 curve in each series to this average curve and, as a consequence, adjusting all other curves in the same series accordingly.

As critical skid-resistance characteristics of an aggregate occur when high-to-ultimate polish is attained, values of each curve for the aggregates in series 1 through 7 (Table 2) were compared to the "standard" average curve shown in Figure 7 at the points indicating the end of the 8th and the 16th hour of machine exposure. (For series 1 through 3, values beyond 8 hours were extrapolated.) At each of these two points, the BPN difference between the standard curve and any other curve was added or subtracted in order to bring BPN to the standard curve values. This difference has been designated as an adjusting factor to be added or subtracted according to sign from the standard curve value at the point in time appropriate. In the seven series that have been tested

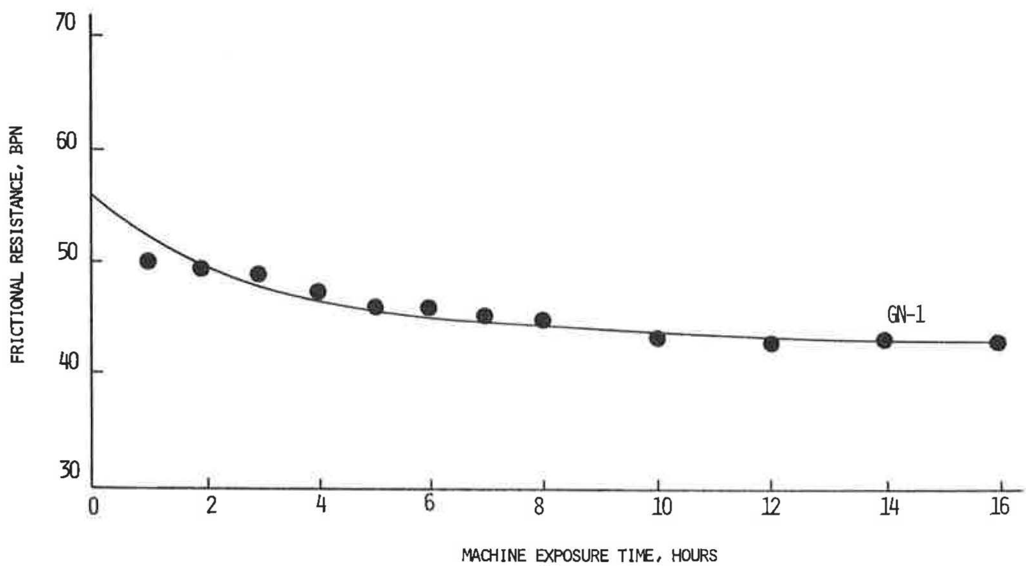

Figure 7. BPN average for seven test series on circular track for GN-1.

and compared, adjusting factor values varied from -2.0 to +2.5 BPN at the end of the 8th hour and from -3.0 to +3.0 BPN at the end of the 16th hour.

This procedure made it possible to compare all 20 aggregates used in this study to one another and to give each aggregate a rating as to its skid-resistance characteristics relative to the other aggregates that have been tested by the same procedure.

Adjusted and unadjusted BPN values for 8 and 16 hours, adjusting factors, and a relative rating for the 20 aggregates used in this study are given in Table 3. Ratings are shown in Figure 8. Generally, the same rating would have been obtained whether the adjusted BPN values at the end of 8 hours or at the end of 16 hours were considered. Because the 16th-hour BPN value for any of the curves being considered is closer to the ultimate state of polish (where the curves generally have leveled off), this value has been used as the criterion for the relative aggregate rating. When two or more aggregates had the same adjusted BPN value at the end of the 16th hour of wear and polish, the aggregate with the higher BPN value at the end of 8 hours of wear and polish has been given the higher rating.

The aggregates tested in this study fall approximately into three major categories: (a) those with high BPN, (b) those with medium-range BPN, and (c) those with low BPN values (Table 3 and Fig. 8). Most of the aggregates fall in the medium range. Some investigators have found that the BPN values given each aggregate result in a valid rating as to the aggregate skid-resistance performance although the BPN value separation may be narrow (11).

