AUTOMOTIVE SAFETY RESEARCH PROGRAM

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THE POLISHING RESISTANCE OF SELECTED SLAG AGGREGATES

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ABSTRACT

The polishing resistance of six sources of slag and five other aggregates was investigated. The Penn State rotary drum polishing machine was used in which aggregate specimen are exposed to the polishing action of a rotating, abrasive covered tire. Progress of polishing is monitored with a Penn State Drag Tester and terminated when the so measured friction reaches a steady value.

The results show significant difference in polishing resistance and in steady friction level for the different aggregates.

ACKNOWLEDGEMENTS

The work reported here was carried out under contract with the National Slag Association and on aggregates furnished by the Association. Mr. Howard K. Eggleston, Managing Director, and Mr. D. W. Lewis, chief engineer of the Association assisted in the planning of the test program and made available the results of physical tests made on the aggregates at the Association's Laboratories.

The Bureau of Materials, Testing and Research of the Pennsylvania Department of Highways supplied two aggregates and consented to the use of the polishing machine, while not used for Department sponsored projects.

The opinions, findings, and conclusions are those of the authors.

INTRODUCTION

Slag has been used as pavement aggregate for many years and is known to provide good skid resistance (Bauman, 1959). However, all pavements are exposed to the polishing action of tires and this process causes a reduction in skid resistance. For this reason a major factor in the selection of aggregates for the surface course is their resistance to polishing. Different groups of materials are known to have different polishing resistance, but the polishing resistance of materials within one group also varies. For the same operating conditions the polishing resistance depends largely on the petrographic properties of the particular aggregate.

The program reported here was undertaken to investigate the polishing resistance of different slags. Some other materials were included for reference and comparison.

POLISHING APPARATUS AND METHOD

The apparatus used in this project was the Penn State rotary drum polishing machine (Kummer, 1966). Six panels, each carrying one type of aggregate, are mounted to the outer surface of the drum. The drum is driven at a surface speed of 35 mph. A 7.50 x 14 tire with a smooth running band, inflated to 50 psi is loaded against the drum with a wheel load of 400 lbs. After an initial break-in period of 10,000 wheel passes without abrasive the actual polishing begins. A continuous spray of abrasive (aluminum oxide - grade 900) is sprayed onto the tire surface by a compressed air gun. The polishing process is completely dry.

At selected intervals (determined by the number of wheel passes) the polishing process is interrupted and friction measurements are taken. The test panels are wetted at a controlled temperature and friction is measured with the Penn State Drag Tester and reported as Drag Tester Number (DTN). The measurements are made at a sliding speed of 0.16 mph to minimize heating of the rubber slider and resulting effects on the measured friction (Meyer and Kummer, 1968). Before polishing is resumed, the drum is run at high speed without wheel load for about ten minutes to allow the test panels to dry. The polishing process is terminated when there are no longer significant changes in the DTN for any of the specimens in the test.

One out of the six panels on the drum is used as reference and remained on the drum during the entire project. The reference panel used was a previously polished sample of uncrushed gravel (Pennsylvania bank gravel).

AGGREGATE SELECTION AND PREPARATION

A total of eleven different aggregates were polished in this project and are listed in Table 1. The National Slag Association supplied nine of the materials and the remaining two identified as 1G and 1L were supplied by the Bureau of Materials, Testing and Research of the Pennsylvania Department of Highways. The physical properties of all aggregates were determined by the National Slag Association and are given in Table 1. Each material was to be tested at least twice, making 22 test specimens. The polishing drum carries six specimen panels; since one was used as permanent reference, there was space for five specimens per test. To accommodate the 22 specimens, a total of five tests were required, with some materials used on three test specimens. The number of panels and the sequence of testing were determined by random selection (Table 2), but provision was made not to polish in the same test run two panels of the same material. One panel (**gravel 1G**) broke during polishing.

The aggregate supplied by the National Slag Association was graded to pass a 3/8 inch sieve and retained on a No.4 sieve. The limestone and gravel supplied by the Pennsylvania Department of Highways was graded to pass a No.3 sieve and retained on a No.4 sieve. The aggregate particles chosen for preparation for the panels were selected individually on the basis of uniform size and shape and in sufficient quantity for two, or in three cases, for three panels (approximately 1 lb. per panel), but without additional sieving. The particles were thoroughly washed and then dried in an oven. A semi-hard epoxy was used to bind the aggregate to the aluminum panels. Each panel has a 12” x 4” aggregate field. Panels of the same type of aggregate contained equal amounts (by weight) of that aggregate.

