

**STUDY OF
THE WEARABILITY AND POLISH RESISTANCE OF
OKLAHOMA'S COARSE AGGREGATES**

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16. ABSTRACT This report describes a laboratory attempt to evaluate the wearability and polishing characteristics of "nonpolishing" stones when blended with a sound, polish susceptible stone. The effects of crystallinity, grain size, cementing strengths, mineralogy, and other petrographic features upon the wearability and polish resistance of aggregates are discussed. The usefulness of "nonpolishing" stones in blends was found to depend on the soundness or wearability of the stone as well as its resistance to polishing. Quartz sandy limestones and sandstones with L.A. abrasion wear loss of 40 percent or less were found to exhibit good resistance to both wear and polish. Relatively pure limestones (< 10% insoluble residue) which resists polishing were found to generally be lesser sound stones than the polish susceptible stone with which they were blended. The resultant faster rate of wear of these less sound stones makes these aggregates dubious for use in blends. The main contributors to skid resistance of chert and quartz were found to be edges and their resistance to wear and polish.					
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TABLE OF TERMS

Asperity - Projection on an uneven surface.

British Pendulum Number (BPN) - A number derived from the British Portable Tester that serves as a measure of friction. The BPN represents a frictional coefficient $\times 100$.

Insoluble Residue - The residue remaining after subjecting a sample to dilute hydrochloric acid (HCL). The leaching process dissolves the carbonate fraction and leaves the non-carbonate fraction in the form of a residue.

Polish Stone Value - A frictional value expressed in British pendulum numbers (BPN) derived from specimens subjected to nine hours of polishing on the British Wheel Test.

INTRODUCTION

Whenever there are highways, builders and users are concerned with the safe passage of vehicles that are operated over them. One aspect of this safety is that there be adequate traction or friction between tire and road surface to sustain driving forces and to allow stopping within safe limits. This aspect of safety is tackled under the general designation of skid resistance.

Nature of Skid Resistance

Kummer and Meyer (1) indicate that the two principal components of rubber friction are adhesion and hysteresis. With the reference to the pavement surface, the adhesion component is principally concerned with the contact area of the tire-pavement interface and the "shearing strength" developed between the tire and the surface as the tire slides across the surface. Thusly, the "shearing strength" depends greatly on the microtexture of the pavement surface and amount of contact area. Adhesion is also dependent upon (tire) pressure and pavement contaminants such as water and road film. Adhesion is usually the dominating factor on dry pavements, but assumes a lesser role with lubrication as on wet pavements. On wet pavement situations, improvement is brought about only by sacrificing contact area; that is, by increasing the surface roughness to facilitate water displacement.

The hysteresis component is concerned with energy absorption. With reference to the pavement surface, the hysteresis component is a function of the energy losses within the tire rubber as it is deformed by the

asperities of the pavement surface. Thus macrotexture is particularly important to the hysteresis component.

The hysteresis component does not depend greatly upon (tire) pressure, or the wet or dry pavement condition, but it is heavily dependent upon the rubber damping characteristics of the tire.

When pavement friction is measured with a rubber slider or by means of a skidding tire, adhesion and hysteresis generally occur together, because no pavement is so smooth as to eliminate hysteresis or so well lubricated as to render adhesion trivial.

Designing For Skid Resistance

Moore (3) expanded on the frictional requirements of pavements and stated that the optimum design for skid resistant pavements shall have asperities three to ten mm wide and that as the sharpness of the asperity decreases the greater the need for micro-roughness and that the optimum microtexture has an order of magnitude of at least ten to one-hundred microns.

Burnett, Gibson, and Kearney (3) established that the skid resistance of bituminous surfaces is governed by the larger aggregates in the mix and that a nearly constant coefficient of friction is reached after some five million equivalent vehicular passes (1 truck = 11 cars).³

Rose, Galloway, and Hankins (4) state that when macroscopic texture exceeds 0.1 inch (2.5 mm) the resultant tire-road noise is annoying to the traveling public and if composed of sharp gritty particles would create excessive tread wear.

Kummer and Meyer (15) and Shupe and Lounsbury (6) state that the binder should wear faster than the aggregate to secure continuing aggregate exposure and that this differential wear is essential for retaining a nonskid surface.

Whereas, the optimum design of an anti-skid, concrete pavement lies in the qualities of the fine aggregate portion and the texturing of concrete while it is still in the paste form; the optimum design for anti-skid bituminous pavements must be based on the behavior of the coarse aggregates and binder after some millions of vehicular passes. This optimum design must consider a twofold problem which may cause the pavement to have a decrease in skid resistance. These two factors are:

1. High rates of aggregate wear cause loss of the drainage area around aggregate asperities; thus, affecting the skid resistance speed gradient under wet conditions.

2. The initially sharply angular aggregates become rounded and polished.

This wear and polish are brought about mainly through abrasion of loose particles either adhering to the tire or resting on the road surface.

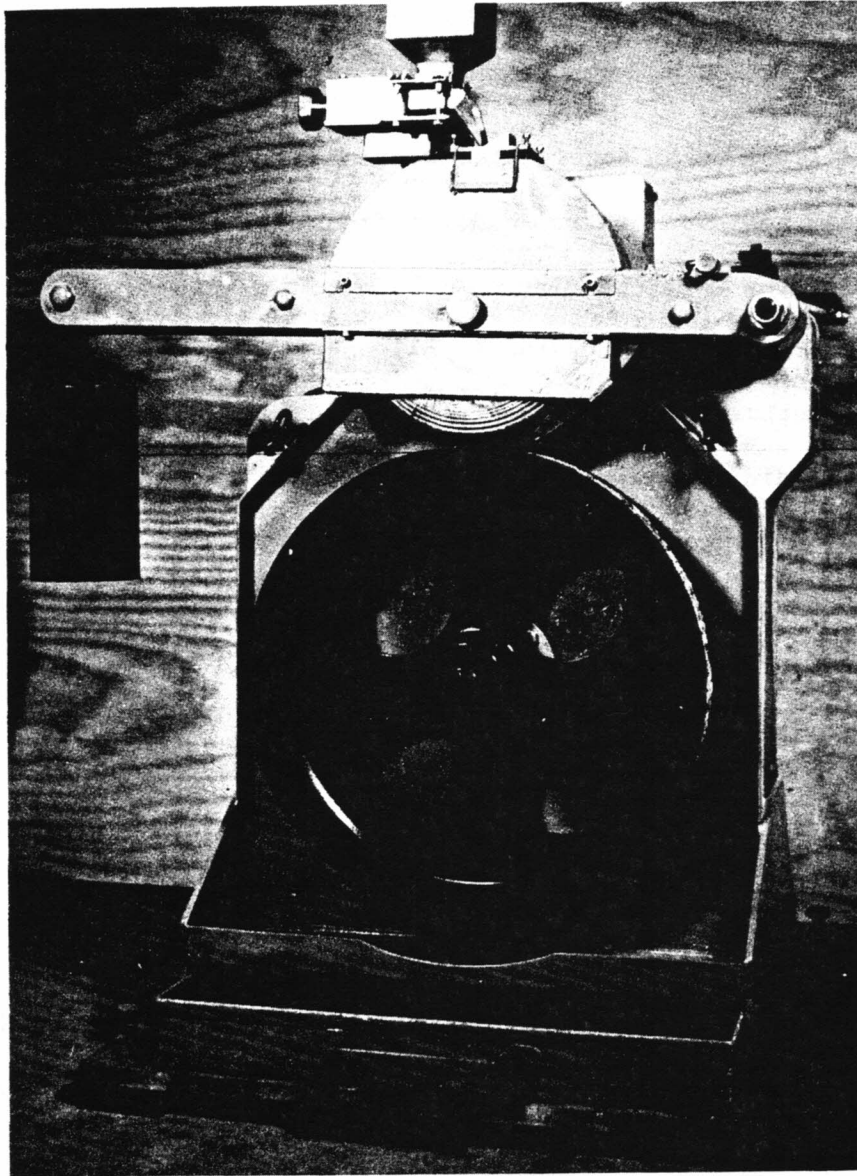
The coarse aggregates, therefore, must be angular and resist wear so the pavement can exhibit good water drainage and hysteresis effects or contain adequate microtexture to replace any loss of angularity. Coarse aggregates with these features are not present statewide in Oklahoma and must be shipped extensive distances.

The high cost of shipping nonpolishing coarse aggregates to some areas of the state has caused consideration in Oklahoma to blending coarse aggregates which exhibit adequate anti-skid and wearability properties with locally available aggregates which polish.

Objective

The object of this study was to evaluate the effects of various crystallinity, granularity, mineralogy, cementing strengths, and other petrographic features upon the wearing performance of certain Oklahoma

nonpolishing aggregates. A secondary objective was to determine the amount of nonpolishing aggregate(s) required in a blend to obtain adequate anti-skid pavements



Accelerated Polish Machine
(British Wheel)

Figure 1

METHOD OF ANALYSIS

The selections of an accelerated wearing and polishing apparatus, grit size, and daily variance control derived from the accelerated wearing and polishing apparatus were the first approach to the analysis. Secondly, the aggregates were ranked both by their polished stone values and their petrographic similarities which contributed to nonpolishing. Thirdly, the nonpolishing candidates were analyzed as to their wearability and polishing behavior when blended with a standard polish susceptible carbonate aggregate. And lastly, these laboratory results were compared with textural and skid numbers of field-tested pavements.

Equipment And Laboratory Tests For Aggregates

The problem of slippery pavements has caused various tests to be used to evaluate aggregates which are to be used in the pavement. Several investigators (3, 6, 9, and 17) have examined limestones from various sources and have found that, although many carbonates polish, they are not alike in their polishing characteristics. These same investigators generally agree that a limestone having some siliceous material in its composition is less likely to polish and become slippery than one having only carbonate composition. Agreement is not general, however, as to the percentage and particle size of siliceous material that must be present in a limestone to make it significantly skid resistant. Most investigators agree that sand-size material retained on the No. 200 sieve (0.074 mm) is the necessary particle size, but recommendations as to the required percentage

of siliceous material vary from a minimum of ten percent to a maximum of thirty percent. A chemical method to determine the amount of siliceous material contained in a carbonate aggregate is the insoluble residue test pioneered by Gray and Renniger (9) and modified by others. This test subjects aggregate specimens to dilute hydrochloric acid (HCL) and is used by some State Highway Departments. Oklahoma's modified procedure is described in Appendix A.

Physical tests involve accelerated wear and polishing machines. These tests may be conducted on a bituminous mix or may be limited to only the coarse aggregates. An accelerated polishing test, B.S. 812, (5) with modifications was chosen and used in this study. The modifications consisted of changing the type of abrasives and length of polish time. The B.S. 812 test was developed by the British and is used for designing their surface courses. The Texas Highway Department has incorporated this test with some modification into their specifications.

