LABORATORY EVALUATION OF AGGREGATES, AGGREGATE BLENDS, AND BITUMINOUS MIXES FOR POLISH RESISTANCE

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The objectives of this research were to develop laboratory tests for preevaluating aggregates and paving mixtures to predict skid resistance properties in the field and to identify mixture designs incorporating optimum skid resistance and polish resistance. Laboratory evaluation methods developed include a circular-track machine using small-diameter pneumatic tires and a petrographic method for evaluating polish susceptibility based on percentage of hard mineral found in aggregate thin sections. Evaluation of the 2 test procedures is provided, and findings are given of laboratory tests on polish resistance properties of aggregates, aggregate blends, and bituminous mixes.

•USE of the North Carolina State University small-wheel circular track for laboratory studies of aggregate and pavement polishing properties was reported to the Highway Research Board in 1970 by Mullen, Dahir, and Barnes (1). Since that time improvements have been made to the track and studies have been extended to include additional aggregates, variations in bituminous pavement mixtures, and aggregate blends including some with crushed waste glass. The track was turned over to the North Carolina State Highway Commission (NCSHC is now the North Carolina Department of Transportation and Highway Safety) in 1973 for a program of experimental preevaluation of bituminous pavement mix designs.

The major improvement to the track was the substitution of a tire 5.25 in. (133 mm) wide for the previous tire, which was 3.50 in. (90 mm) wide, to widen the wear path and eliminate possible edge effects on measurements made with the British portable tester (ASTM E 303-69). New calibration curves were developed by comparing the laboratory control aggregate results to earlier results with narrower tires. Results from old and new tires were comparable.

Characteristics of the polishing curve from the first hour up to 100 hours were established to help interpret results of polish tests. The petrographic method of comparing the effect of hard and soft mineral content of aggregate particles on polish resistance was extended to include vesicular lightweight aggregates.

Findings of the laboratory study indicated that the petrographic method can predict polishing characteristics of aggregates, that mixture design affects pavement polish level, and that blending of aggregates produces polish levels that reflect an averaging of individual aggregate polishing resistance in proportion to percentages used in the mixtures. Also, it was found that coarse, aggregate-sized crushed glass particles produce mixes with low polish resistance. Mixes containing sand-sized crushed glass particles compare favorably to sand-asphalt mixes for polish resistance.

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PETROGRAPHIC METHOD EXTENSION

Results of the petrographic thin-section method for preevaluation of aggregates reported in 1970 (2, 3) have been extended to include lightweight vesicular aggregates. Three such aggregates produced and marketed in North Carolina that have proven to be relatively polish resistant were included in the study. These aggregates are expanded slates produced by belt sintering or by rotary kiln processes.

Determining the percent of hard minerals in the expanded aggregate was accomplished by assuming that the sintered parts were greater than H = 5 and that the void spaces of the vesicules were less than H = 5, which of course is true. The percent of hard mineral in the expanded aggregate was computed by taking the ratio of the specific gravity of the expanded material to the specific gravity of the unprocessed slate and multiplying by 100.

British portable number (BPN) values for 16-hour circular-track exposure for all the aggregates evaluated, including the 3 lightweight aggregates, are given in Table 1 together with hard mineral percentages. BPN and hardness values for all aggregates also are plotted in Figure 1. Aggregates with hard mineral percentage in the 40 to 70 percent range were more polish resistant than were aggregates of either greater or lesser hard mineral content.

Including the 3 lightweight aggregates seemed to improve the correlation reported previously by filling out the data gap between 40 and 70 percent hard mineral aggregates. The better polish resistance in this hard mineral range resulted because these aggregates are essentially sacrificial, that is, the soft matrix releases the hard grains before they can be polished.

It will be seen later that hard aggregates and soft aggregates do not polish at the same rate. Therefore, the low laboratory friction values for some hard aggregates that are not prepolished by nature or manufacturing process may not be reached in all field exposures.

