LABORATORY AND FIELD INVESTIGATION OF BITUMINOUS PAVEMENT AND AGGREGATE POLISHING

S. H. Dahir, Department of Civil Engineering, Pennsylvania State University, Middletown;
W. E. Meyer, Department of Mechanical Engineering, Pennsylvania State University, University Park; and
R. R. Hegmon, Office of Research, Federal Highway Administration

To investigate the field performance of aggregates, 11 test strips containing replicate sections of bituminous pavements used in Pennsylvania were designed and constructed by a joint industry-Pennsylvania Department of Transportation task force. In the investigation, 52 aggregate samples and 223 pavement cores of the test sections were polished in the laboratory by using various polishing methods and friction measurement techniques. Correlations between field and laboratory data were sought, and factors associated with skid-resistance variations were observed and investigated. Laboratory-field data correlations indicated that the general level of skid-resistance characteristics of surface aggregates may be determined in the laboratory and that the aggregates may be ranked similarly by both approaches. However, the correlations failed to produce regression equations that could, with confidence, define specific mathematical relationships for predicting specific field skid numbers. A minimum field skid number occurred in the late summer and fall and correlated better with laboratory results than a mean skid number. The minimum number appears to stabilize after 2 years of pavement exposure to traffic, irrespective of the level of traffic. Higher average daily traffic produced a lower skid-resistance level, and one truck was equivalent to about 18 passenger cars in polishing effects. Cumulative traffic also caused reduction in the skid number until the surface stabilized; then the number leveled off. Temperature correction of the minimum skid number appears to have little or no effect on skid data analysis. Increase in the percentage of insoluble residue of carbonate aggregates indicated only possible increases in skid resistance, but no dependable quantitative correlation could be obtained from available tests.

•RECENTLY, there has been a continuing effort in Pennsylvania to arrive at satisfactory, updated solutions to the problem of how best to use available materials and methods for providing long-lasting pavement surfaces with wet skid-resistance characteristics. As part of this effort, a cooperative laboratory-field skid-resistance testing program has been conducted in Pennsylvania since 1968, primarily to evaluate aggregate skid-resistance performance on bituminous surfaces. Eleven test strips (1) planned by Pennsylvania Department of Transportation and industry were constructed in 11 geographic locations of the state and have been monitored for field skid-resistance data. The Pennsylvania State University (Penn State) Automotive Research Program conducted part of the laboratory investigations on bituminous pavement polishing (8). Laboratory and field data were pooled and analyzed so that laboratory polishing performance of aggregates could be obtained for establishing correlations with field skid data from Pennsylvania DOT test strips and for determining the effects of aggregate type and other related factors on surface skid resistance.

Laboratory data were obtained by using three polishing methods, three friction measuring techniques, and four sample forms. Field data were obtained on the test strips periodically by Pennsylvania DOT by using skid trailers conforming to ASTM E 274 at

40 mph (64 km/h). Other pertinent data were also obtained and used in the analysis and discussion. All tests were performed on aggregates and sections used in the test strip program.

Results of laboratory tests using various procedures were correlated with one another and with field skid resistance. Other factors influencing skid resistance, such as time, traffic, and insoluble residue of carbonate aggregates, were also investigated when they were relevant to the research.

AGGREGATE POLISHING

Fifty-two samples from 10 aggregate types representing those used in the test strip program were supplied by Pennsylvania DOT. The strips included 156 replicate sections of 1,000-ft (304.8-m) length or more each, totaling about 44 lane miles (13.4 km). Test strip layouts and pertinent data have been documented in department reports (1, 2). A summary of the test strip sections and of the aggregates used in the polishing program is given in Table 1.

All aggregate samples were polished. From each sample, two 4 by 12-in. (102 by 305-mm) panels were prepared by setting ¼ to ⅜-in. (6.35 to 9.53-mm) aggregate particles in an epoxy matrix. The panels were polished with the Penn State rotary drum polishing machine (RDM) (3). Panel frictional resistance was measured with the Penn State drag tester (3) in drag tester numbers (DTN) and with the British portable tester (BPT) in British portable numbers (BPN), according to ASTM E 303-69. An overall view of the rotary drum machine (RDM) is shown in Figure 1.

In addition, two other 3 by 5-in. (76 by 127-mm) panels were similarly prepared and polished with the modified Penn State reciprocating pavement polisher (RPP) (3), and frictional resistance was measured with the British portable tester in BPN units. An overall view of the RPP is shown in Figure 2.

Two other simplified aggregate polishing methods were investigated: the jar mill tumbler used in North Carolina (4) and a small drum machine (SDM) used for aggregate wear at Penn State (5) and modified for use in this project.

In the case of the jar mill tumbler, polishing of loose, coarse individual aggregate particles was easy to achieve, but there was no convenient way to measure the frictional properties of the aggregate particles. The particles had to be molded into a Plaster of Paris cast, then the average friction was measured with the British portable tester. This procedure seemed to defeat the objective of a simplified approach. For this reason, the jar mill tumbler method was not pursued beyond the trial stage.

As an alternate simplified procedure, the SDM was modified to polish up to 10 individual ¼-in. (6.35-mm) particles of the same aggregate and, simultaneously, to measure the average frictional resistance of the particles electronically. A general view of the modified SDM and friction-measuring equipment is shown in Figures 3 and 4.

Experience with aggregate polishing has shown that carbonate aggregates generally polish more evenly than most other aggregate types. For this reason, samples prepared from 15 available limestones were polished and tested for frictional resistance by using the SDM and other methods. In addition, 223 pavement cores representative of the test sections and supplied by Pennsylvania DOT under a different, but related, project (6) were also polished with the RPP, and friction was measured by using the BPT. A summary of the laboratory polishing results obtained by the various methods on the tested aggregate and core samples is given in Table 2. Also included in Table 2 is a summary of field testing data that will be discussed later.