British Wheel Test (Modified B.S. 812 Test)

The B.S. 812 test for coarse aggregates involves the measurement of the coefficient of friction of aggregate specimens after subjecting the specimens to wearing and polishing on an accelerated polish machine (which is termed the "British Wheel").

The major components of the British Wheel are as follows (see Figure 1):

Road Wheel - A steel wheel 16 inches in diameter, 1 and 3/4 inches wide, around which 14 aggregate specimens are clamped.

Rubber Tired Wheel - A smooth rubber tired wheel (8" x 2") rests on the road wheel test specimens with a force of 88 (± 1) pounds. This force is developed by a weighted lever system in which the axle of the rubber tired wheel is fixed.

Aggregate Specimen - The aggregate(s) to be tested is molded in a

polyester binder with flat faces outward. The specimen size is 3.5" x 1.75", having the thickness of a single layer of aggregates; and the specimens are molded to the same radius of curvature as the road wheel, around which they are attached. The aggregates tested passed the one-half inch sieve and are retained on the No. 4 sieve.

Grit Feed System - Accelerated wearing and polishing is induced by the continuous, uniform application of abrasives between the rubber tire and the road wheel. The grit is vibrated from a small hopper to a chute at a specified rate. Water is supplied (also at a specified rate) and washes the grit onto the road wheel near the point of contact of the road wheel and the rubber tire.

The road wheel is rotated at 315 to 325 revolutions per minute or 18,900 to 19,500 tire applications per specimen per hour.

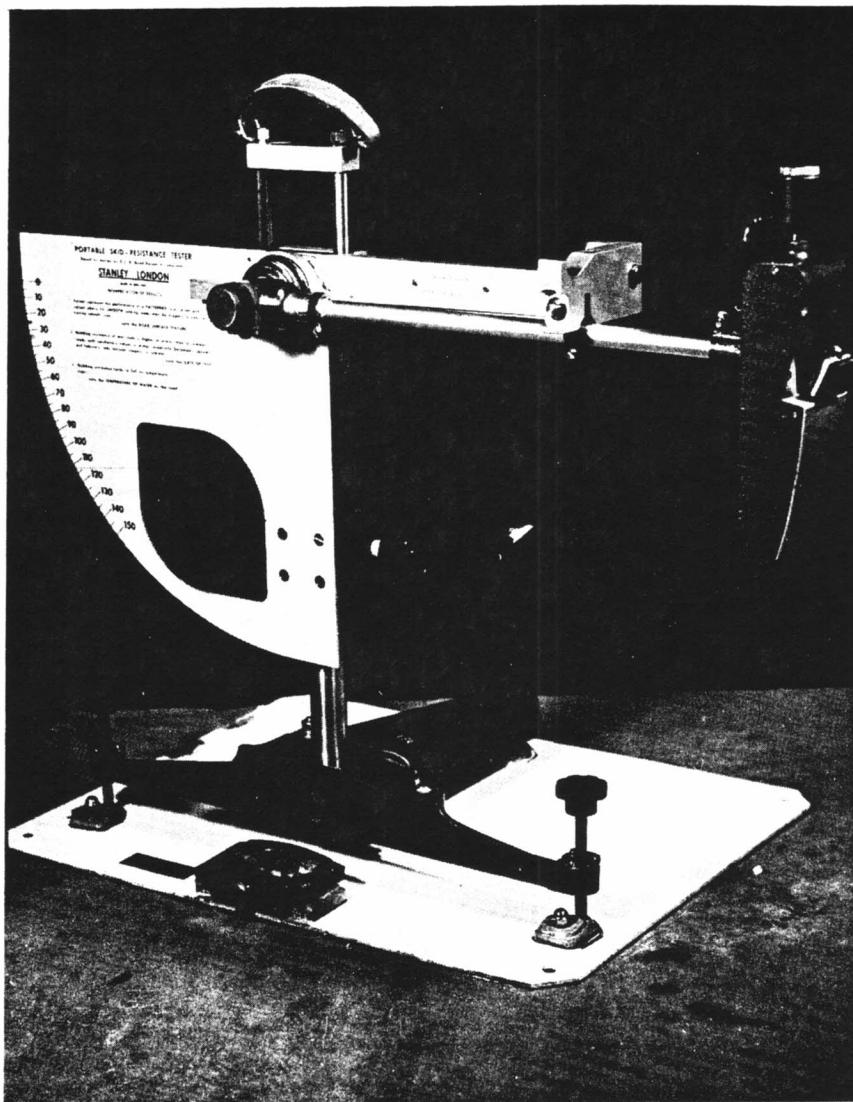
British Portable Skid Resistance Tester - This is a dynamic pendulum impact-type tester used to measure the energy loss when a rubber slider edge is propelled over a test surface (see Figure 2). The pendulum length is an established 20 inches, while height of the pivot point from the test specimen is adjustable. This adjustment allows for a specified length of slider contact path to be maintained on different sizes and types of specimens. The pendulum is placed in a near horizontal position as it is cocked, and released by the trigger mechanism allowing the arm to swing freely. A pointer "rides" the arm to the maximum upswing, and then it remains in place to indicate the BPN (British Pendulum Number). These numbers range from 0 to 150, representing a frictional coefficient x 100. The higher the resistance encountered by the rubber slider edge as it sweeps over the test specimen, the higher the BPN indicated by the pointer.

The instrument was developed by the British Research Laboratory for testing slick pavements, but was modified for the B.S.812 test (13). Under field conditions, the tester used a three-inch wide rubber slider and a five-inch slide path, while for laboratory use the test uses one and one-fourth inch wide slider and a three-inch slide path. The reduction in sliding length makes it necessary to have an auxiliary scale on which scale dimensions are reduced in the ratio 3:5. The results are expressed as "polish stone values." The auxiliary scale has such small scale increments that it is hard to read; therefore, for this study the auxiliary scale was ignored and "polish stone values" are represented by British Pendulum Numbers (BPN).

Selection of Grit Size and Hardness

Particle Size

Lapidary artists have known for years that coarse abrasives grind a stone faster than fine abrasives, but it does not exert as fine a polish on the stone as fine abrasives. Maclean and Shergold (16) of Great Britain, while performing initial experimentation with the British Wheel, observed that fluctuations in friction values are proportional to the size of grit used in the test. This knowledge was used in selecting the abrasive sizes for B.S. 812 specification in which No. 36 corn emery (25-52 sieve size material) was introduced to the stone specimens for three hours and then air-floated emery flour which passes the No. 300 sieve (53 microns) was introduced to the stone specimens for three hours. This test allows the corn emery to destroy much of the rugosity of the stone formed by quarry crushers and the flour emery to polish the stone to its minimum friction value.



British Portable Tester

Figure 2

Schneider (14) established that for a given abrasive size and given aggregate, there is an ultimate state of polish which is reached after a finite time, as results of his work can be seen in Figure 3.

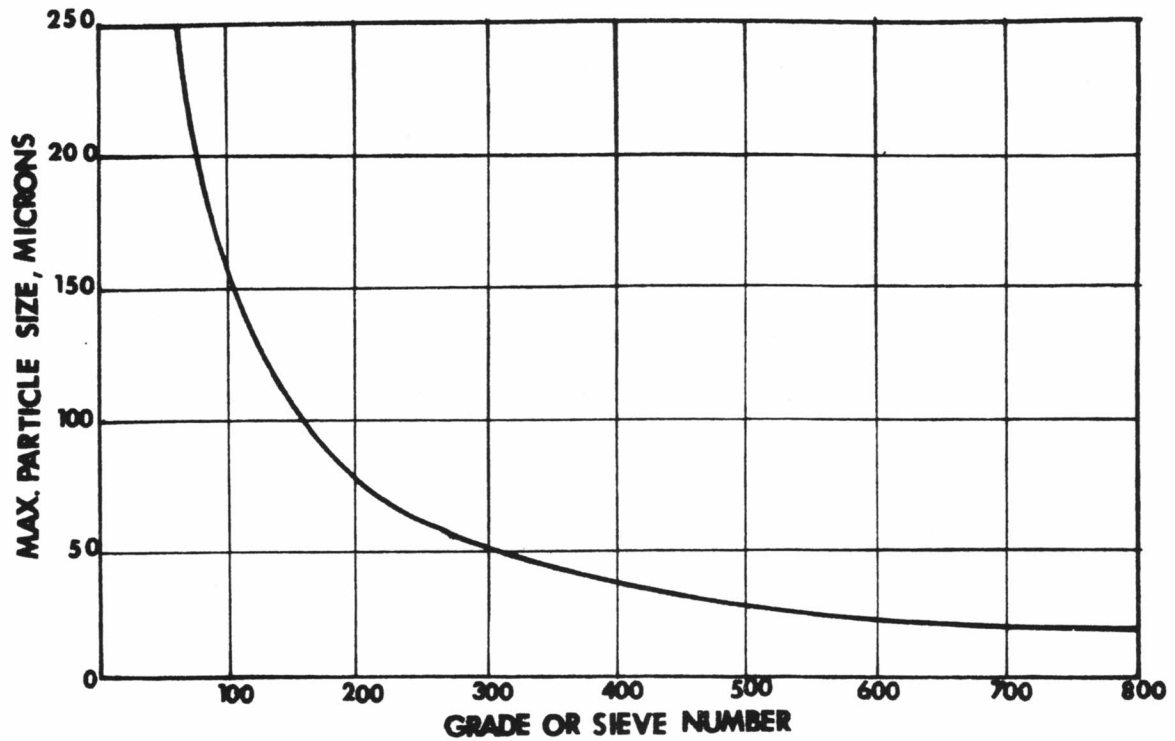
Underwood, Hankins, and Garana (11) of Texas also established with the British Wheel that the various size abrasives formed stair-step friction values with the finest grit forming the lowest friction value. They selected the No. 150 (100 microns) silicon carbide grit and a nine hour test for a Texas Highway Department specification as their research was concerned with the rate of wear as well as a "polish stone value."

Particle Hardness

No abrasive will cut anything harder than itself. For abrasive wear to take place, the abrasive material must be harder than the surface to be abraded. The hardness limitations to the abrasive wear process form the basis of the Mohs hardness scale. A comparison of Mohs' and Vicker's hardness scales is given in Figure 4, showing an approximate logarithmic relationship between the two hardness scales. Figure 4 also points up a great difference in the hardness of calcite and quartz minerals, the main constituents in such aggregates as limestone and silica. Silicon carbide exhibits a Vicker's hardness of approximately 4500+ or a Mohs' hardness of 8+.

Schneider (14) established that silica abrasives produced very much the same polishing results on siliceous aggregates as carborundum, a much harder abrasive.

Stiffler (12) observed that rapid wear occurred when the abrasive was harder than the mineral being tested and that wear was extremely low when minerals being tested under load were harder than the abrasives. He also



Maximum Particle Size vs. Abrasive Agent Grade
(102 micron = 0.004 inch).