The finished panels differed in aggregate size, but it was decided not to delay the program by remaking some of the panels. Instead one test panel of gravel **1G** of aggregate passing a 3/8 inch sieve and retained on a No.3 sieve was prepared and tested. The results are listed in Table 3 as gravel **1G**, panel No.2 and the data are seen to differ no more than for other panels of same size aggregate. It was therefore concluded that the size effect could be disregarded.

To ascertain the size distribution of the aggregate supplied by the National Slag Association the left over samples were sieved to determine the fraction passing a No. 3 and being retained on a No.4 sieve. The results are given below.

Sample	12A	12J	12K	10C	12C	2A	11C	12I	8C
Percent	69	72	66	66	64	45	70	60	70

TEST RESULTS AND DISCUSSION

Table 3 gives the initial and final DTN for all panels. The largest difference between two test panels of the same material is 5 units in initial DTN and 8 units in final DTN. The largest difference in DTN drop is only 3 units, thus the larger differences in absolute values must probably be accounted for by the shape factor of the test surfaces. Although like panels were prepared from the same aggregate samples and equal weights were used for each panel, the irregular shape of the particles will invariably produce some variation in surface texture as seen by the slider. The relatively large size of the test panels on the rotary drum polishing machine tends to average out the shape effect and therefore test results obtained with only two samples per material seem to be sufficient and representative. The repeatability of the friction testing was excellent as can be seen from the DTN of the reference panel in the lower graph of Figure 1.

The average DTN for each material was calculated and Figure 1 shows the change in average DTN during polishing. It can be seen that the performance of both steel slags **12A** and **12J** is similar. Also the blast furnace slags **12K** and **10C** as well as **12C** and **2A** gave similar results. There is a large spread in the performance of the three gravels and of the two limestones.

Percent of crushed aggregate (Table 1) and the friction test data for the three gravels seem to correlate. Gravel **1G** did not perform as well as gravel from the same source used about four years earlier in another project. Both gravels were analyzed for their components. The older gravel was found to contain about 40% of siliceous pebbles against only 27% for gravel **1G**. The limestones, **8C** and **1L,** were found to have an insoluble residue of 41.3 and 2.2 percent weight respectively of sample larger than sieve No. 200. These facts are probably responsible for the differences in the measured friction data.

A better comparison of the results can be obtained by ordering the materials according to performance. Table 4 shows the eleven materials listed in three columns, starting each column with the best average test result. As can be seen, the order of the aggregates in the three columns varies, but the sum of the relative standing of each material in all three columns may be taken as measure of its overall performance. For example, steel slag **12J** has first place in column 1, second place in column 2 and third place in column 3, for a total rank number of 6. Limestone 1L has tenth place in columns 1 and 2 and last place in column 3 for a total of 31. All materials are listed in order of ascending rank or performance number in Table 5, with the smallest number indicating best performance.

Using all three criteria (initial, final and change in friction) is preferable to just using the final friction value, since it accounts for the polishing resistance, i.e., the drop in friction. The best possible rating by this method would be 3, for a material having highest initial and final DTN and smallest drop in DTN. The poorest possible rating is three times the number of aggregates in the test, in this case 33. (A rating based on final DTN and drop in DTN only gives results very similar to the rating of Table 5)

Immediately the question arises if this performance determined in friction and polishing tests can be correlated with any property of the particular material. Shupe and Lounsbury (1958) have concluded that: “Unfortunately, there appears to be no relationship between any of the standard physical tests and the resistance to polishing of an aggregate in a bituminous mixture. . . . . The petrographic description and the photomicrographs of the various aggregates provided a somewhat more fruitful source of information for relating aggregate properties and anti-skid characteristics."

Hosking (1967) investigated the polishing resistance of ten blast furnace slags and found that, at least, some types of slag seem to have better polishing resistance, the lower the specific gravity.

Since no chemical or petrographic analysis was available at the writing of this report, an attempt was made to correlate the polishing test results with the physical properties given in Table 1 and rearranged in Table 6 in descending order.

TABLE 1 TEST AGGREGATES AND THEIR PHYSICAL PROPERTIES

Aggregate Type	Sample Identification	Unit Weight, lbs/cu. ft. (Oven Dry) ASTM C-29* Loose	Compact Rodded	Compact Jigged	Absorption 24 hours, percent, ASTM C127	Specific Gravity Bulk Dry ASTM C127	L.A. Abrasion 'C' Grading ASTM C131	% Crushed (Gravel) One Face	Two Faces
Steel	12A	100.6	111.0	115.0	2.0	3.13	23.1		
Slag	12J	110.0	121.6	126.4	1.3	3.33	27.6		
Blast	12K	68.4	75.4	78.4	3.8	2.34	35.0		
Furnace	10C	65.0	72.6	75.0	4.8	2.20	35.8		
Slag	12C	80.8	89.8	93.0	1.6	2.65	27.3		
	2A	72.2	80.2	82.8	2.9	2.37	38.3		
Gravel	11C	90.0	98.6	101.8	2.2	2.54	22.3	91.9	83.0
	12I	90.2	98.8	101.4	2.9	2.53	21.1	83.3	66.7
	1G	89.6	98.0	101.1	2.2	2.51	-	58.5	49.4
Limestone	8C	80.0	90.2	93.8	0.6	2.65	15.8		
	1L	86.2	96.6	100.0	0.5	2.68	20.8		