COMPARISON AND CORRELATION OF LABORATORY TEST RESULTS

Comparison of the laboratory-polishing and friction-measurement procedures was achieved by plotting results obtained on the 15 limestone aggregates polished and tested by all the methods used in the research. These results (given in Table 2) are shown in

Table 1. Test strip sections and aggregate samples tested for polishing.

Aggregate Type	Number of Sources	Number of Test Sections	Length (miles)	Number of Samples
Carbonates	20	59	25.43	
Limestone				15
Dolomite				4
Slags	8	20	3.73	9[a]
Gravels	9	18	3.83	9
Blends	15	29	5.27	—
Miscellaneous	12	30	5.62	
Argillite				7
Diabase				3
Quartzite				1
Gneiss				1
Sandstone				2
Siltstone				1
Total	64	156	43.88	52

Note: 1 mile = 1.6 km.
[a]Slag samples 80 and 88 were obtained from the same source.

Figure 1. Penn State rotary drum machine.

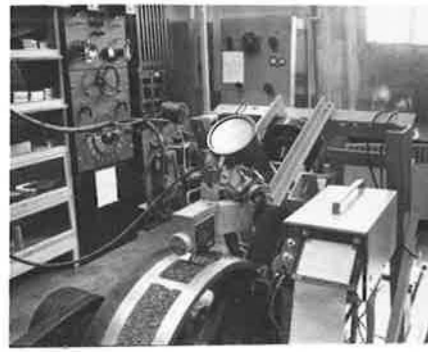


Figure 2. Penn State reciprocating pavement polisher.

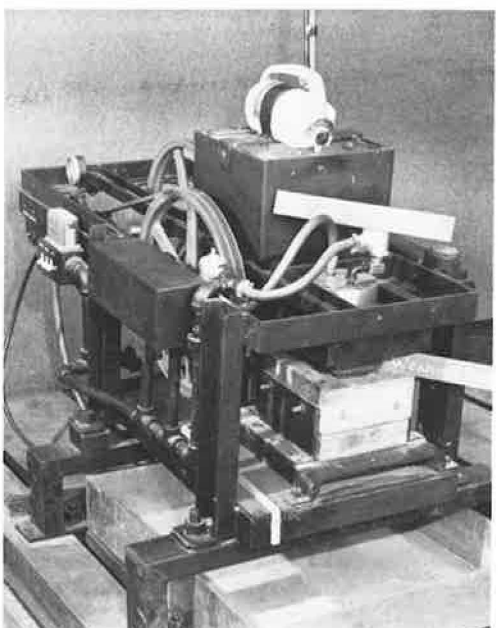


Figure 3. Modified small drum machine.

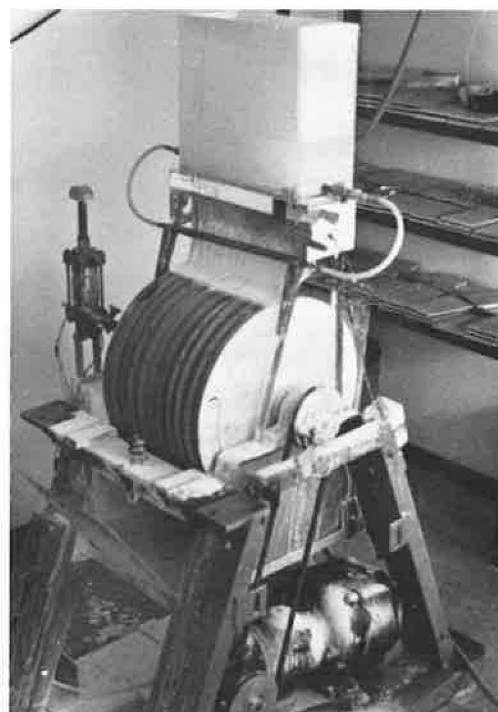


Figure 4. Aggregate particle mount.

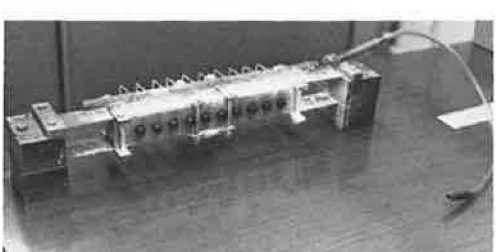


Table 2. Results of aggregate and pavement polishing and friction measurement by various procedures.