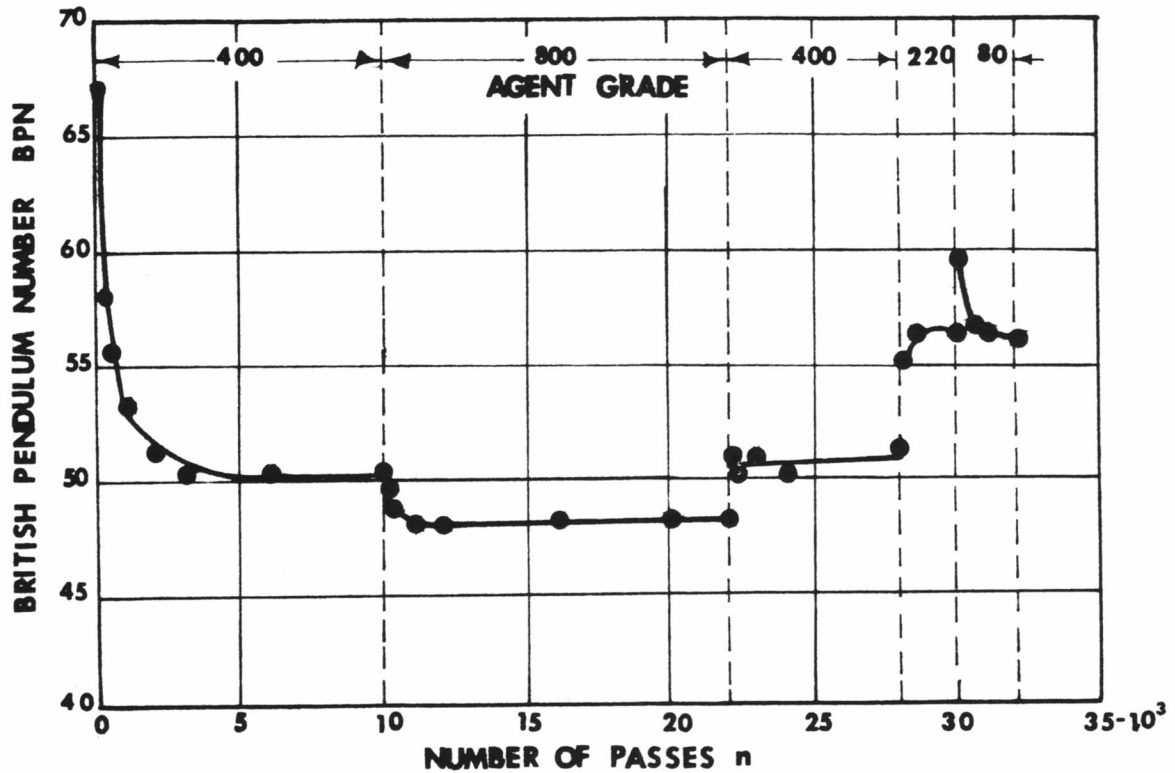
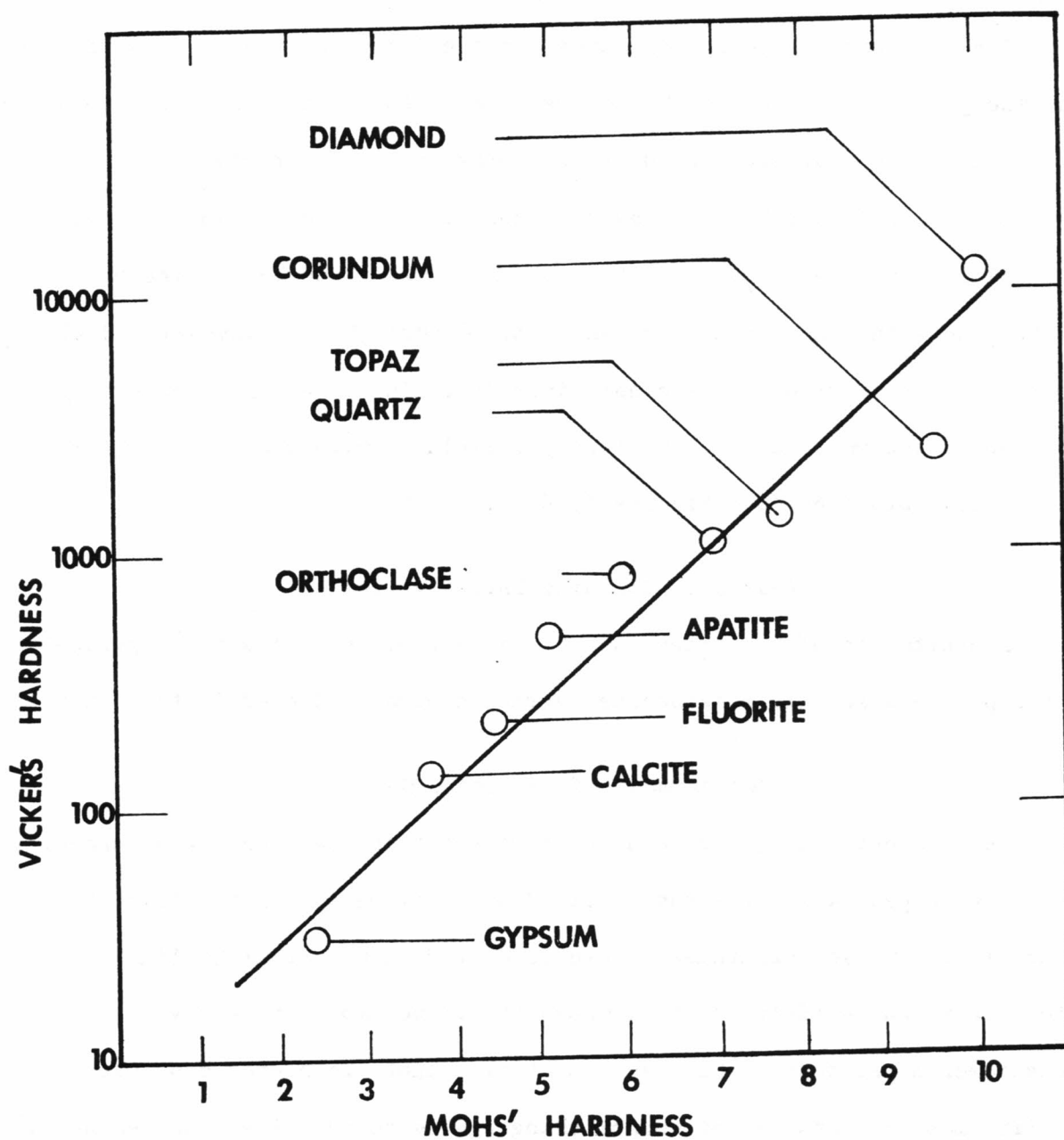


FIG. 3. Skid Resistance (BPN) of Limestone Aggregate as Function of the Number of Passes (n), From Shneider (14).

FIG. 4



VICKER'S vs. MOHS' HARDNESS, FROM TABOR (19)

collected abrasives from the roadways and found that they were dominated by particles in the 5 to 40 micron range.

The high cost of emery abrasives and the fact that the No. 150 silicon carbide grit did not polish the test specimens to as low a friction value as the emery led our study into using another type of abrasive. Two uniform silica (quartz) abrasives obtained locally from within the state from glass sand operations were tested and it was found that three hours of testing with the coarse abrasives (No. 70 through 140 sieves*) and six hours of testing with the fine abrasives (No. 270 sieve* or 50 microns*) obtained friction values which closely correlated with the six hour test with emery abrasives (See Figures 5, 6, 7, and 8).

Aggregate Blending Investigation

Substitution of 25 percent and 50 percent of "nonpolishing" aggregates for a polish susceptible carbonate aggregate were conducted in this study.

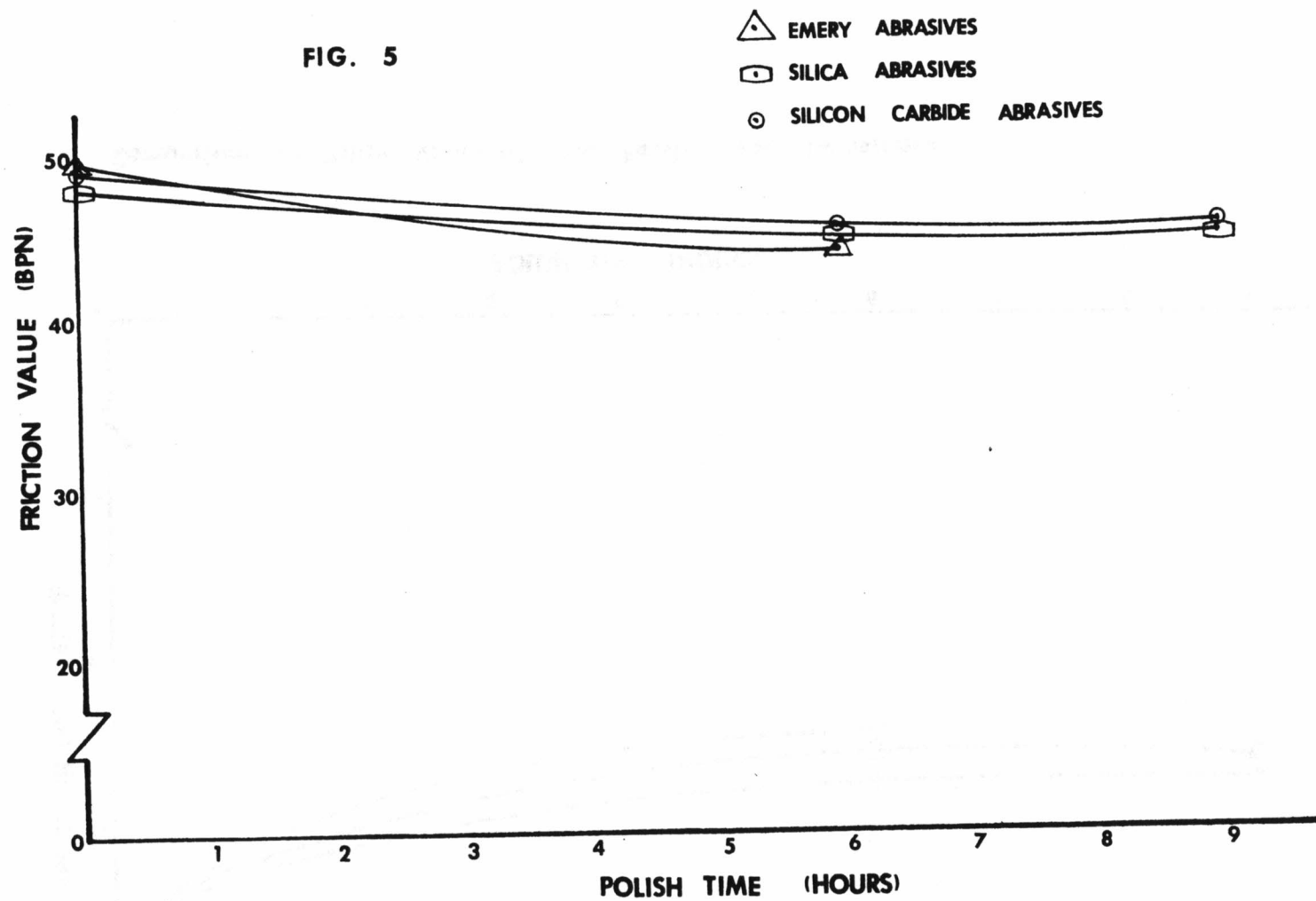
Measurement of Aggregate Wear

Measurements of aggregate heights of the test specimens were conducted in the wheelpath which the rubber tired wheel traverses in the British Wheel Test. These measurements were conducted with a straight-line micrometer and consisted of five measurements per mold or twenty measurements per test. The measurement of heights in blends consisted of five measurements of the nonpolishing aggregate and five measurements of the polish susceptible aggregate per mold. Careful markings on the polyester resin molds were made to insure making the repetitive readings in the same location.