*Sieve	Total Percent Passing
1/2 inch	100
3/8 inch	90
No.4	20
No.8	0

TABLE 2 PANEL ARRANGEMENT

Run No	Aggregate				
1	2A	10C	2A	1L	1G
2	2A	12K	12A	12I	8C
3	8C	12J	12C	1L	1G
4	12J	10C	12C	11C	1G
5	12I	I2K	10C	11C	8C

TABLE 3 RESULTS OF FRICTION TESTS ON SPECIMENS

Sample		Initial DTN	Final DTN	Drop in DTN
Steel Slags	12A1	72	56	16
	2	67	48	19
	12J 1	73	52	21
Blast Furnace Slags	12K1	72	49	23
	2	70	48	22
	10C1	71	52	19
	2	72	50	22
	2	70	49	21
	3	69	49	20
	12C1	67	44	23
	2	63	42	21
	2A 1	67	45	22
	2	67	43	24
Gravel	11C1	70	45	25
	2	66	42	29
	12I 1	62	40	22
	2	59	36	23
	1G 1	55	32	23
	2	50	29	21
Limestone	8C 1	73	52	21
	2	70	48	22
	3	69	47	22
	1L 1	60	35	25
	2	59	31	28

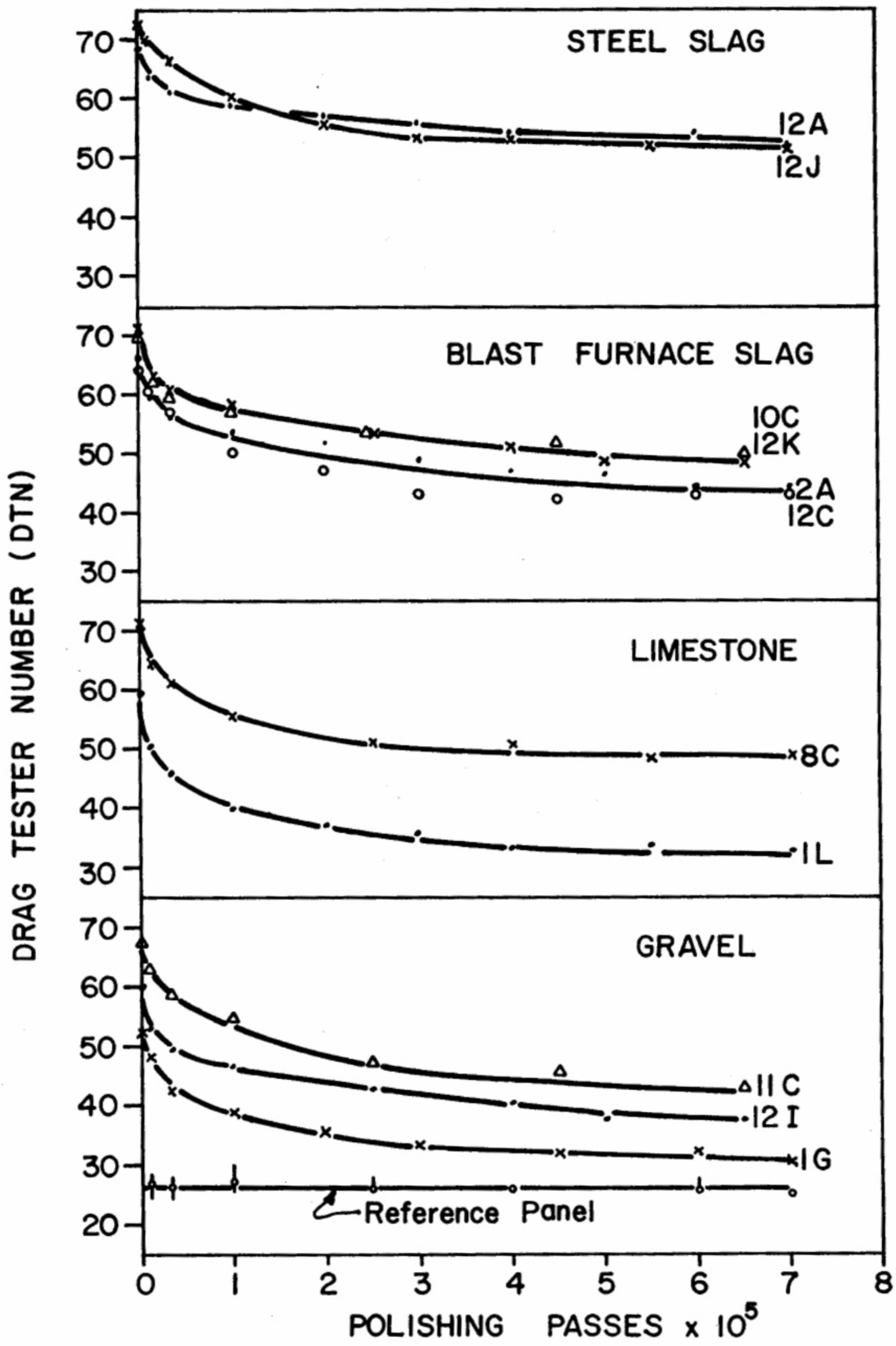
STEEL SLAG
12A
12J
BLAST FURNACE SLAG
10C
12K
2A
12C
LIMESTONE
8C
1L
GRAVEL
11C
12 I
1G
Reference Panel
DRAG TESTER NUMBER (DTN)
POLISHING PASSES x 10^5
70
60
50
40
30
20
0
1
2
3
4
5
6
7
8