Aggregate	Percentage of Insoluble Residue	Laboratory Identification Number	Test Sections	SDM (f × 100)	4 by 12-In. Panel RDM DTN	4 by 12-In. Panel BPT BPN	3 by 5-In. Core RPP	3 by 5-In. Core BPT BPN	Minimum 3-Year Average	Minimum SN_{40}
Limestone	6.3	44	2-1, 2-3, 2-8	34	33	31	60	50	41	36
	2.8	46	5-1	39	32	40	56	57	42	41
	24.1	47	5-4	41	32	40	69	63	46	44
	8.7	48	8-3	27	32	37	64	52	44	42
	37.5	49[a]	8-1	60	37	49	73	75	54	47
	1.0	50	9-6	24	29	33	53	55	41	35
	3.7	51	9-1	26	29	31	56	59	38	35
	37.5	52[a]	10-1	59	42	54	74	65	38	38
	38.4	53[a]	10-4	56	44	50	74	67	36	34
	1.2	55	11-1	32	42	37	67	64	46	41
	10.1	56	3-1	—	31	38	53	47	30	27
	1.5	57	3-2	24	31	33	54	48	27	21
	2.1	58	4-4	29	32	41	54	66	42	38
	0.8	59	6-1	27	32	39	58	43	33	25
	7.1	60	7-5	37	31	41	57	58	44	34
Avg				36.8	33.9	39.6	61.4	57	40	35
Dolomite	2.6	54	11-2	—	31	38	61	64	46	41
	2.2	61	7-1	—	32	37	55	59	48	37
	2.2	62	7-2	—	31	36	54	62	48	36
	0.9	91	1-2, 1-3, 1-4, 1-12, 1-25	37	32	41	—	48	44	38
Avg				37	32	38	57	53	45	38
Gravel[b]		70	1-13		65	62	73	65	51	45
		71	2-7		60	53	64	61	50	44
		72	2-4		67	64	84	65	50	45
		73	5-3		68	57	68	70	49	45
		74	9-5		46	62	67	67	53	41
		75	10-2		44	54	57	56	41	33
		76	11-4		43	53	71	71	49	44
		77	4-1		48	—	76	62	56	51
		78	7-4		46	—	65	63	54	42
Avg					54	57.9	69.4	65+	50	44
Slag		79	1-11, 1-8		49	55	73	65	49	46
		80	1-18		45	62	68	61	46	43
		81	8-2		48	—	67	71	51	46
		82	9-8		48	—	66	69	50	41
		83	10-3		50	63	63	62	34	33
		84	11-3		46	60	63	70	49	44
		88	2-5		46	52	61	58	45	38
		89	3-4		56	69	82	57	46	38
		90	6-3		52	70	73	59	44	37
Avg					48.9	61.6	68.4	65-	47	42
Argillite		41	1-1		37	45	62	63	42	40
		42	1-17, 1-19		60	45	76	71	49	44
		63	3-3		60	—	81	61	33	27
		64	7-3		60	77	73	64	48	37
		65	6-5		56	67	67	42	44	35
		66	4-2		58	—	80	62	56	51
Avg					55.2	58.5	73.2	64	45	39
Diabase		67	6-2		44	—	58	46	37	31
		68	6-4		45	—	57	53	37	30
Avg					45		58	49	37	31
Gneiss		40	1-14		36	—	56	56	43	40
Sandstone		86	2-2		53	65	71	69	54	49
		87	5-2		53	67	77	73	51	48
Avg					53	66	74	71	53	49
Quartzite		85	1-23		46	—	69	54	46	42
Siltstone		45	2-9		41	51	71	58	51	45

Note: 1 in. = 25.4 mm.

[a]Were considered to be calcareous sandstone by Pennsylvania DOT petrographers.

[b]In Pennsylvania, consist of mostly (65 to 90 percent) sandstone or siltstone material (2).

Figure 5. Polishing results of various laboratory procedures on limestone aggregates.

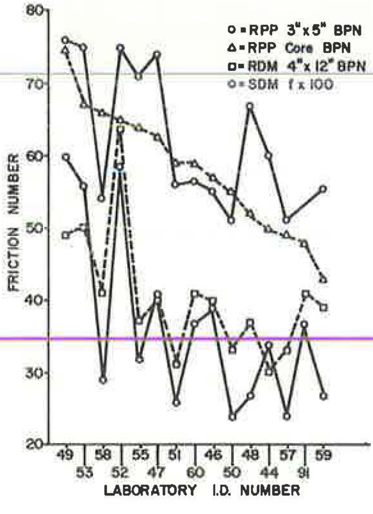


Table 3. Correlation coefficients for laboratory polishing results.

Sample	Method: Polishing	Method: Measurement	Polished Core, RPP (BPN)	3 by 5-In. Panel, RPP (BPN)	4 by 12-In. Panel, RD (BPN)
3 by 5-in. panel	RPP	BPN	0.58	—	0.71
4 by 12-in. panel	RDM	BPN	0.64	0.71	—
4 by 12-in. panel	RDM	DTN	0.51	0.91	0.60
10 particles	SDM	f × 100	0.70	0.77	0.82

Note: 1 in. = 25.4 mm.

Figure 5. A polished-core BPN was plotted in descending order of magnitude against the aggregate laboratory identification number. Results obtained by using the other methods were plotted in the same order as the cores for easy comparison. The rank method (7) was used to correlate each two sets of results, and the correlation coefficients are given in Table 3.

Figure 4 shows that the various polishing methods and friction measurement procedures resulted in different frictional number levels and ordering of the aggregates tested. However, all methods seem to indicate similar trends in evaluating the polishing characteristics of the aggregates. The coefficients of correlation given in Table 3 varied from poor to fairly good, and this indicated the degree of similarity between results obtained by using one method or the other. Of particular interest are the fair correlations obtained between results of polishing individual aggregates by the exploratory SDM and the other methods. The encouraging results seem to imply that, with further possible improvements, particularly on sample preparation, the SDM may become an expedient method for determining aggregate frictional properties.

COMPARISON OF LABORATORY AND FIELD SKID TEST RESULTS

Data Used in Comparison

A few weeks after construction, field skid measurements were made periodically on the test sections by Pennsylvania DOT according to ASTM E274. These data, covering from 1968 through 1973, were supplied together with aggregate petrographic classification, insoluble residue for the carbonates, average daily traffic (ADT) and average daily truck traffic (ADTT) obtained after construction, and pavement surface temperature at the time of testing. Skid numbers (SN) were also corrected for temperature to a base of 70 F (21.1 C) at the rate of ±3 SN/10 F (3 SN/5.6 C). These and other details of the test strip program are contained in department reports (1, 2). Reduction of the data to a form usable in this phase of the research was made and tabulated by type of aggregate, as is given for limestone in Table 4.

Since considerations of safe highway travel demand examination of the worst (most polished) surface condition, the annual minimum SN for each section was extracted from the data. Values obtained for replicate sections were generally close enough to justify averaging. Average values were calculated and tabulated, and, for each replicate pair (or more) or sections, the average was plotted in two curves, one for temperature-corrected and one for uncorrected values (8). Furthermore, because SNs have been found to vary with time (season and year), traffic, and other conditions of testing (1, 2, 9, 10), the average of the last 3-year minimum average SNs was calculated. We consider this average to represent a realistic, unbiased average minimum value of the steady-state frictional properties of surface aggregates after the pavement had relatively stabilized. The 3-year minimum average SN, the absolute minimum SN, core BPN, and percentage drop (from initial to polished) in SN and BPN are also given in Table 4.