The height differential between nonpolishing aggregates and the polish susceptible aggregate was found to be dependent upon the spacing of the

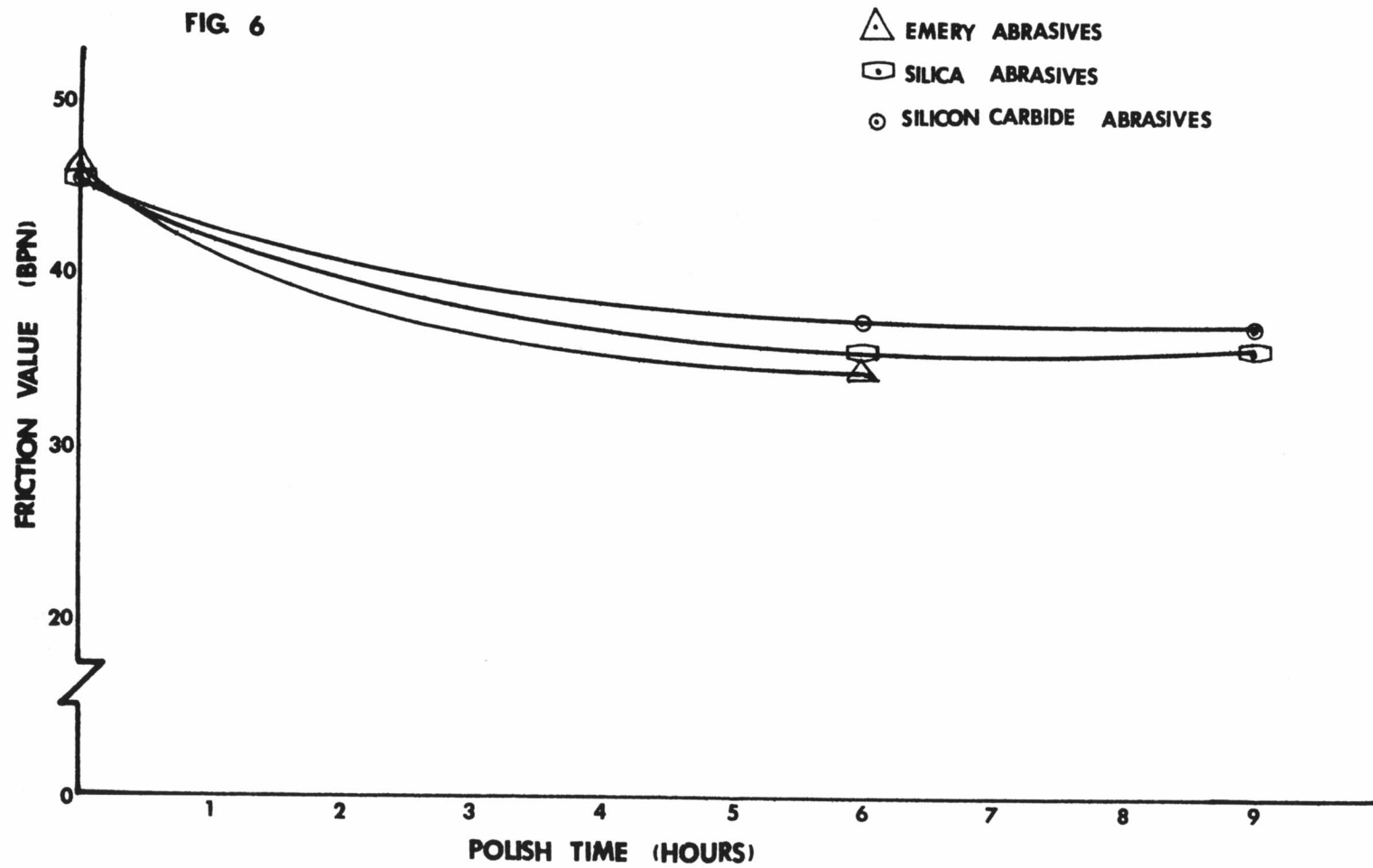
*ASTM Standard Sieves

FIG. 5

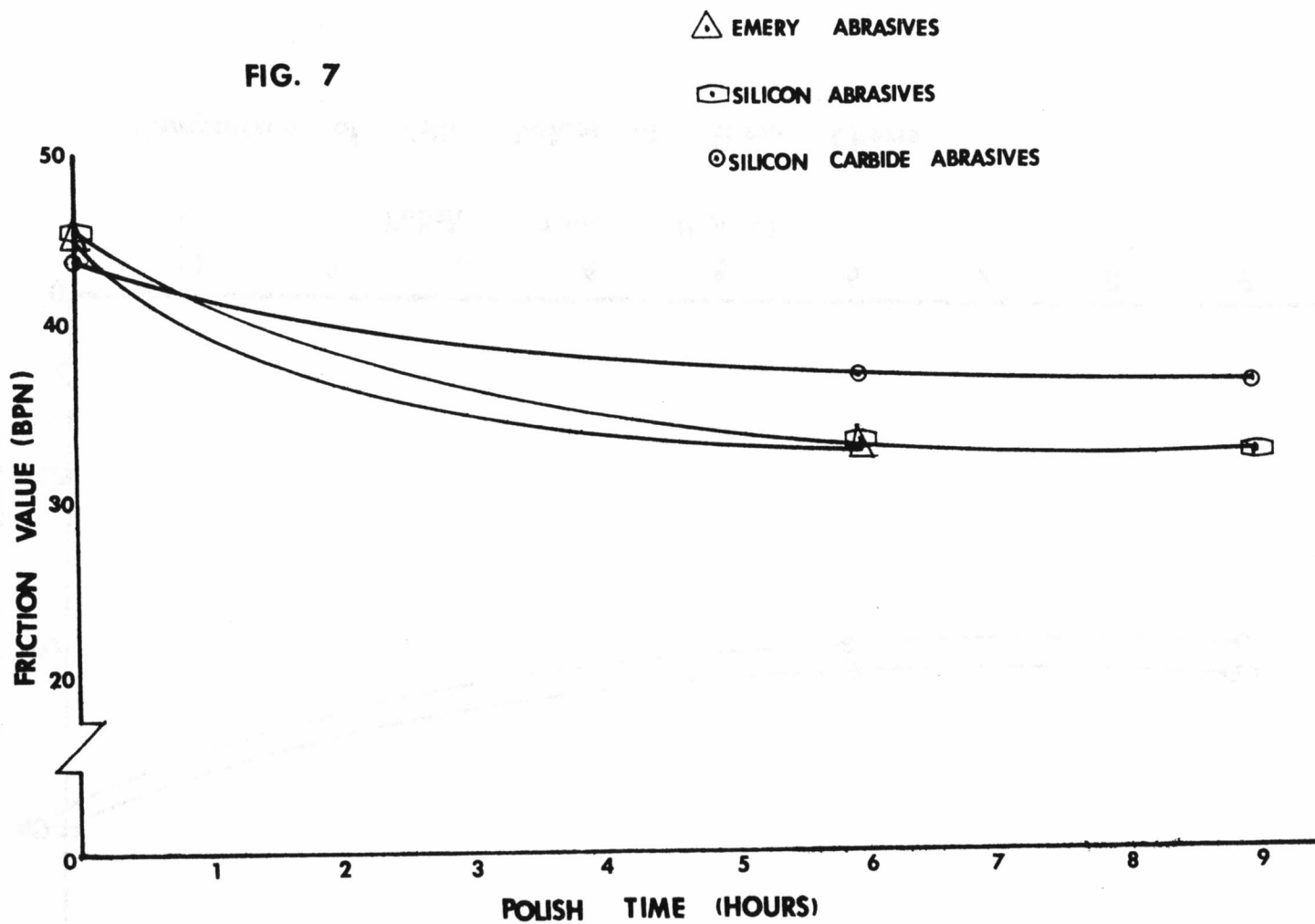


Comparison of Polish Values of Three Sandstones

FIG. 6



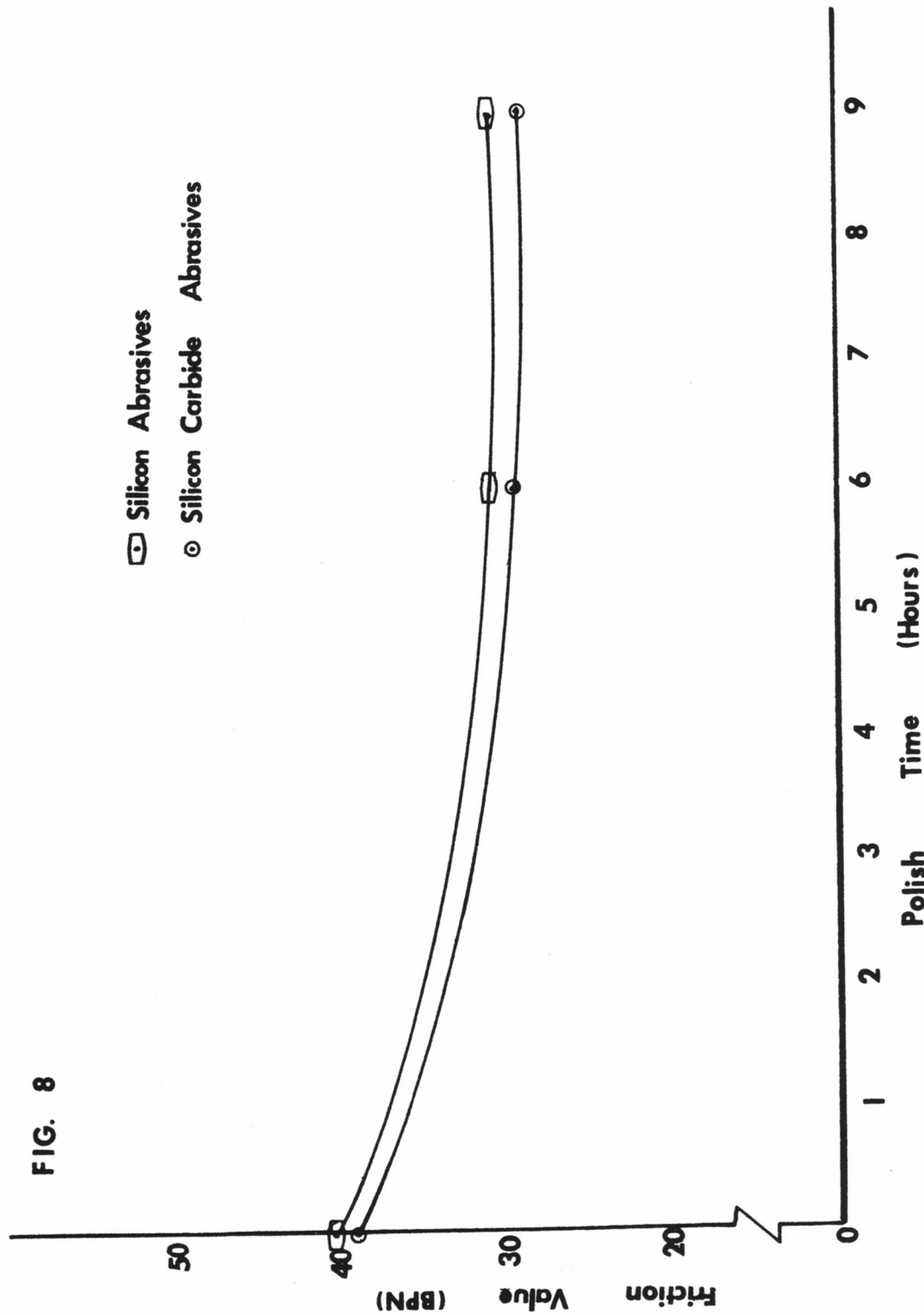
Comparison of Polish Value of Five Fossiliferous Limestones



Comparison of Polish Values of Six Micritic Limestones

FIG. 8

 Silicon Abrasives
 Silicon Carbide Abrasives



Comparison of Polish Values of Three Cherts

respective aggregates in blends. Therefore, wear measurements may be expressed as qualitative measurements.

Variance Control of Study

Calibration of the British Portable Tester

The British portable tester was calibrated by the tentative test method described in ASTM designation E 303-66T (10). No correction was found to be necessary.

Daily Variance Control of British Portable Tester Values

Three polished control specimens ranging from low to high BPN readings were selected for daily variance control. At least two of the specimens were tested before readings were taken on the test specimens. If "day to day" variations occurred on the control specimens, then a correction factor was applied to the test specimens. The control specimens were regularly checked against other previously tested specimens to affirm that the control specimens' BPN values were remaining constant.

The testing of control specimens was beneficial in ascertaining when changing of the rubber pads was needed as BPN values tended to decrease with repetitive testing with the same rubber pad.

Correlation of American Rubber with British Rubber

Since studies on skid resistance often use various rubbers, tires, and skid vehicles, it is deemed pertinent that the results of this study be graphically expressed in American rubber readings; although, some of the results were obtained with British rubber.

The correlation results indicate that 1.1 BPN obtained by American rubber with a one and one-fourth inch pad and a three inch slide path equals 1.0 BPN obtained by British rubber.

Test Variance

Four molds of each specimen were tested for each blend of "nonpolishing" aggregates and the standard polish susceptible limestone. The molds were divided into two different run series on the British Wheel to prevent as much as possible any variation from one round of testing to another.

The percentage of each source material was controlled by placing the individual aggregates so that they comprised as closely as possible the required area in the test specimen, as dictated by the blend.

Some error occurs in the measurement of aggregate heights due to the selection of good flat surfaces instead of ridges or bumps on the face of the aggregate, but twenty measurements is thought to minimize the error.

Selection of Test Aggregates

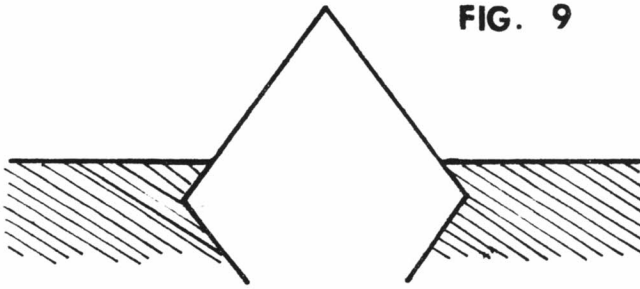
Twenty-one sample aggregates representative of the aggregate types used in Oklahoma were selected and used in the study. Most were selected from commercial material operations, but some samples were selected from ledge rock exposures and crushed for testing. These specimens were sampled to give a broader spectrum of test specimens containing disseminated hard minerals.