WIDE TIRE CALIBRATION

For the 1970 reports (1, 2, 3), all polishing data reported were for open-graded mixtures polished with the narrow pneumatic tires. When the wider tires were substituted, it was necessary to develop a new standard aggregate calibration curve. Also, work was begun at this time with dense-graded mixes and with mixes incorporating coarse aggregates of different maximum sizes.

Calibration curves for the standard laboratory aggregate open-graded mix polished with narrow pneumatic tires and the same mix polished with wide pneumatic tires had no significant difference in rate of polishing. In these tests the specimens first were cleaned of surface coating by wiping with solvent to expose aggregates before polishing. For later work this practice was discontinued, and, as a result, initial BPN values were higher. Circular-track polishing without precleaning is more indicative of the course of field polishing even though terminal BPN values do not seem to be affected.

ONE-HOUR CURVE

Other work was done to establish the early part of the polishing curve on the circular track with specimens that were not precleaned with solvent to remove asphalt coating from the aggregate. The polishing curve for the open-graded mix for the first hour is plotted on an expanded horizontal scale in Figure 2 together with the full 16-hour curve plotted on the normally used scale. Loss of 8 to 10 BPNs in the first 2 minutes of exposure probably corresponded to the wearing away of asphalt coating and surface fines in the asphalt coating. Comparison of initial BPN values for specimens precleaned to specimens not precleaned revealed a reduction of about 10 due to precleaning. Also, initial BPN values for specimens not precleaned fluctuated over a wider range than did initial BPN values for those that were precleaned.

CALIBRATION FOR DENSE MIXES

Most of the work done after 1970 was with dense-graded mixes and pavement cores.

Table 1. BPN and range of hard mineral content.

Aggregate Symbol	BPN After 16-Hour Circular-Track Exposure	Percent Mineral Content[a]	
		H = 2 to 4	H = 5 to 7.5
SS-1	58.5	30 to 40	60 to 70
SO-1	54.0	40 to 46	54 to 60[b]
SL-2	46.0	50 to 55	45 to 50
SL-1	45.0	55 to 60	40 to 45
GL-2	45.0	10 to 15	85 to 90
GT-2	44.5	10 to 12	88 to 90
GT-3	43.5	10 to 12	88 to 90
GT-4	43.0	8 to 10	90 to 92
GN-1	43.0	8 to 10	90 to 92
GN-2	43.0	10 to 15	85 to 90
GN-3	42.5	15 to 20	80 to 85
GT-1	42.0	10 to 15	85 to 90
RH-1	41.5	10 to 12	88 to 90
TR-1	40.5	0 to 2	98 to 100
GL-1	40.0	1 to 3	97 to 99
LS-4	40.0	55 to 65	35 to 45
LS-3	40.0	65 to 70	30 to 35
LS-2	39.0	95 to 97	3 to 5
LS-1	35.0	93 to 95	5 to 7
TU-1	52.7	33 to 38	62 to 67[b]
ST-1	51.6	31 to 35	65 to 69[b]

[a]Determined by petrographic thin section examination.
[b]Expanded slate lightweight aggregates.

Figure 1. BPN values versus hard mineral content.