Laboratory-Field Data Correlation

For all the aggregates and sections used in the test strips, BPNs on laboratory-polished pavement cores were correlated with SN_{40}. Previously (6), correlations between polished-core BPN and mean SN through 1971 resulted in poor coefficients ranging from 0.35 to 0.50. This time, correlations were attempted between polished-core BPN and minimum SN and between core BPN and the 3-year minimum average SN. Both correlations were only fair and resulted in coefficients of 0.67 and 0.69 respectively. The latter correlation, BPN versus 3-year minimum average SN, is shown in Figure 6. Correlations between field data and laboratory polishing tests on aggregate panels resulted in a similar trend but in fewer satisfactory correlations having coefficients rang-

Table 4. Skid test data for limestone test strip sections.

Test Section	Percentage of Insoluble Residue	ADT/ADTT	Annual Minimum SN_{40}: Initial	1969	1970	1971	1972	1973	Avg 1971-73	Absolute Minimum	Percent Drop[a]	1973 Vehicle Passes	BPN on Cores: Unpolished	Polished	Percent Drop[b]
2-1	6.3	1,130/102	58	46	49	35	52	39	42	35	39.6	2,160,000	70	51	27.1
2-3	6.3	1,130/102	48	48	53	35	48	35	39	35	27.1	2,160,000	66	48	27.3
2-8	6.3	1,130/102	50	52	58	39	51	40	43	39	22.0	2,160,000	71	51	29.2
3-1	10.1	15,700/804	35	28	34	27	31	32	30	27	26.7	24,580,000	61	47	23.0
3-2	1.5	15,700/804	30	21	31	22	28	30	27	21	30.0	24,730,000	63	48	23.8
4-4	2.1	1,900/374	63	65	53	39	50	38	42	38	39.7	3,120,000	74	66	10.8
5-1	2.8	5,000/377	51	45	50	41	44	41	42	41	19.6	9,530,000	66	57	13.6
5-4	24.1	5,000/377	51	47	52	45	50	44	46	44	13.7	9,490,000	74	63	14.9
6-1	0.8	5,500/568	42	28	43	36	37	25	33	25	40.5	8,810,000	58	43	25.9
7-5	7.1	4,500/252	58	68	37	50	48	34	44	34	41.4	6,920,000	68	58	14.7
8-1	37.4[c]	625/129	51	47	64	60	51	52	54	47	7.8	1,130,000	77	75	2.6
8-3	8.6	625/129	46	42	49	43	45	44	44	42	8.6	1,130,000	67	51	23.9
9-1	3.7	4,243/299	49	35	46	40	39	35	38	35	28.6	8,050,000	71	59	16.9
9-6	1.0	4,243/299	53	35	45	45	42	35	41	35	33.9	7,910,000	74	55	25.7
10-1	35.5[c]	4,676/168	49	47	43	38	38	38	38	38	22.4	8,850,000	75	65	13.3
10-4	38.4[c]	4,676/168	45	38	46	34	38	37	36	34	24.4	8,850,000	74	67	9.5
11-1	1.2[d]	3,813/288	64	48	57	49	49	41	46	41	35.9	7,060,000	77	64	16.9
Avg			49	44	48	40	43	38	40	35	28.6		70	57	18.6

[a]Initial to minimum. [b]Initial to polished. [c]Loyalhanna. [d]Ohio.

Figure 6. Polished-core BPN versus 3-year minimum average SN_{40} on all sections.

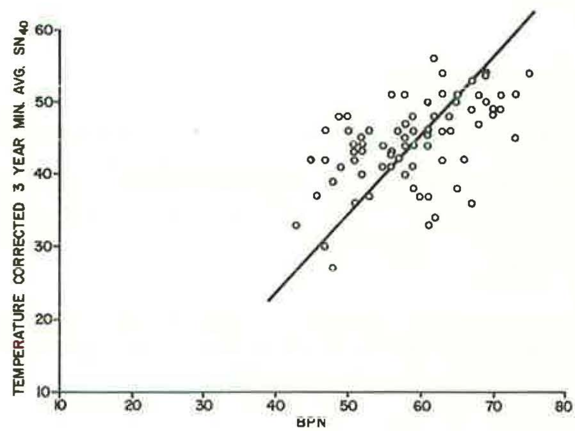


Figure 7. 3-year minimum average SN_{40} versus 5-year absolute minimum SN_{40} on all sections.

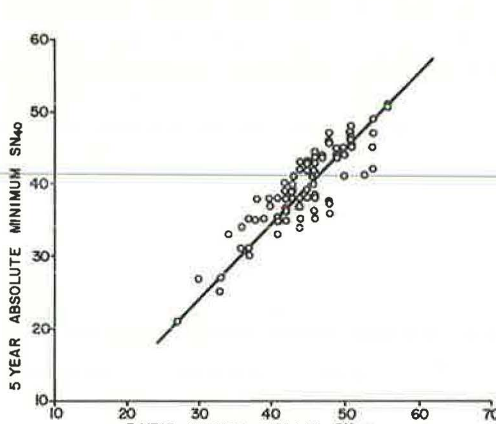
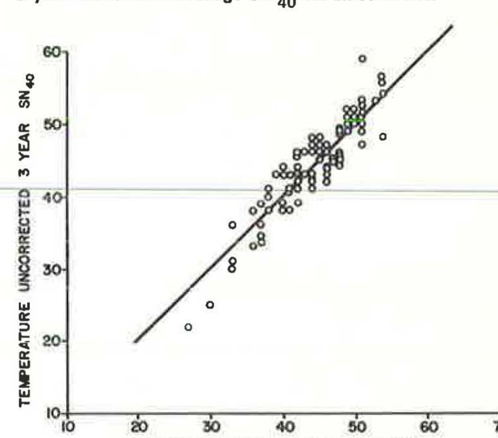


Figure 8. Temperature-corrected versus uncorrected 3-year minimum average SN_{40} on all sections.



ing from 0.55 to 0.65.