The test aggregates were chosen from polish stone values, insoluble residue data, petrographic features, and history of skid tested pavements with Oklahoma's skid trailer. Briefly, they may be grouped accordingly to a modification of Hosking's classification of nonpolishing aggregates (8) (Figure 9).

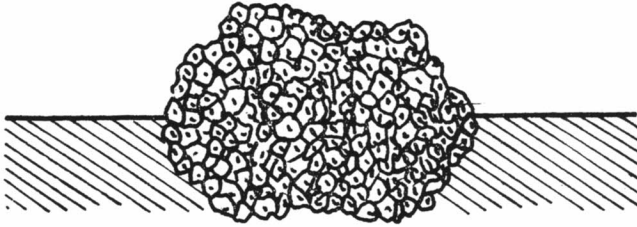
1. Very hard materials (> 5 Mohs' scale) consists of chert, quartz, and granite.
2. Conglomerations of small hard particles and dispersions consist of hard particles in a softer matrix. These materials consist of quartzsandy limestones, and sandstones which may have a calcareous cement, siliceous cement, or both.
3. Materials which fracture in an irregular angular manner and vesicular materials are grouped together. (The only sample tested consists of an expanded shale synthetic aggregate.)
4. Aggregates which may exhibit a combination of the stated non-polishing traits also are added. These aggregates include relatively pure carbonates which contain some porosity, hard minerals, crystallinity, and partial silicification of calcite, which may or may not be classified as hard minerals.

A polish susceptible limestone source (No. 57-01) was chosen as a standard for blending with the nonpolishing aggregates. The standard was chosen from other relatively pure limestones because of its soundness (26 percent L.A. Abrasion wear loss), source homogeneity, and low polish value. The limestone is mostly micritic (fine-grained).

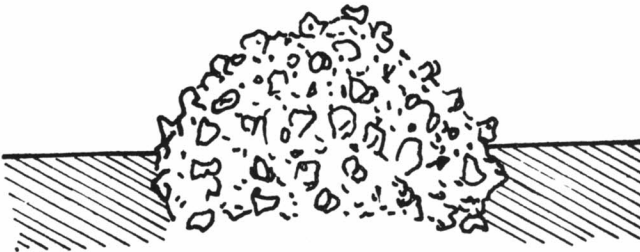
FIG. 9



VERY HARD
MATERIALS



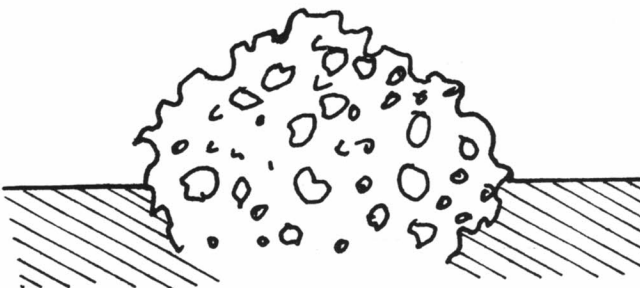
CONGLOMERATIONS
OF SMALL, HARD
PARTICLES



DISPERSIONS OF
HARD PARTICLES
IN A SOFTER
MATRIX



MATERIALS WHICH
FRACTURE IN AN
IRREGULAR ANGULAR
MANNER



VESICULAR
MATERIALS

SOME THEORETICAL TYPES OF POLISH-RESISTANT ROADSTONE
From Hosking (8)

Physical tests and insoluble residue tests for this study were conducted by the Oklahoma Highway Department's Materials Testing Laboratory. Physical properties of test specimens are included in Table 1.

Chemical analysis of test specimens was conducted by the Oklahoma Geological Survey and is included in Appendix D.

Table 1. Physical Properties of Test Specimens

Identification Code or Symbol	General Classification	% Insoluble +200 Sieve	L.A. Abrasion Loss (C)%*	Before Polish Value (BPN)	Polished Stone Value (BPN)	Absorption (Water) %	Bulk Sp. Gr.
08-01	Calcareous sandstone	60	32	46	39	0.92	2.64
11-02	Quartz sandy limestone	25	40	53	43	3.07	2.55
11-03	Quartz sandy limestone	45	54	54	47	3.20	2.529
31-01	Siliceous sandstone	96	35	50	44	2.40	2.48
46-01	Siliceous sandstone	92	35	50	49	4.13	2.47
68-02	Quartz sandy limestone	36	31	49	39	0.94	2.69
12-01	Chert gravel	99	25	36	28	1.50	2.56
35-02	Granite	99	34	43	33	0.20	2.61
45-01	Heterogeneous gravel	98	25	47	39	1.30	2.69
58-01	Chert	95	21	43	33	1.20	2.56
63-01	Chert gravel	100	25	43	32	1.00	2.58
01-01C	Quartz gravel	95	30	43	31	1.20	2.58
01-01T	Heterogeneous gravel	77	25	41	32	0.90	2.64
07-01	Limestone	1	38	48	39	3.79	2.49
11-01	Limestone	2	33	43	34	0.92	2.66
15-01	Limestone	10	27	50	36	2.65	2.55
50-02	Limestone	9	25	44	35	1.11	2.69
61-01	Cherty limestone	23	24	48	37	0.96	2.66

Table 1. (Continued)

Identification Code or Symbol	General Classification	% Insoluble +200 Sieve	L.A. Abrasion Loss (C)%*	Before Polish Value (BPN)	Polished Stone Value (BPN)	Absorption (Water) %	Bulk Sp. Gr.
72-01	Limestone	0	33	46	35	1.92	2.59
74-01	Limestone	0	31	47	38	2.26	2.62
Shale	Expanded shale	--	--	47	37	----	----
57-01	Limestone standard	0.5	26	41	28	1.50	2.68