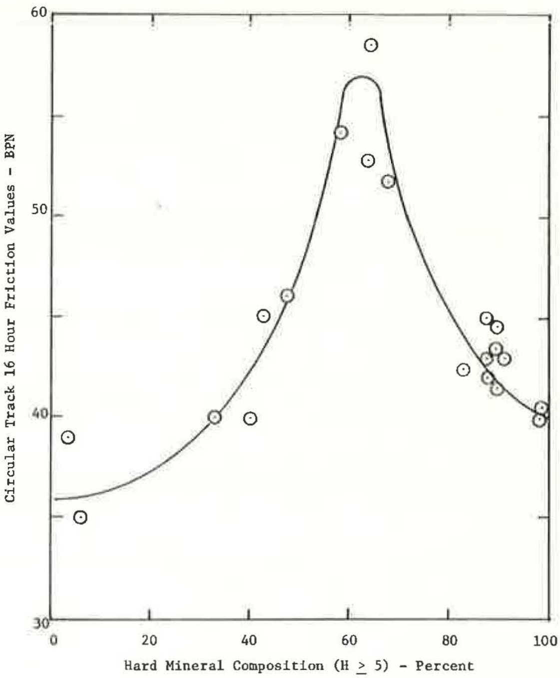
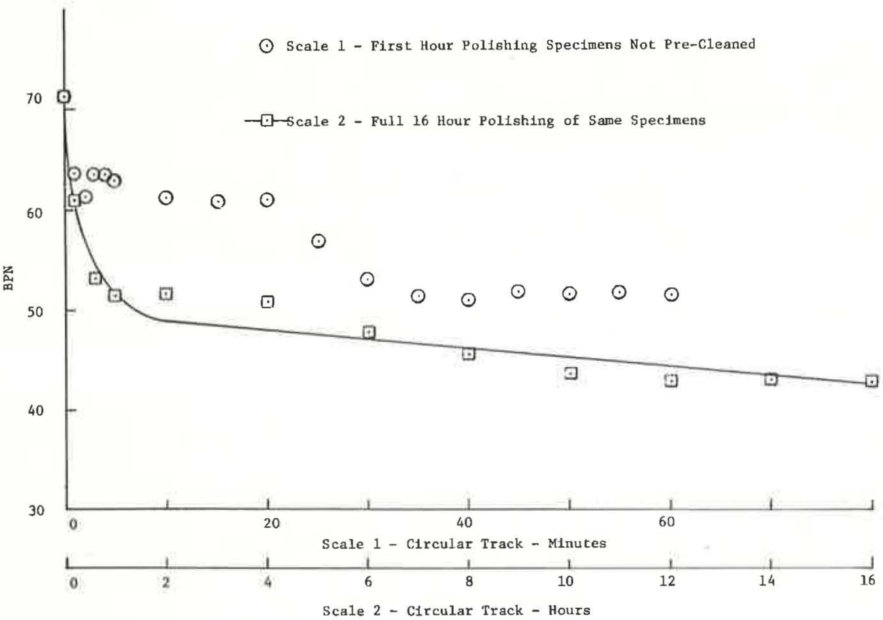


Figure 2. First hour of polishing curve, open-graded mix control aggregate.



The 2 dense-graded mixes used were the No. 4 mix and the I-2 mix having 90 to 100 percent passing the ¾-in. (19.0-mm) and ⅜-in. (9.5-mm) sieves respectively. To establish some control for these mixes, both open-graded and dense-graded laboratory control aggregate mixes were included in early runs to compare for calibration. Comparison curves are shown for these mixes in Figure 3. Open-graded and No. 4 aggregate dense-graded specimens were precleaned with solvent before testing; I-2 dense-graded specimens were not precleaned, which explains to some degree the much higher initial BPN value for the I-2 mix in Figure 3.

It is significant that the I-2 dense-graded mix with the same size stone as the open-graded mix showed higher polish values throughout than did the open-graded mix. When a larger aggregate No. 4 mix was checked, the calibration curve fell below both open-graded and I-2 mix values.

EXTENDED POLISHING

Extended polishing to 100 hours was conducted in a series of tests to determine whether additional exposure would produce significant changes in rate of polishing or level of polishing. Data for 2 sets of I-2 samples are shown in Figure 4. Four other sets representing other aggregates were tested with essentially the same results. About 5 BPNs were lost after 16 hours when exposure was extended to 100 hours and essentially no additional polish was gained after about 30 hours.

In light of other work with field cores (4), we believe that extended polishing on the circular track is of no value in estimating field performance.