Similar correlations obtained from using minimum SN and 3-year minimum average SN encouraged us to find whether correlations existed between these two parameters, when used in either the temperature-corrected or the uncorrected form. Figure 7 shows the correlation between the temperature-corrected 3-year average SN and the absolute minimum SN for all test sections, and Figure 8 shows corrected versus uncorrected 3-year minimum average SN for the same sections. It is apparent from the figures that, in both cases, good correlations ($r > 0.90$) and close relationships existed between the parameters. Generally, the 3-year minimum average SN is about five skid numbers higher than the absolute SN, but temperature-corrected and uncorrected SN have approximately a 1:1 relationship. Accordingly, only one set of data representing any of these parameters needs to be used in subsequent correlations.

Other attempts included a correlation between polished-core BPN and minimum SN for the carbonate sections only. The scatter of data points and the coefficient for this correlation were even worse than for the similar correlation of data for all sections; this probably indicated the large variability between aggregates within the carbonate group and pointed to the need for investigating individual carbonate aggregates on their individual merit, although as a group they seem to fall into the poor to marginal performance category.

Several factors could have contributed to the generally unsatisfactory correlation results obtained between laboratory and field frictional numbers. These factors include, but are not limited to, basic differences in measurement method and testing speed (10) and probable variations between core and field surface texture due to local variations and field surface changes caused by climatic changes and increased use of studded tires. Therefore, in the future, BPNs should also be measured in the field simultaneously with SN measurements, if some good correlations are to be achieved.

In the past decade or so, several attempts have been made to correlate portable testers and skid trailers (11, 12, 13). Correlation results have ranged from poor to fair or good, but there seems to be no general agreement among researchers on a resulting regression equation or set of equations that can be used with confidence.

Comparison and Ranking of Aggregates

All aggregates used in this research were grouped into 10 general types (Table 1). For a comparison of aggregates by type, the annual minimum SN for all sections in each group were averaged (Table 4). For each type, an average curve representing the group by type was plotted, as shown in Figure 9. These curves show the performance of each aggregate type. However, variations within each type due to the spread of data around the average ranged from fairly small (about ±3 SN) for dolomites, to very large (about ±12 SN) for limestones. Furthermore, the zigzag pattern of some curves makes definitive ranking of the aggregates by this procedure very difficult. Accordingly, another approach had to be followed.

For a ranking of the aggregates by each type, the 3-year minimum average SN, the absolute minimum SN, and the polished-core BPN values were pooled and averaged, and this resulted in one grand average of each friction number per aggregate type. These average values are given by aggregate type in Table 5. To indicate the extent of variation from the average value, the range around each average was also recorded in Table 5. One parameter had to be used as reference for the ranking. The 3-year average was chosen for reasons that have been discussed. Ranking of the aggregates was now attainable by the three parameters, and ranking results appear in both Table 5 and Figure 10. The obvious anomalies or suspicious deviations were given in the notes to Table 5.

Correlation of Ranking Data

From Figure 10 and Table 5, one can see that the 3-year minimum average and the

Figure 9. Average minimum SN for five aggregate types.

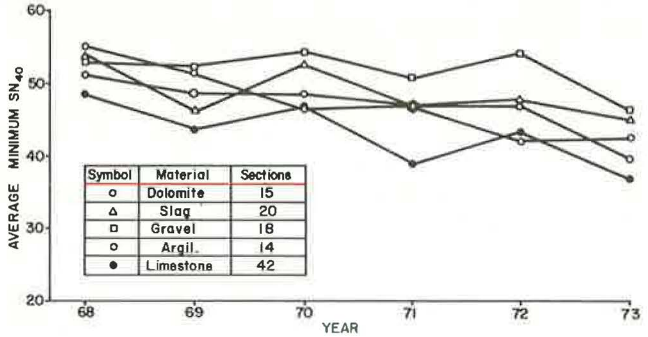
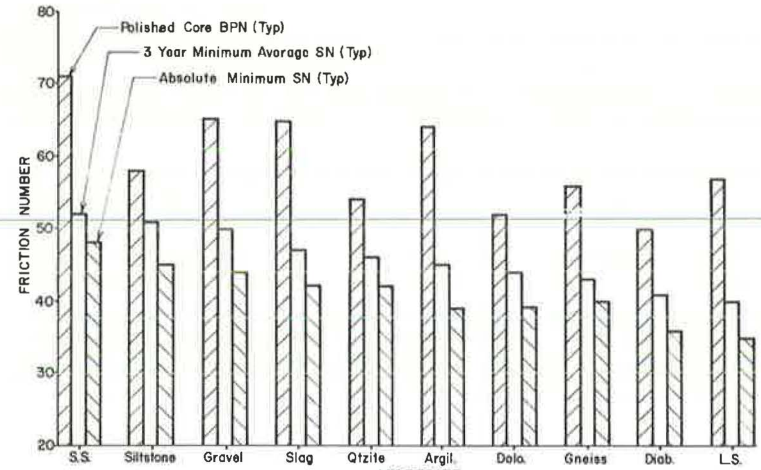


Table 5. Ranking of aggregates used in test strips.