*AASHO Designation T 96

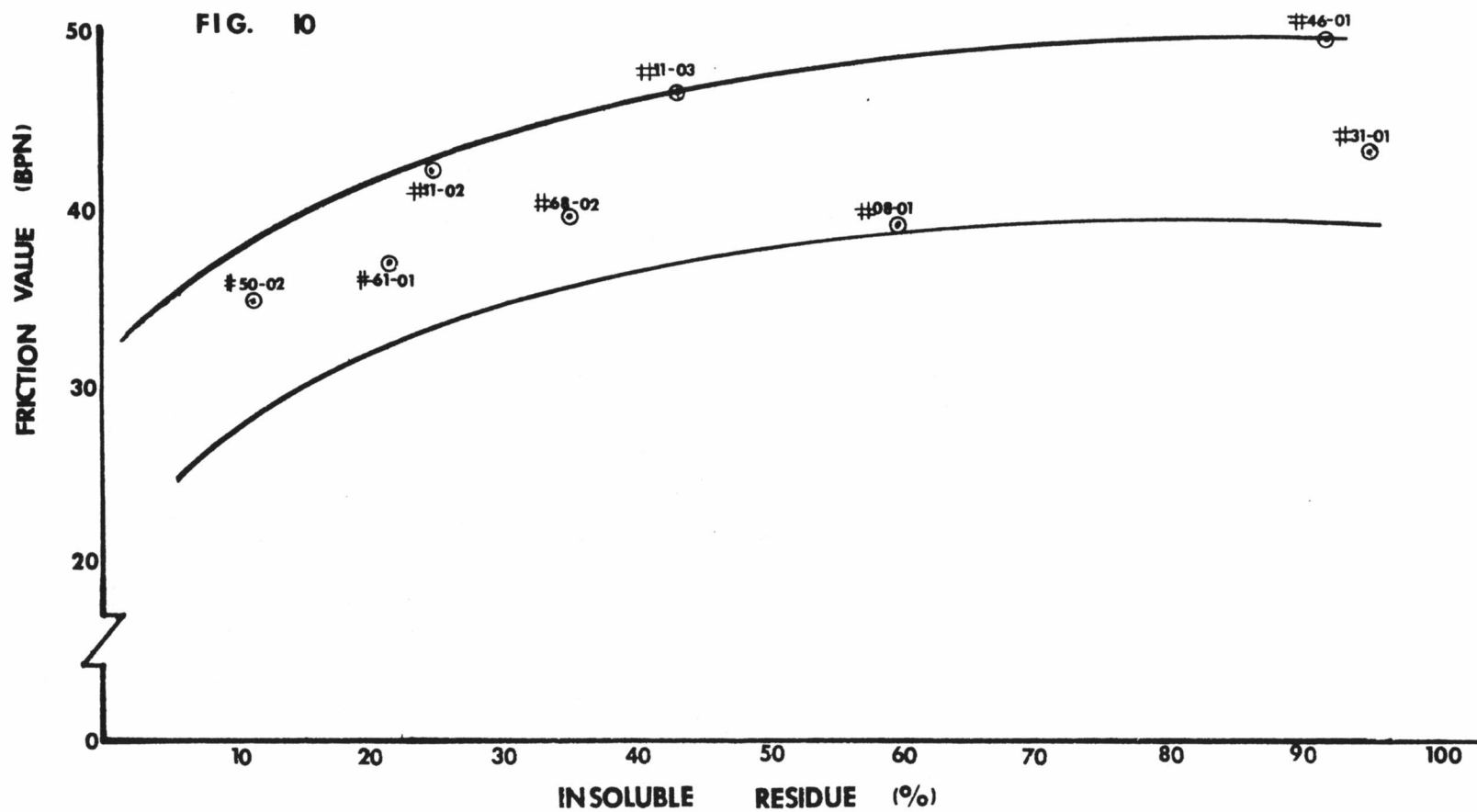
DISCUSSION OF RESULTS

Sandstones and Quartz Sandy Limestones

Polish Stone Value

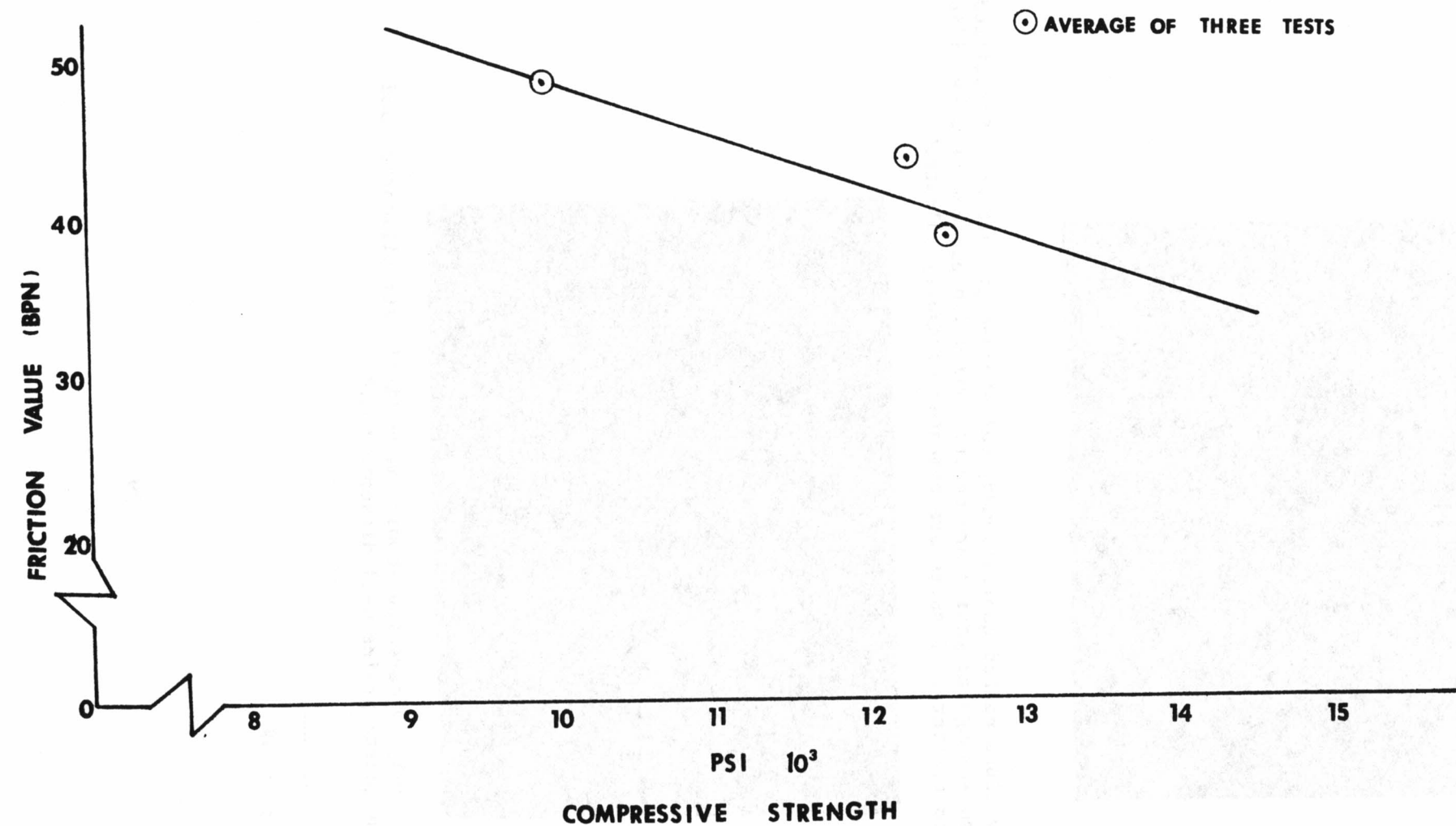
Sandstones and quartz sandy limestones exhibited the highest polish stone values. The "surface renewal" of the test specimen by either a softer cementing matrix wearing faster than the individual grains and/or loss of intergranular cementing strength allowing loss of individual grains before polishing permit these aggregates to resist polishing. The ranking of these specimens does not point to any one petrographic feature which clearly causes one aggregate to have a higher polish stone value than the other. Mullen (7) stated that the optimum aggregate shall consist of 50 to 70 percent hard minerals and 30 to 50 percent soft minerals, but as can be seen in Figure 10, sandstone No. 08-01 clearly falls in the middle of this optimum classification but does not exhibit the highest polish stone value. Instead, a range of polish stone values on tested specimens occur between 35 - 50 BPN when the insoluble residue exceeds 10 percent. Other petrographic features which affect the ranking of these aggregates are grain size, cementing strength (Figure 10), angularity of grains, presence of grain intergrowth or grain clusters from siliceous cement (Plate 1), stratification of soft and hard disseminated minerals or degree of dissemination (Plate 1), and packing of grains (Plate 2).

When one compares the soundness (L.A. wear values and compressive cementing strengths) of the test specimens, it is apparent that the more

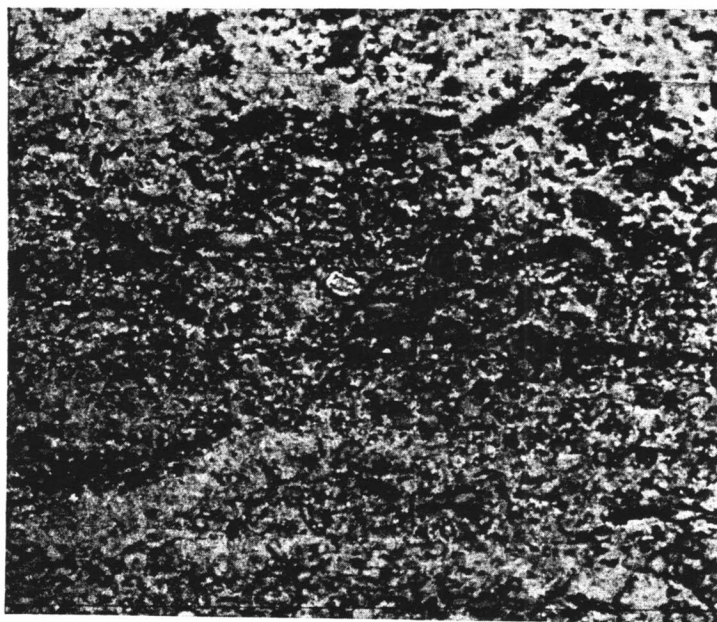


Relation of Polish Stone Value to Disseminated Hard Minerals

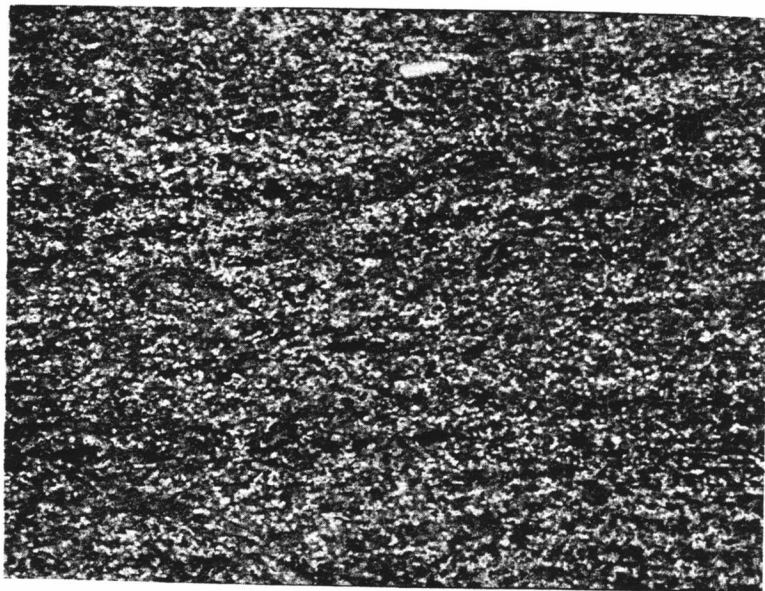
FIG. II



Relation of Compressive Strength and Polish Stone Values of Three Sandstones.