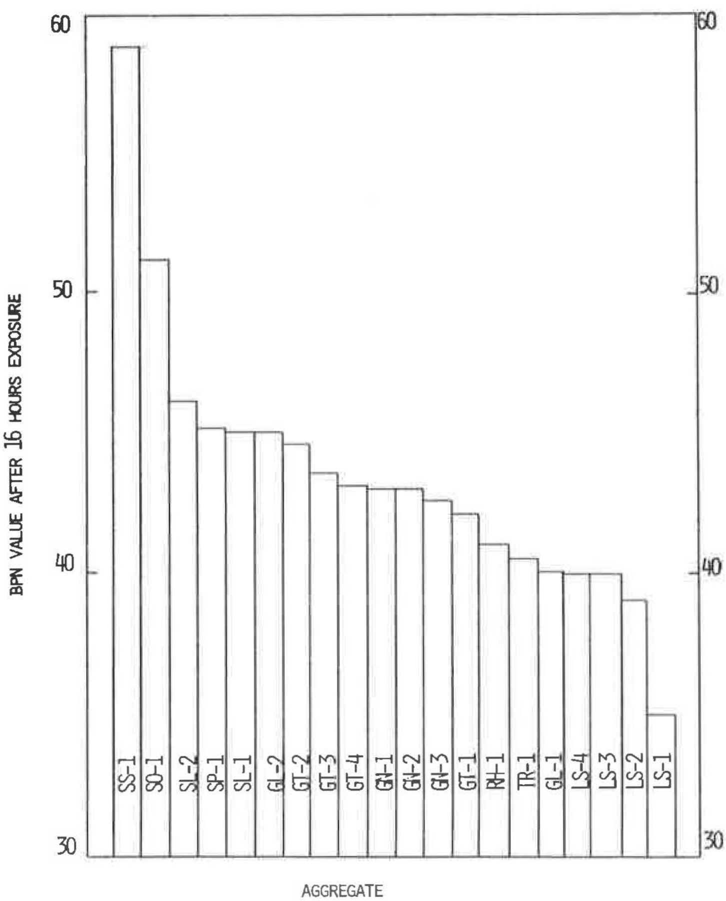

Figure 8. Skid-resistance rating of selected aggregates.

TABLE 3

RELATIVE RATING OF SKID-RESISTANCE CHARACTERISTICS OF SAMPLE AGGREGATES

Aggregate	BPN Values (8 hours)			BPN Values (16 hours)			Relative Rating
	Unadjusted Curve Value	Adjusting Factor	Adjusted Value	Unadjusted Curve Value	Adjusting Factor	Adjusted Value	
SS-1	61.5	-0.5	61.0	60.0	-1.5	58.5	1
SO-1	52.5	-0.5	52.0	52.5	-1.5	51.0	2
SL-2	44.0	2.5	46.5	43.0	3.0	46.0	3
SP-1	47.0	-0.5	46.5	46.5	-1.5	45.0	4
SL-1	47.0	-1.0	46.0	46.5	-1.5	45.0	5
GL-2	43.8	1.5	45.3	43.5	1.5	45.0	6
GT-2	43.5	1.5	45.0	63.0	1.5	44.5	7
GT-3	46.0	-1.0	45.0	44.5	-1.0	43.5	8
GT-4	46.5	-2.0	44.5	46.0	-3.0	43.0	9
GN-1	44.2	0.0	44.2	43.0	0.0	43.0	10
GN-2	44.0	-0.25	43.7	43.5	-0.5	43.0	11
GN-3	42.0	1.5	43.5	41.0	1.5	42.5	12
GT-1	45.0	-2.0	43.0	45.0	-3.0	42.0	13
RH-1	41.0	2.5	43.5	38.5	3.0	41.5	14
TR-1	41.0	2.5	43.5	37.5	3.0	40.5	15
GL-1	43.0	-1.0	42.0	41.0	-1.0	40.0	16
LS-4	43.5	-2.0	41.5	43.0	-3.0	40.0	17
LS-3	42.5	-1.0	41.5	41.5	-1.5	40.0	18
LS-2	41.5	-1.0	40.5	40.5	-1.5	39.0	19
LS-1	37.0	-1.0	36.0	36.0	-1.0	35.0	20

JAR MILL WEAR METHOD

It is generally conceded that a slippery-when-wet pavement condition occurs when the pavement surface aggregate has been polished through gradual but continuous frictional wear. It was reasoned that, if samples of loose aggregates were subjected to any reasonable gradual method of wear and polishing, the polished particles should, when tested, reflect the skid-resistance characteristics of the particular aggregate they represent. A laboratory jar mill utilizing porcelain jars was used to achieve the gradual wearing and polishing of aggregate samples. This method and the results that were obtained by using it are described in the following paragraphs.