TABLE 4 RANKING OF AGGREGATES BY MEAN DTN

Rank	Initial DTN	Final DTN	Drop in DTN
1	12J	12A	12A
2	12K	12J	10C
3	8C	10C	12J
4	10G	8C	8C
5	12A	12K	12C
6	11C	2A	1G *
7	2A	11C	12K
8	12C	12C	121*
9	12I	12I	2A
10	1L	1L	11C
11	1G	IG	1L

*12C and 12G, 12K and 12I had the same drop in DTN

TABLE 5 PERFORMANCE RATINGS

Material		Performance Number
1 Steel Slag	12 J	6
2 Steel Slag	12 A	7
3 Blast Furnace Slag	10 C	9
4 Limestone	8 C	11
5 Blast Furnace Slag	12 K	14
6 Blast Furnace Slag	12 C	21
7 Blast Furnace Slag	2 A	22
8 Gravel	11C	23
9 Gravel	12 I	26
10 Gravel	1G	28
11 Limestone	1L	31

TABLE 6

Average Unit Weight	Spec. Gravity	Absorption %	L. A. Abrasion
12J	12J	10C	2A
12A	12A	12K	10G
11C	1L	2A	12K
12 I	8C	12 I	12J
1G	12C	11C	12C
1L	11C	1G	12A
8C	12 I	12A	11C
12C	1G	12C	12 I
2A	2A	12J	1L
12K	12K	8C	8C
10C	10C	1L	*

*Not given for gravel 1G

The fact that the two steel slags of greatest specific gravity gave the best performance must be taken as coincidence, since the other materials do not line up in order of their specific weights. However, when the four blast furnace slags are compared (Table 7), an inverse relationship between specific gravity and polishing performance appears possible.

TABLE 7

Decreasing Polishing Performance	Increasing Specific Gravity
10C	10C
12K	12K
12C	2A
2A	12C

This tendency is in agreement with the finding of Hosking (1967) and, if confirmed by a larger number of tests, could be an important indicator of relative polishing resistance of different blast furnace slags. There seems to be no correlation with the Los Angeles Abrasion Resistance. The two processes of abrading and polishing are different and the lack of correlation serves to emphasize the need of a polishing method which reproduces closely the polishing action of tires on the pavement.

The rotary drum polishing machine used in this project does indeed rank aggregate similar to their ranking on the pavement, as was shown by Kummer (1968) for blends of aggregates and will be shown for different aggregate in a forthcoming report (Hegmon, 1969). The British Road Research Laboratory uses a similar polishing machine and correlation with field data was shown by MacLean & Shergold (1958).

CONCLUSIONS

It should be emphasized that the ratings obtained in the polishing tests are comparative and, at the present state of knowledge, correlations with field performance is inadequate. The results obtained with the two limestones clearly reflect the insoluble residue, which is known to be a major factor in skid resistance of limestone pavements. One can therefore hope that the relative performance found for the slag samples in these laboratory tests are representative of the field performance one may expect.

The objective of this project, to evaluate the relative polishing resistance of selected slag samples, was met. It remains to find a correlation to slag characteristics.

The polishing and testing procedures proved reliable. Any variation in data is presumably caused by variation in sample preparation, which by the nature of the materials, cannot produce identical test samples.