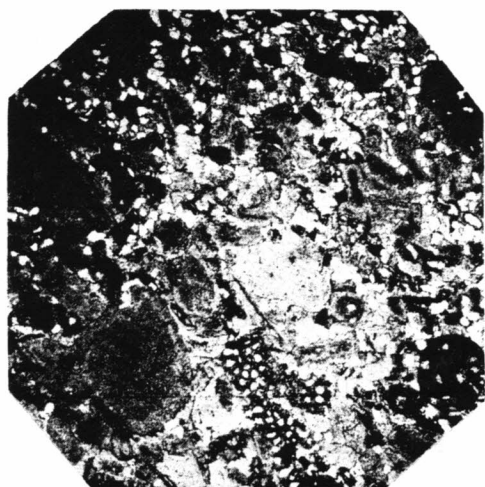
1. Overly close packed quartz sandy, pelmatozoan grainstone. Stratified, whitish subangular grains are quartz sand which are cemented by silica to form clusters. Fossils are cemented by sparry calcite.*



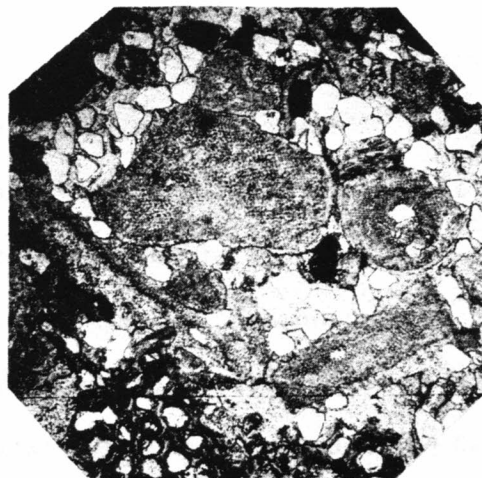
2. Quartz sandy calcarenite showing very little stratification and whitish quartz grains well disseminated.*

* Magnification 5X

PLATE II



1



2

1. Overly close packed quartz sandy, pelmatozoan grainstone cemented with sparry calcite (20%). Whitish subangular grains are quartz sand (20%) and large skeletal debris consists of pelmatozoans (43%).*
2. Close view of same quartz sandy, pelmatozoan grainstone. Note quartz grains in pores of bryozoan fragment, lower left. Some quartz grains show partial replacement by calcite.**

*Photograph No. 1 is 6X magnification.

**Photograph No. 2 is 20X magnification.

unsound stones exhibit the highest polish stone values (Table 1 and Figure 11), but the other petrographic features mentioned may cause quite a range of polish stone values.

Wearability

All of the specimens tested with the exception of source No. 11-03 had less wear than the polish susceptible aggregate. A comparison of the soundness and wear of the specimens with the standard (Figure 12) indicates that the soundness of specimen No. 11-03 is dubious with a 54 percent L.A. abrasion loss. This data supports specifications which require a maximum of 40 percent loss that many states have adopted. Measured wear and L.A. values below 40 does not present a clear interpretation.

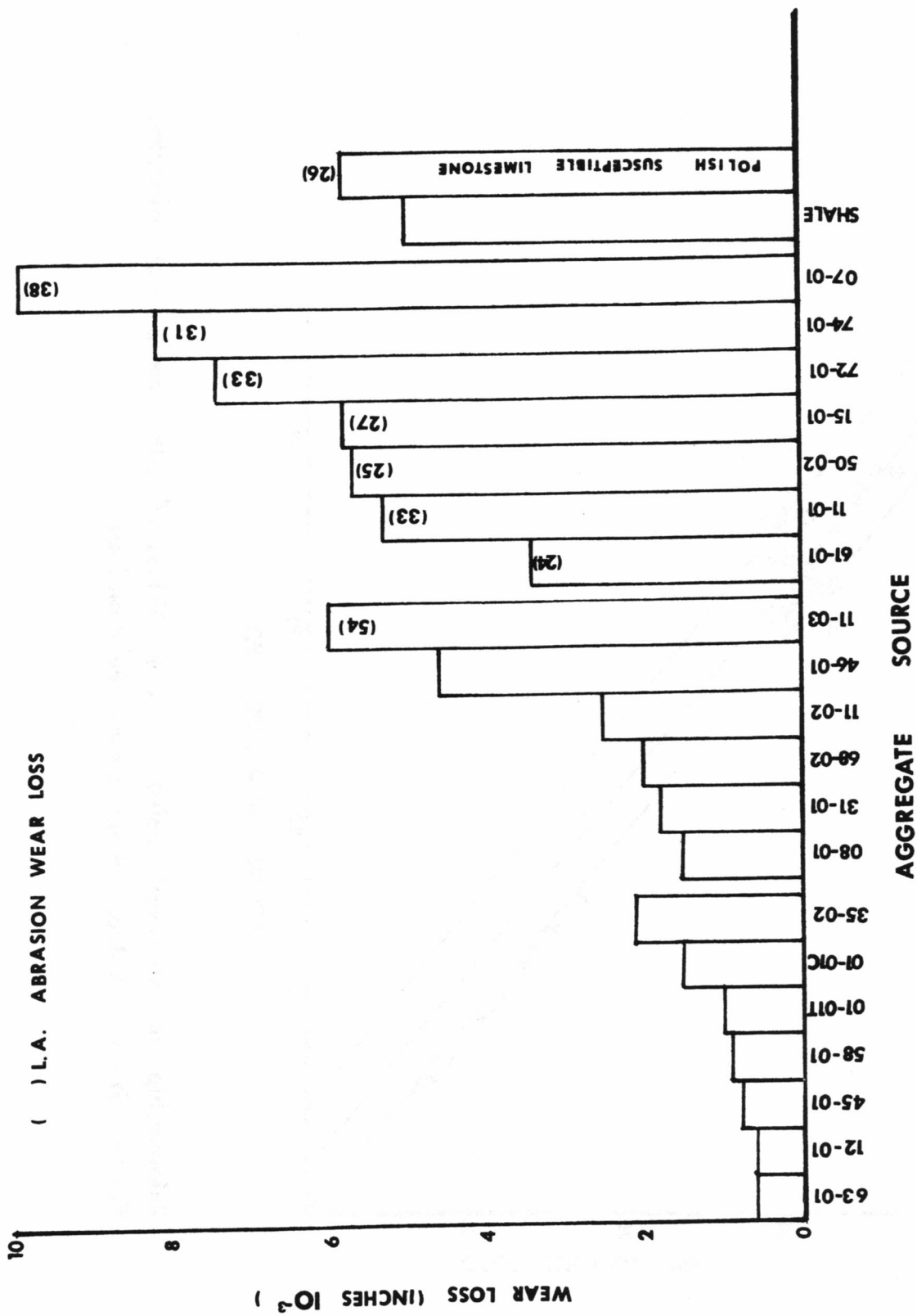
The differential wear in the blends between the nonpolishing aggregate and the polish susceptible aggregate resulted in some "macrotexture" and frictional values higher than calculated values from a linear relationship of polish stone values, see Figure 13 and 14.