NORMAL ASPHALT CONTENT VARIATION

One further series of tests was performed to determine sensitivity of the circular-track procedure to reasonably normal changes in asphalt content (AC) in dense-graded mixtures. Results are given in Table 2 and indicate no particular sensitivity for the range of ACs investigated. None of the specimens showed evidence of bleeding or flushing during the test exposure.

AGGREGATE BLENDING

The petrographic method of aggregate evaluation for laboratory polish resistance (Fig. 1) indicated that polish resistance measured by the circular-track method was highest when an optimum percentage of hard and soft minerals was present within individual aggregate particles. It has been conjectured that this principle could be extended to mixes so that the same benefits might be attained through blending of hard aggregates and soft aggregates in some optimum proportions.

Limestone and Silica Gravel

The results of the limestone and crushed-silica-gravel blend are shown in Figure 5 and indicate that the polishing properties of the blends of these 2 coarse aggregates in an open-graded mix were affected generally in proportion to the percentages of the 2 aggregates in the blend. Each point represents the average for 3 specimens run concurrently. Values are adjusted by the control aggregate. Initial values are for specimens with surfaces precleaned of asphalt coating.

Crushed Glass Blends

A series of test blend mixes were made with crushed waste glass and coarse and fine aggregates with various substitutions of coarse and fine aggregates from limestone, granite gneiss, and natural silica sand sources. The purpose of these trials was to determine the beneficial effects, if any, of blending a waste material with a low polish-resistant aggregate. The mixture used for this investigation was the I-2 mix and 1 mix using only fine aggregates. Mix combinations are given in Table 3. Glass aggregates were obtained by crushing and sizing washed glass bottles obtained from a local glass collection drive. Bottles were put in sacks and smashed with a hammer; the fragments

Figure 3. Wide pneumatic tire correlation curves for the standard aggregate.

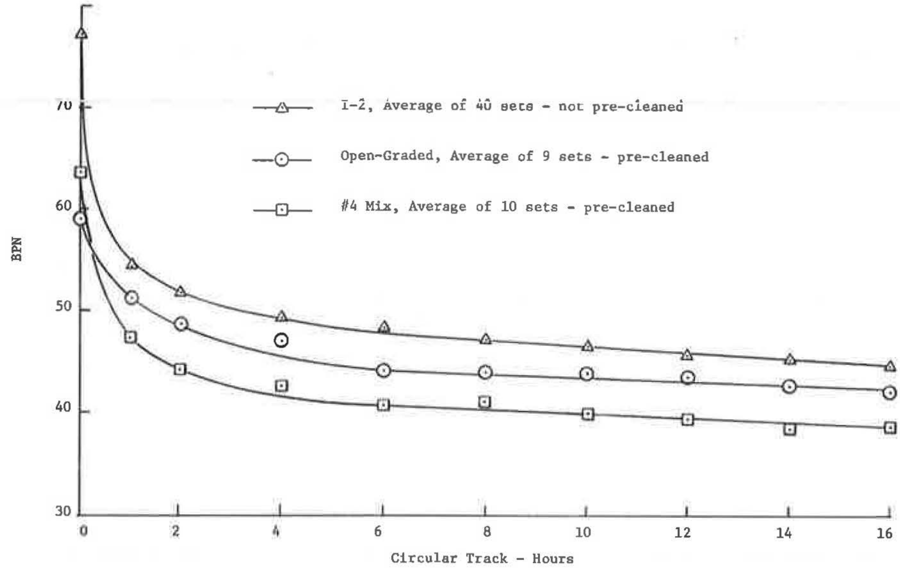


Table 2. Effect of normal range variation of asphalt content on circular-track polish values for control aggregate I-2 mix.

Circular-Track Hours	BPN Versus AC[a]			
	6 Percent	6.5 Percent[b]	7.0 Percent	7.5 Percent
0	76.7	76.3	76.3	76.7
1	50.3	49.3	49.7	49.7
2	52.0	51.7	51.7	51.7
4	50.0	51.7	51.3	51.7
6	48.3	49.3	47.0	48.7
8	48.0	47.7	47.0	47.7
10	47.0	47.0	47.0	46.3
14	45.7	47.0	46.0	43.5
14	43.7	43.7	45.7	42.3
16	43.7	44.0	44.3	42.7

[a]All values adjusted to standard I-2 curve.
[b]AC for normal control mix.