Apparatus and Procedure

In the jar mill method, glazed porcelain jars, each having an inside diameter of approximately 9.0 in., a clear depth of 8.5 in., and a mouth opening diameter of 5.0 in., were charged with 1,000 grams of loose aggregate and 1,000 grams of ¾-in. flint pebbles for an abrasive charge. Aggregate to be used in the jars was obtained from NCSHC No. 13 stone by sieving the fraction passing the ⅜ in. and retained on the No. 4 sieve. The sieved fraction was washed and oven-dried before 1,000 ± 0.1 grams were weighed for the jar. Flint pebbles were similarly washed and dried before being charged into the jar (Fig. 9). Sealed jars were placed on the rollers of a jar mill (Fig. 10) where they were rotated at 52 rpm for the period of time required.

In experiments with this method of aggregate wear, samples were tumbled for short periods of time, from 1 to 20 hours. Results indicated that day-long increments would produce measurable changes. Periods of exposure of 0, 20, 48, 72, 96, and 120 hours were adopted for the jar mill procedure. Other abrasive charges were tried, including hard rubber balls, but flint pebbles have been found most effective.

Two rounds of tests were completed for each of the aggregates used. A round for one aggregate consisted of a control sample and separate 1,000-gram samples for each of the five exposure increments. For example, the jar containing the 20-hour sample was removed after 20 hours and processed, the 48-hour sample at 48 hours, and so on.

At the end of all wearing cycles, the aggregate sample was sieved mechanically over ⅜-in. and Nos. 4, 8, 16, 30, 50, 100, and 200 sieves for gradation. Aggregate retained on the No. 4 sieve was washed, oven-dried, and weighed to determine loss from the

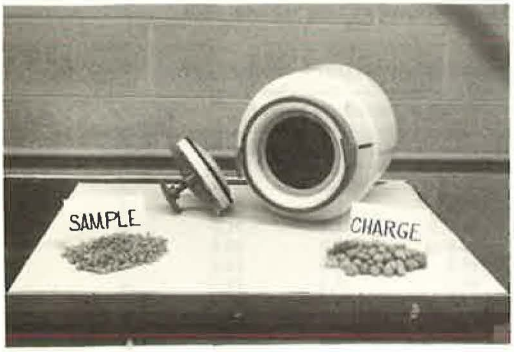

Figure 9. Jar, aggregate sample, and charge.

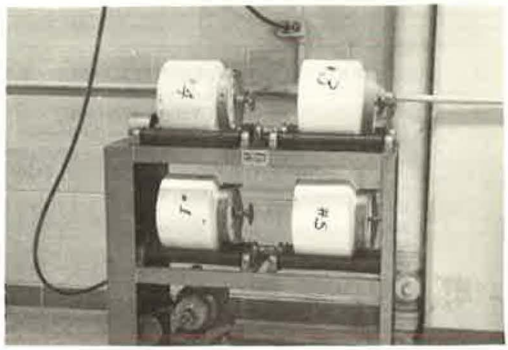

Figure 10. Jar mill machine.

original 1,000-gram weight. The No. 4 material was saved for incorporation into a laboratory pavement specimen.

Wear Test Results

Eight of the aggregates that had been tested by the circular track polishing machine method (Table 1) were selected for preliminary testing by the jar mill method. They were selected to represent differing types of aggregates that were used in this study. Results of the jar mill testing for the eight aggregates selected, computed as percentage of wear loss versus number of hours of grinding, are shown in Figure 11. Each percentage value is the average of two test results for each aggregate and wearing period.