Aggregate	Number of Test Sections	3-Year Minimum Average SN_{40}			5-Year Minimum Average SN_{40}			Polished Core BPN			
		SN	Range	Rank	SN	Range	Rank	BPN	Range	Rank[a]	Rank[b]
Sandstone	4	52	51 to 54	1	48	48 to 49	1	71	69 to 73	1	1
Siltstone	2	51	48 to 54	2	45	42 to 48	2	58	54 to 62	5	5
Gravel	18	50	41 to 56	3	44	33 to 51	3	65+	56 to 71	2	2
Gravel[c]	16	51	49 to 56	3[d]	45	41 to 51	3[d]	66	61 to 71	2[d]	2[d]
Slag	20	47	34 to 51	4	42+	33 to 47	4	65-	57 to 71	3	3
Slag[e]	18	48	44 to 51	4[d]	43	38 to 47	4[d]	65	57 to 71	3[d]	3[d]
Quartzite	2	46+	43 to 49	5	42-	39 to 45	5	54	52 to 56	8	7
Argillite	14	45	33 to 54	6	39+	27 to 51	7	64	52 to 73	4	4
Argillite[f]	12	46	42 to 54	6[d]	41	35 to 51	6[d]		52 to 73	4[d]	4[d]
Dolomite	17	44	40 to 48	7	39-	36 to 43	8	52	45 to 64	9	9
Gneiss	2	43	41 to 45	8	40	39 to 42	6, 7[d]	56	54 to 58	7	6
Diabase	6	41	37 to 48	9	36	30 to 47	9	50	46 to 53	10	10
Diabase[g]		48		4[d]	47		4[d]		—		
Limestone[a]	42	40	27 to 54	10	35	21 to 47	10	57	43 to 75	6	
Limestone[b]	39	39	27 to 46	10	34	21 to 44	10	54	43 to 64	—	8

[a]Including six sections of Loyalhanna formation, considered calcareous sandstone by Pennsylvania DOT petrographers.
[b]Excluding six sections of Loyalhanna formation, considered calcareous sandstone by Pennsylvania DOT petrographers.
[c]Excluding section 10-2, which had fine grained material and very dense mix that tends to decrease skid resistance (2).
[d]Alternate rank.
[e]Excluding section 10-3, which consistently had an anomalously low SN attributed, at least in part, to excess asphalt content (2).
[f]Excluding section 3-3 in which the coarse aggregate contained 60 percent sericite (very fine-grained mica—Moh's number, H=2) that is suspected of contributing to the low SN for this section.
[g]Two sections (1-21 N and S), where the fine aggregate was also diabase; other sections (6-2 and 6-4) had limestone as the fine aggregate.

Figure 10. Ranking of aggregates based on field and laboratory data.



absolute minimum SNs ranked the aggregates in approximately the same order, but a different ranking resulted when core BPN values were used. This follows the lack of good correlations between BPN and SN, as has been discussed. However, correlations between core BPN and SN by aggregate type, as shown in Figure 11, resulted in relatively high coefficients (r = 0.85 by the rank method for Figure 11), and this indicated that at least a general trend exists in ranking aggregate types by both laboratory and field methods. Similar correlations using other laboratory-polished samples and SNs followed a similar pattern with coefficients ranging from 0.75 to 0.85.

Another approach was to correlate the percentage drop in the core BPN with the percentage drop in SN, as shown in Figure 12. The resulting coefficient of correlation was slightly less than 0.50; this indicated that the approach was unsatisfactory.

OTHER OBSERVATIONS ON BITUMINOUS PAVEMENT SKID RESISTANCE

Periodic Variations in Skid Resistance

Skid resistance was measured periodically on all test strip sections. SNs varied from period to period, probably because of changes in season and in environmental conditions of testing such as temperature, rainfall, and other weather-related factors, but SNs seemed to follow some cyclical annual pattern resembling a sine wave, as was observed by Gramling and Hopkins (1). However, in most cases, SN-time wear curves had a downward negatively sloping trend similar to laboratory polishing curves; this indicated a general decrease in the level of SN with passage of time and traffic until a leveling-off occurred. Minimum SNs generally occurred in the summer and fall, and the larger portion occurred from August through October, as may be seen in Figure 13. SN annual variation between minimum and maximum had a wide range for some aggregates like the limestone and a narrow range for other aggregates like the gravel and quartzite (2). In addition, high ADT caused more seasonal variation in SN than low ADT (1).

Previous research has reported that temperature does affect SN. Rates of change ranging from <½ to >3 SN/10 F (<½ to >3 SN/5.6 C) have been reported (10). However, there seems to be no general agreement among researchers on a correction factor. It may be that correction for temperature is not necessary in the ranking of aggregate performance, as was implied by Figure 8. However, it seems that more thorough research in this area is still needed, especially if corrective measures are to be taken when SN_{40} falls below an adopted arbitrary level.

Effect of Traffic on Skid Resistance

Traffic and aggregate characteristics have generally been recognized as the most important factors that influence pavement surface polishing (1, 10, 14). Some aggregate factors have already been discussed in this paper and elsewhere (15). As for traffic on any given surface, the higher the traffic is, the lower the skid number will be, as shown in Figure 14. The curves in Figure 14 represent actual test data on limestone test sections carrying different ADT.

In the laboratory, traffic is simulated by polishing equipment such as circular tracks, stationary rotating wheels, or reciprocating equipment (9, 11, 16). On laboratory-polished samples, frictional numbers generally deteriorate as cumulative polishing passes increase until a practically stable state is reached. In the field, pavement surfaces have been found to regain in SN level after some initial loss due to the polishing effect of traffic. Therefore, the question has been raised about whether ADT or accumulated vehicle passes should be considered in investigating SN deterioration. Both concepts have been used in skid-resistance investigations (1, 9, 12, 14), and claims have been made that one parameter or the other is the more dependable to use. In this research, it was found that both parameters, ADT and accumulated traffic, should be considered because both parameters appear to influence the level of skid resistance reached,

Figure 11. Polished-core BPN versus minimum SN_{40}.

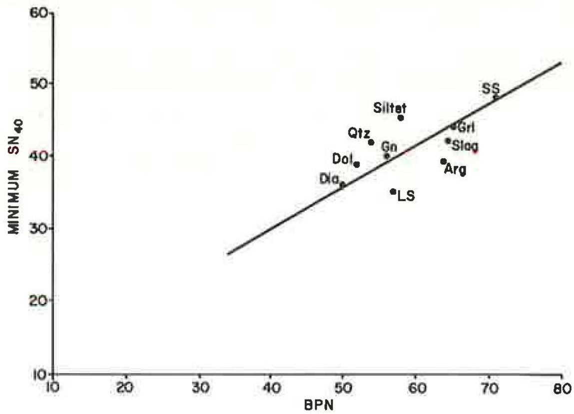


Figure 12. Percentage drop in core BPN versus percentage drop in SN_{40}.