Figure 4. Extended polishing, I-2 standard aggregate control mix.

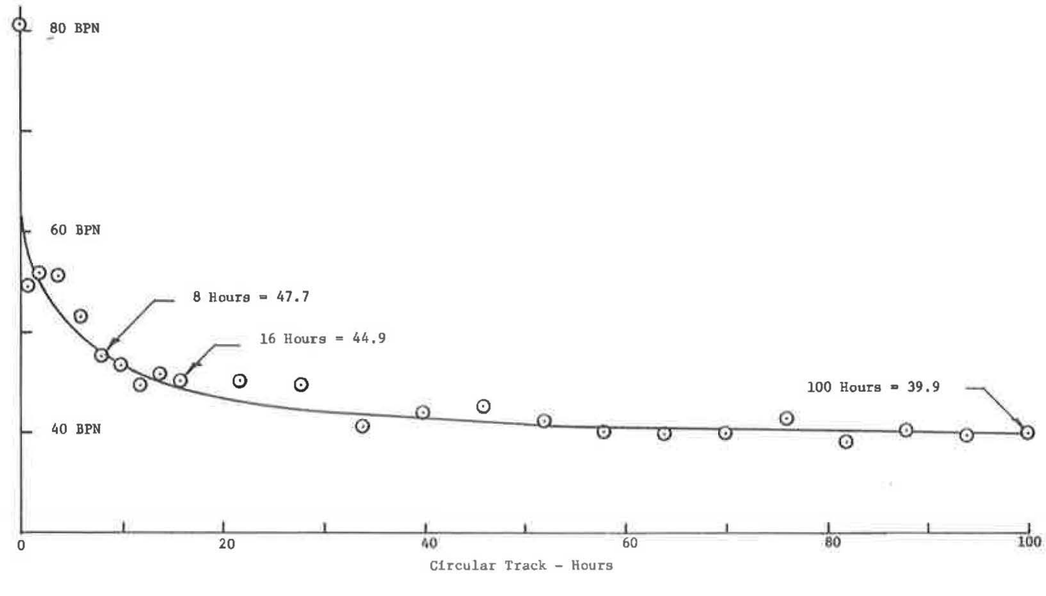


Figure 5. Polishing properties of blended aggregates in an open-graded mix.

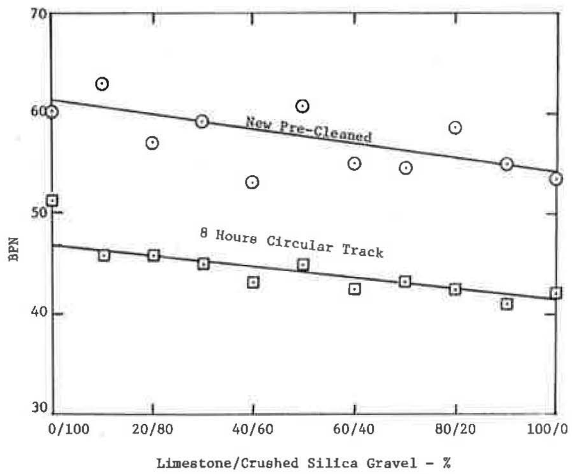
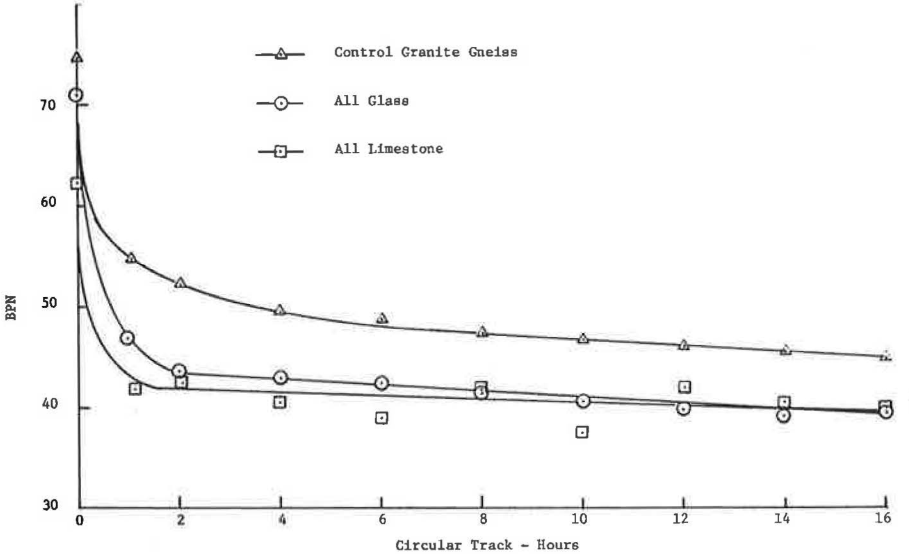