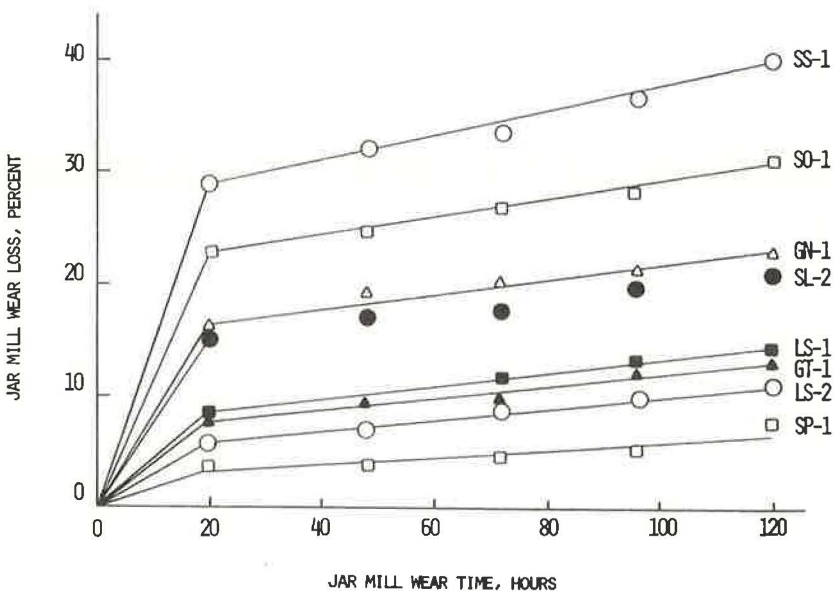

Figure 11. Jar mill wear loss versus wear time.

Skid-Resistance Test Specimen

The worn material retained on the No. 4 sieve from each of the aggregate samples was used for molding a 6-in. diameter pavement specimen. Each specimen was made with two unlike surfaces: One surface was made of the material worn in the jar mill, whereas the opposite surface of the same specimen was made from the same type and size of unworn aggregate. Each specimen had the mix gradation given in Table 4. Specimens were bound by using 5 percent by weight of aggregate of an 85 to 100 penetration asphalt cement. Eighty specimens were manufactured representing two complete series of tests for each of eight aggregates. All specimens were made by the same operator.

TABLE 4

JAR MILL PAVEMENT SPECIMEN GRADATION

Sieve		Percent Retained on Each Sieve	Accumulative Percent Retained
Passing	Retained		
3/8 in.	No. 4	88.0	88.0
No. 30	No. 50	8.5	96.5
No. 50	No. 100	1.0	97.5
No. 100	No. 200	0.5	98.0
No. 200	Pan	2.0	100.0

The final step in specimen preparation was the removal of asphalt cement from exposed aggregate surfaces by carefully cleaning with trichloroethylene. Aggregate fines were also removed from the surfaces during this cleaning procedure.

Measurement Results and Discussion

Each of the 80 specimens was tested on both surfaces for skid resistance by one operator using the British portable tester in accordance with ASTM Designation E 303-66T. Two sets of readings were taken on each specimen face at 90-deg orientation. Average results are shown in Figure 12.

Comparison of data shown in Figure 12 and in Figure 8 reveals that, for the eight aggregates being compared, both the jar mill method and the circular track method produced the same rating of aggregate for skid-resistance characteristics and the same relative grouping into high, medium, and low categories. As would be expected, initial BPN values of unworn aggregate are the same for each aggregate in each test method, but BPN values of worn aggregate are higher for the jar mill method than for the circu-

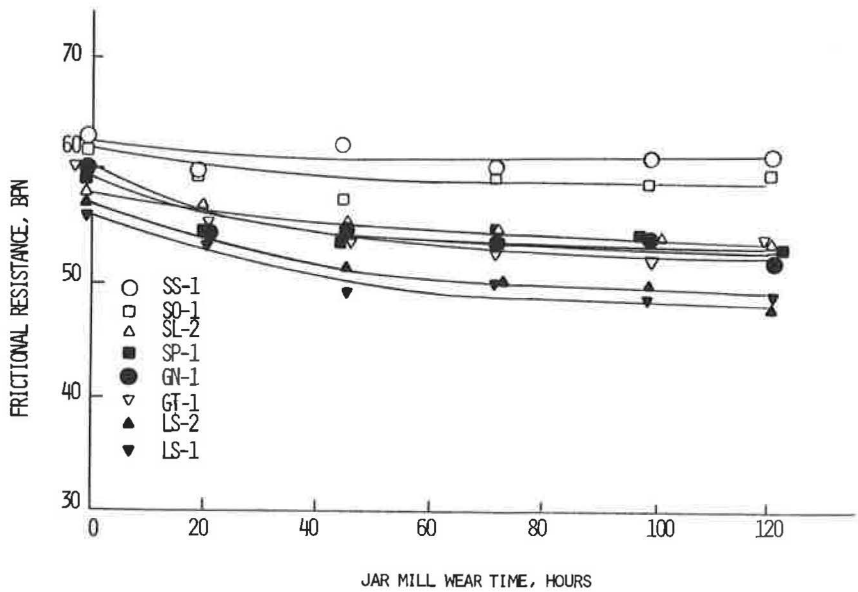

Figure 12. BPN versus jar mill wear time.