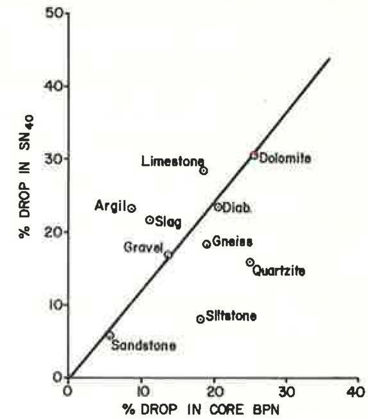


Figure 13. Frequency of occurrence of minimum SN_{40} versus time of year for 1969-73.

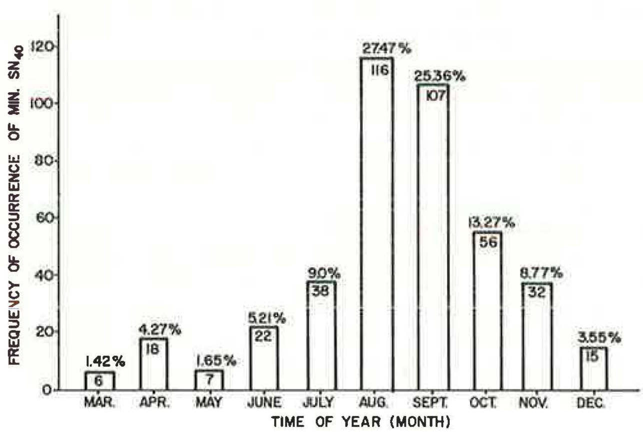
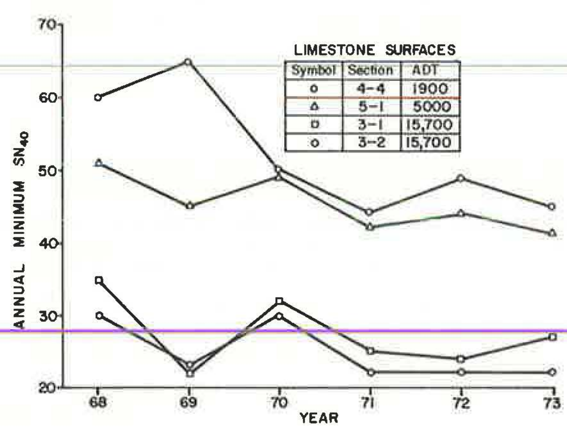


Figure 14. Effect of ADT on minimum SN over limestone surfaces.



as may be seen from Figures 15 and 16 for ADT and cumulative traffic respectively.

Figure 15 shows that similar correlations are obtained between 3-year SN and ADT, and between 3-year SN and ADT (truck). Furthermore, at 3-year SN = 40, the effect of an average truck on pavement polishing is equivalent to about 18 passenger cars. This equivalency varies depending on at what SN level it is estimated, but the ratio of 1:18 taken at SN = 40 represents an average value. Similar correlations using all the test sections resulted in similar equivalencies. Furthermore, slopes of curves using data from all sections resulted in about a 1:20 ratio.

From Figure 16, one can see that the 3-year average SN generally deteriorates as the number of vehicle passes increases, despite intermediate recoveries due to surface rejuvination. From charts like Figure 16, drawn for a particular type of surface and aggregate, one can estimate the number of vehicle passes that a pavement will be expected to endure before a predetermined minimum SN is reached. The rate of SN deterioration with accumulated traffic can also be estimated for a given surface and aggregate.

Insoluble Residue and Skid Resistance

Earlier research has indicated that skid resistance of the carbonate aggregates increases as the portion of insoluble residue in the aggregate increases. Quantitative relationships have been sought between the two parameters, and several have been reported (2, 17, 18). But there seems to be neither general agreement on the percentage of residue that will produce a predetermined minimum SN nor on the rate of increase of SN as the percentage of residue increases.

In this research, an attempt was made to correlate both laboratory BPN on cores and field 3-year minimum average SN with the percentage of insoluble residue. The correlations are shown in Figure 17. The wide scatter of data in the figure indicates unsatisfactory quantitative relationships between the residue and the frictional number. However, there appears to be a trend of increase in both the laboratory and the field frictional numbers as the percentage of residue is increased. It appears that the influence of residue may be more pronounced in laboratory polishing than it is in the field. Figure 17 shows that carbonate samples having residue distributed at 2 to 5 percent intervals in the range of 10 to 35 percent are needed to produce sufficient data points. The implication is that a more thorough investigation covering these intermediate levels of insoluble residue will be needed before definitive quantitative relationships between insoluble residue and SN can be established. If carbonates having residues in the 20 to 35 percent range can be shown to provide a significantly higher level of skid resistance than those with less residue, selective quarrying may enable some producers to meet higher levels of skid-resistance requirements.

SUMMARY AND CONCLUSIONS

The research discussed was part of a cooperative effort to evaluate bituminous pavement and aggregate polishing, both in the laboratory and in the field, and to investigate whether correlations of practical application existed between the two approaches. Influences of other factors encountered in the research process, such as environmental, traffic, and petrographic characteristics of surface aggregates, were also observed and reported on.

A test strip program containing 156 pavement sections in 11 different locations in Pennsylvania and incorporating various aggregates was initiated and monitored periodically for field skid resistance. Fifty-two aggregate samples and 223 pavement cores representative of the test sections were polished and tested for friction in the laboratory. Correlations were made between laboratory and field results. The following conclusions are supported by the findings from this research:

1. Different methods of laboratory polishing and friction measurement produce

Figure 15. ADT and ADTT versus 3-year minimum average SN_{40} grouped by ADT.