Table 3. Crushed glass, natural aggregate blend percentages.

I-2 Mix			Fine Aggregate Mix			
Glass	Limestone	Granite Gneiss[a]	Glass	Limestone	Natural Sand	Granite Gneiss[a]
100	0	0	100	0	0	0
100	0	0	50	50	0	0
50	50	0	100	0	0	0
50	50	0	0	100	0	0
0	100	0	50	50	0	0
0	0	0	50	0	50	0
100	0	0	50	0	0	50
50	0	50	100	0	0	0
0	100	0	0	100	0	0
0	0	100	0	0	0	100

[a]GN-1 laboratory control aggregate.

Figure 6. Comparison of glass, limestone, and control aggregate I-2 mixes.



were run through a laboratory jaw crusher. Larger pieces had 2 smooth molded surfaces and were flatter than what is ideal. Smaller particles resembled sharp sand grains. All sizes of the crushed glass could be handled with bare hands.

Initial trials were with all-glass mixtures that were found to polish rapidly to a relatively low BPN value. Examination of polished mixture surfaces revealed numerous flats lying parallel to the surface. The all-glass mixture results, shown in Figure 6, are compared for polishing characteristics to a polishing limestone mixture and to the laboratory control aggregate.

Blends in which 50 percent of glass coarse aggregate was replaced by another aggregate are shown in Figure 7. Some overall improvement is obtained in combining glass with the granite-gneiss control aggregate, but no benefit is gained with the coarse or fine limestone blends. What is important, however, is that the rate of polish for up to 4 hours of machine time was reduced considerably for all mixes compared to the rate of polish for the all-glass and all-limestone mixes in Figure 6. This reduction in polishing rate could prove to be significant information in light of field tests that indicated that field exposure to as many as 40 million wheel passes may not exceed wear equivalent to 2 or 3 hours of machine time (4).

In Figure 8, test results for mixes in which fine aggregate substitutions of 50 percent were made are shown together with results of 1 sand asphalt mix containing 50 percent crushed glass sand and 50 percent natural silica sand. No particular benefits were gained from blending fine aggregates in the I-2 mixes, but the sand-asphalt mix exhibited excellent early and terminal friction characteristics compared to the other mixes, including the laboratory control mix.

Experience with the glass and granite-gneiss blends indicated that blending poor polish-resistant aggregates with good polish-resistant aggregates offers a better chance to improve overall mix polishing characteristics than does blending of hard and soft aggregates both of low, terminal polish resistance.

SUMMARY

It has been possible during the course of this research to develop workable methods to determine the wear and polishing properties of aggregates and bituminous paving mixtures in the laboratory. Blending of aggregates produces an average polish resistance generally proportional to the percentage of each aggregate in the blend. Thus, it may be possible to improve marginal polish-resistant aggregates to an acceptable level by blending appropriate percentages of high polish-resistant aggregates.