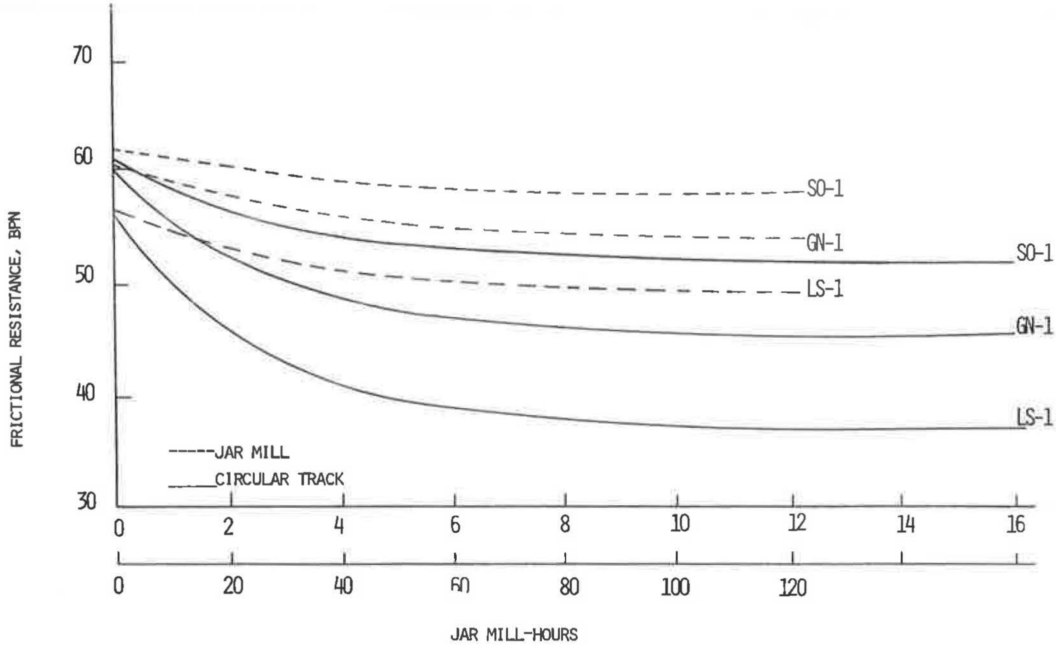

Figure 13. Comparison of typical skid resistance curves for circular track and jar mill wear exposures.

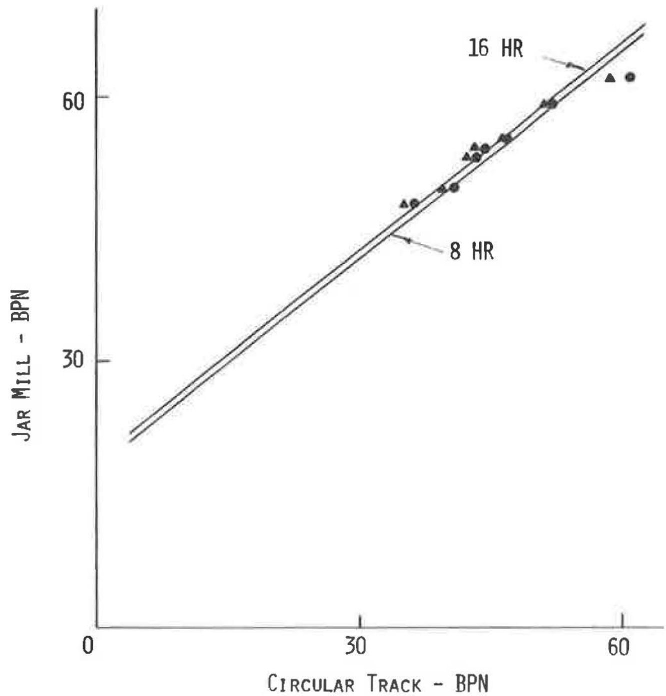

Figure 14. Correlation between BPN values for circular track and jar mill methods.

lar track method. The two methods are comparable but not equal as shown in Figures 13 and 14. Figure 14 shows that fairly good linear correlations are developed between the two methods for two-time increments of the circular track method. Particularly important is the lack of a correlation between percentage wear loss shown in Figure 11 and terminal skid resistance after wear shown in Figure 12. This lack of correlation seems to eliminate the possibility of using a wear loss test as a means of pre-evaluating aggregates for skid resistance.

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