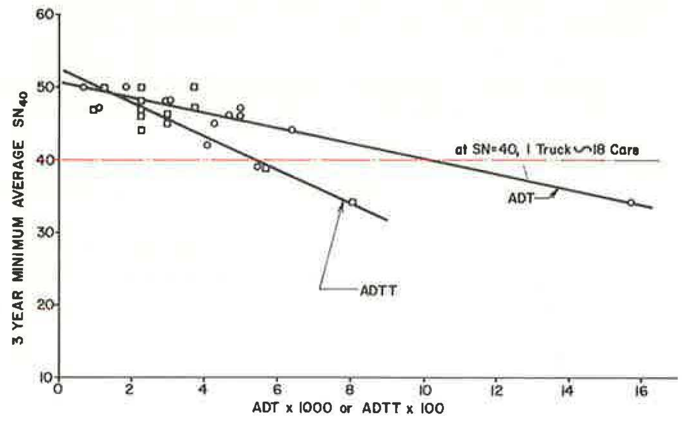


Figure 16. 3-year minimum average SN_{40} versus cumulative traffic on carbonate sections.

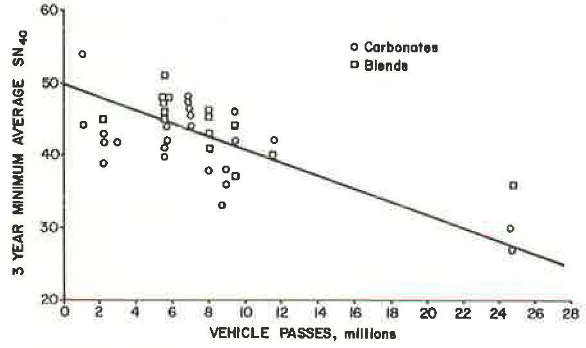
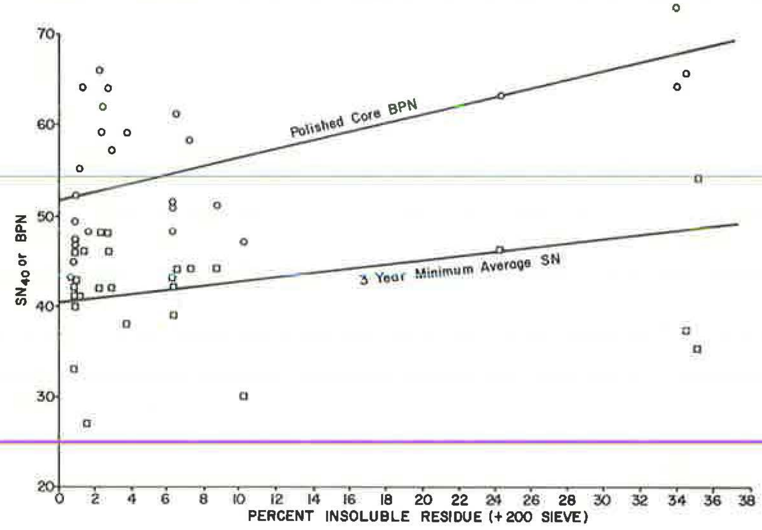


Figure 17. Percentage of sand-size insoluble residue versus friction number.



different friction number levels and do not always rank the tested aggregates in the same order; however, they do indicate similar general trends and predict similar general levels of aggregate resistance to polishing.

2. The exploratory SDM seems to be useful for expedient laboratory evaluation of aggregate polishing characteristics.

3. Correlations between laboratory and field data indicate similar trends in polishing characteristics, but they do not produce, through regression equations, satisfactory mathematical relationships that can be applied with confidence for the prediction of specific numerical values of field SN based on laboratory-measured SN.

4. Field and laboratory methods rank aggregates in a closely similar order, but not always in the same order; therefore, a specific correlation should always be established between the particular method to be used for laboratory and field SNs.

5. Minimum SNs correlate significantly better than mean SNs with laboratory-polishing results. No significant difference in analysis seems to result whether an absolute minimum or 3-year minimum average SN is used. Both rank aggregates in practically the same order.

6. Temperature-corrected and uncorrected minimum SNs rank aggregate performance similarly, when used in skid-resistance analysis.

7. Minimum SNs generally occur in the late summer and fall of the year and predominate in August through October.

8. Percentage drop in frictional number between the initial and the polished condition is not a good indicator of pavement or aggregate skid-resistance performance.

9. On any given surface, the higher the ADT is, the lower the skid-resistance levels will be. For any ADT and surface, the skid-resistance level fluctuates widely at first but stabilizes and levels off after about 2 years of service; and for a given ADT, the skid-resistance level is lower on some aggregates like limestones than on others like gravels.

10. There seems to be an equivalency in polishing effects between trucks and passenger cars. One truck appears to be equivalent to about 18 cars.

11. Until a pavement surface stabilizes, skid-resistance level decreases with passage of time and traffic, mainly because of accumulated traffic action.

12. In this research, increase in portions of insoluble residue gave only general trends of increase in skid resistance. Further tests are needed on samples that will cover narrow intervals in the range of 10 to 35 percent insoluble residue content.

13. Where the more polish-susceptible aggregates interact with high traffic volumes to produce a pronounced seasonal cyclic pattern of skid resistance, a procedure should be developed for predicting minimum SN from field tests taken at any time during the cycle.

ACKNOWLEDGMENTS

This research was sponsored by the Pennsylvania Department of Transportation in cooperation with the Federal Highway Administration. The work was performed at the Pennsylvania Transportation Institute, Pennsylvania State University. Progress of the research was aided by many of the personnel of Pennsylvania DOT and FHWA, as well as by several Pennsylvania State University faculty, staff, and students.

The contents of this paper reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented. The contents do not necessarily reflect the official views or policies of the Pennsylvania DOT or FHWA. This paper does not constitute a standard, specification, or regulation.

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