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The opinions, findings, and conclusions reported in this paper are those of the authors and not necessarily those of the sponsors or the Federal Highway Administration.

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Figure 7. Comparison of I-2 mix blends with 50 percent glass coarse aggregate replacement.

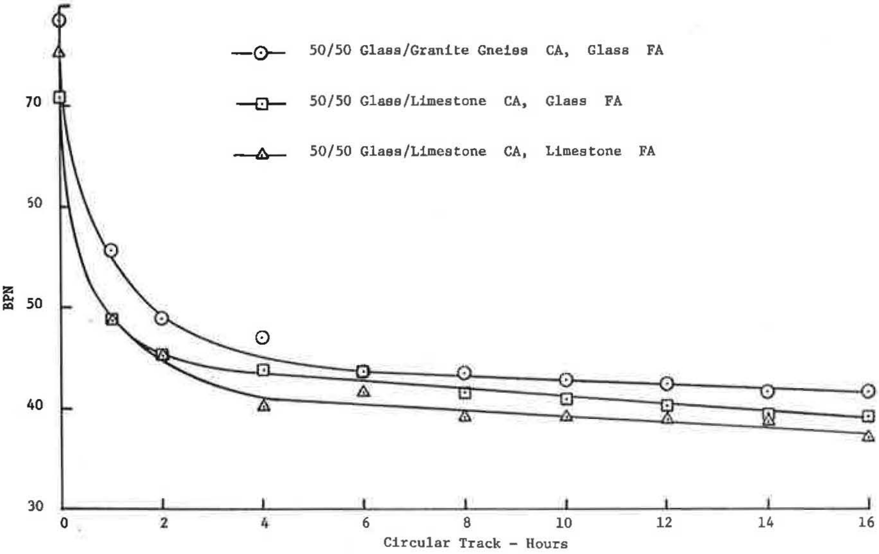
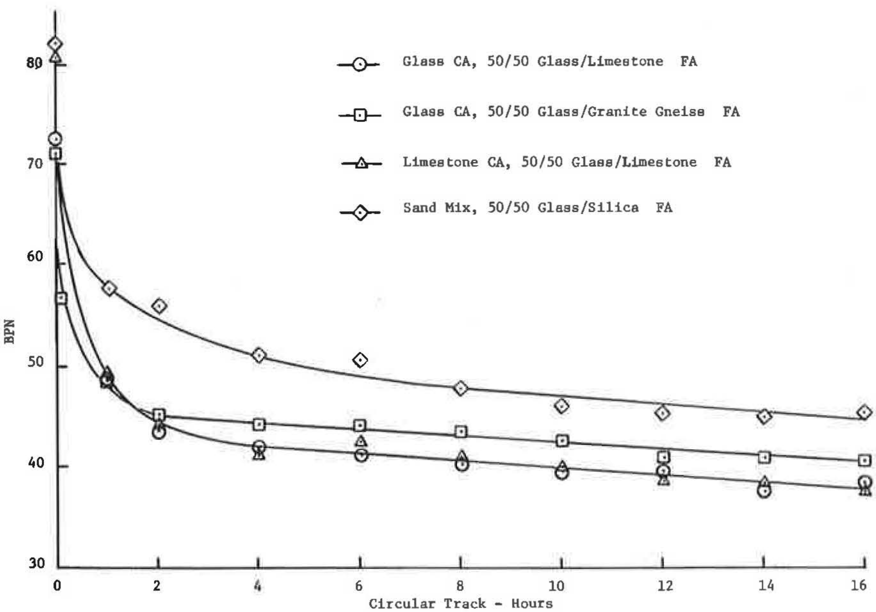


Figure 8. Comparison of I-2 mixes with 50 percent glass fine aggregate replacement.



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