Hard Sharp Materials

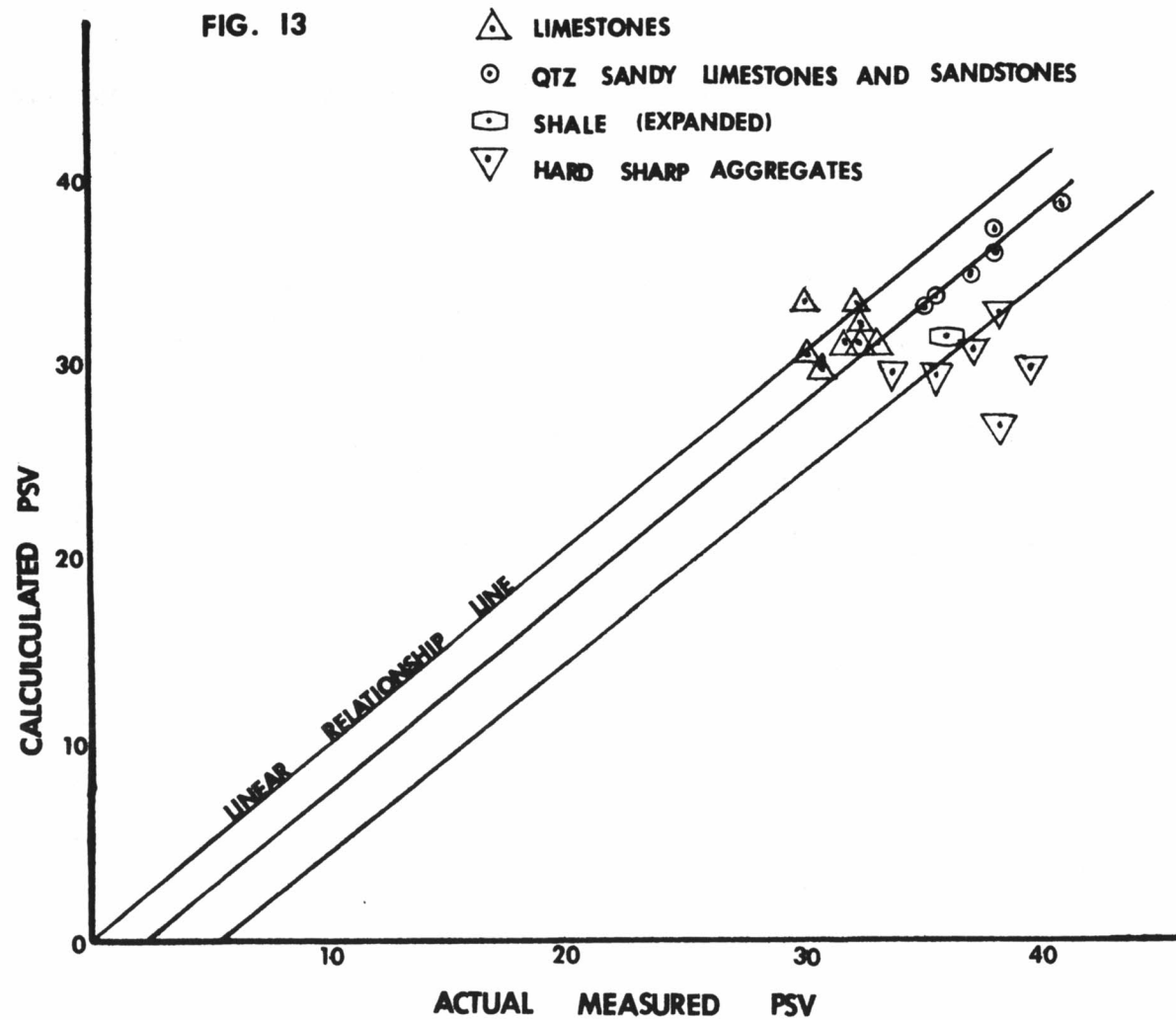
Polish Stone Values

Chert, quartz, and granite specimens had low to moderate (27.5 to 30 BPN) polish stone values when tested separately, Table 1. In 50 percent blends with the polish susceptible aggregate, these aggregates exhibited much higher values (34-40 BPN), Figure 13, rather than lower values as one would expect if a linear relationship of polish stone values exists between the two aggregates. A correlation of polish stone values of these aggregates with skid-tested pavement data was also unsuccessful and will be discussed separately in this report. The discrepancy in the laboratory

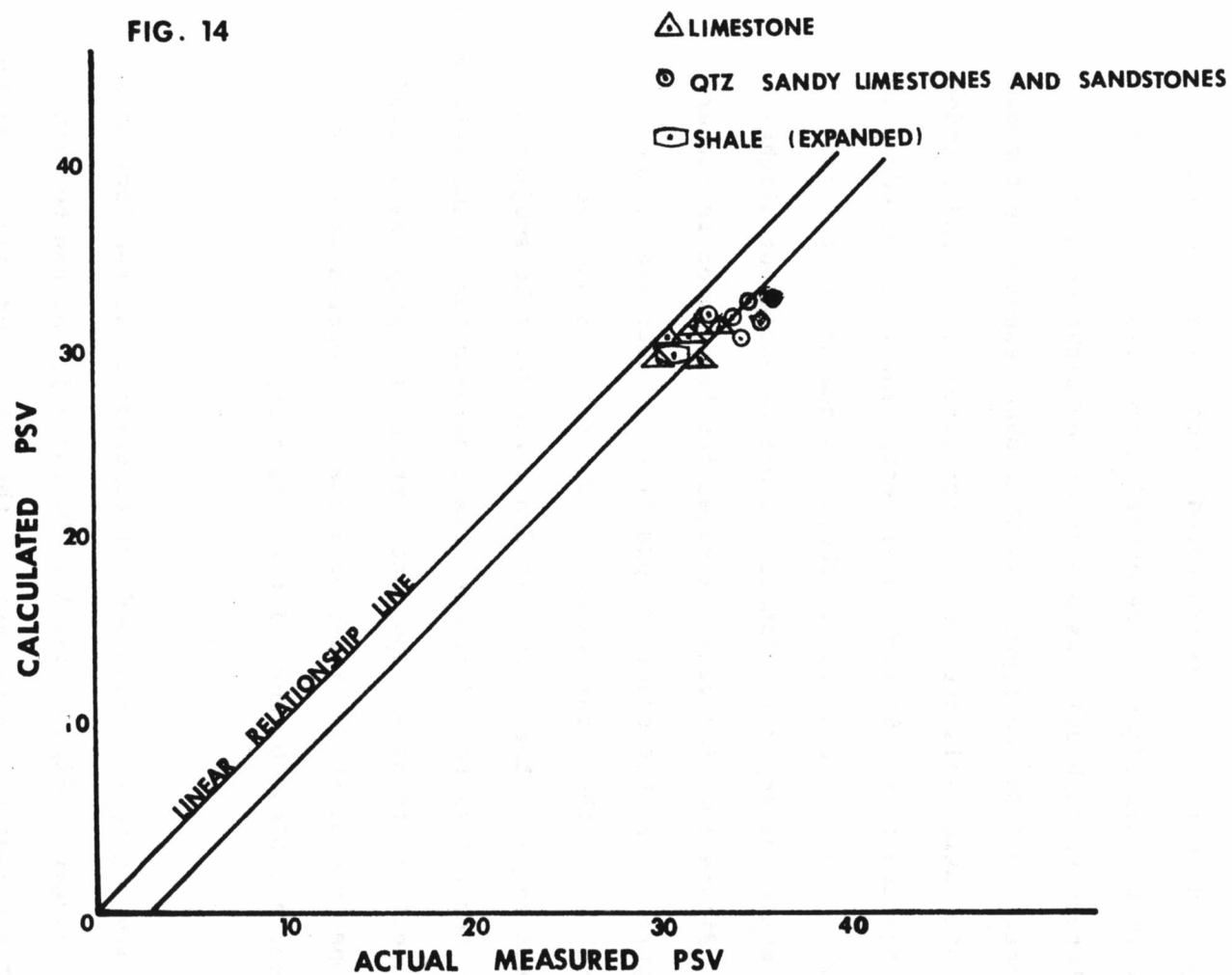
FIG. 12



MEASURED WEAR LOSS OF TEST SPECIMENS IN NINE HOUR



Relationship of Measured Polish Stone Values of 50% Blends and Calculated Polish Stone Values From Linear Relationships



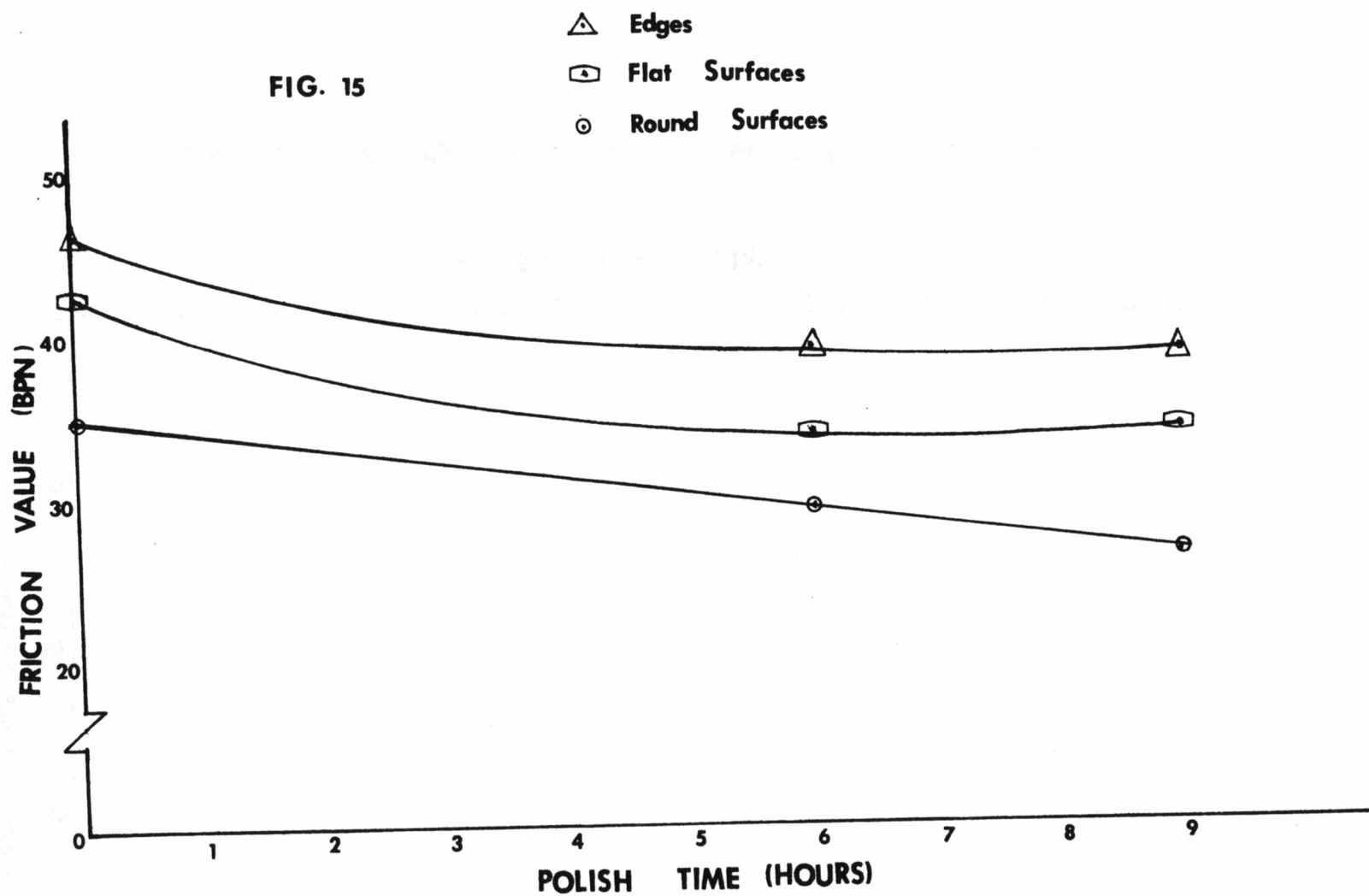
Relationship of Measured Polish Stone Values of 25% Blends and Calculated Polish Stone Values From Linear Relationships

tests with these hard materials and lack of correlation with skid-tested pavements resulted in a close scrutiny of the B.S. 812 polishing procedure.

A microscopic examination and an examination of before polish frictional values (Table 1) indicate that quartz and chert generally do not exhibit as much rugosity as do carbonates on fractured faces. Also, the examination revealed that sharp edges of these hard aggregates are perhaps the main contributors to high skid resistance values although some microtexture is present. To test the hypothesis that sharp edges were the main contributors to high skid resistance, edges, fractured faces, and rounded surfaces were subjected to the British Wheel Test. The value of edges for improving skid resistance, Figure 15, of chert and quartz gravels can readily be seen while the edges for sandstones are valuable but slightly less pronounced, Figure 16. The value of edges for limestones is rather nonexistent, Figure 17, as the edges are practically destroyed by the wearing and polishing of the abrasives during the test. Since the British Wheel Test requires that only flat fractured faces be subjected to the polishing test, this test does not give consideration to the value of edges of hard sharp materials; thus, an important portion of aggregates in roadways are not properly evaluated. These hard sharp aggregates were not tested in a 25 percent blend because of these factors.

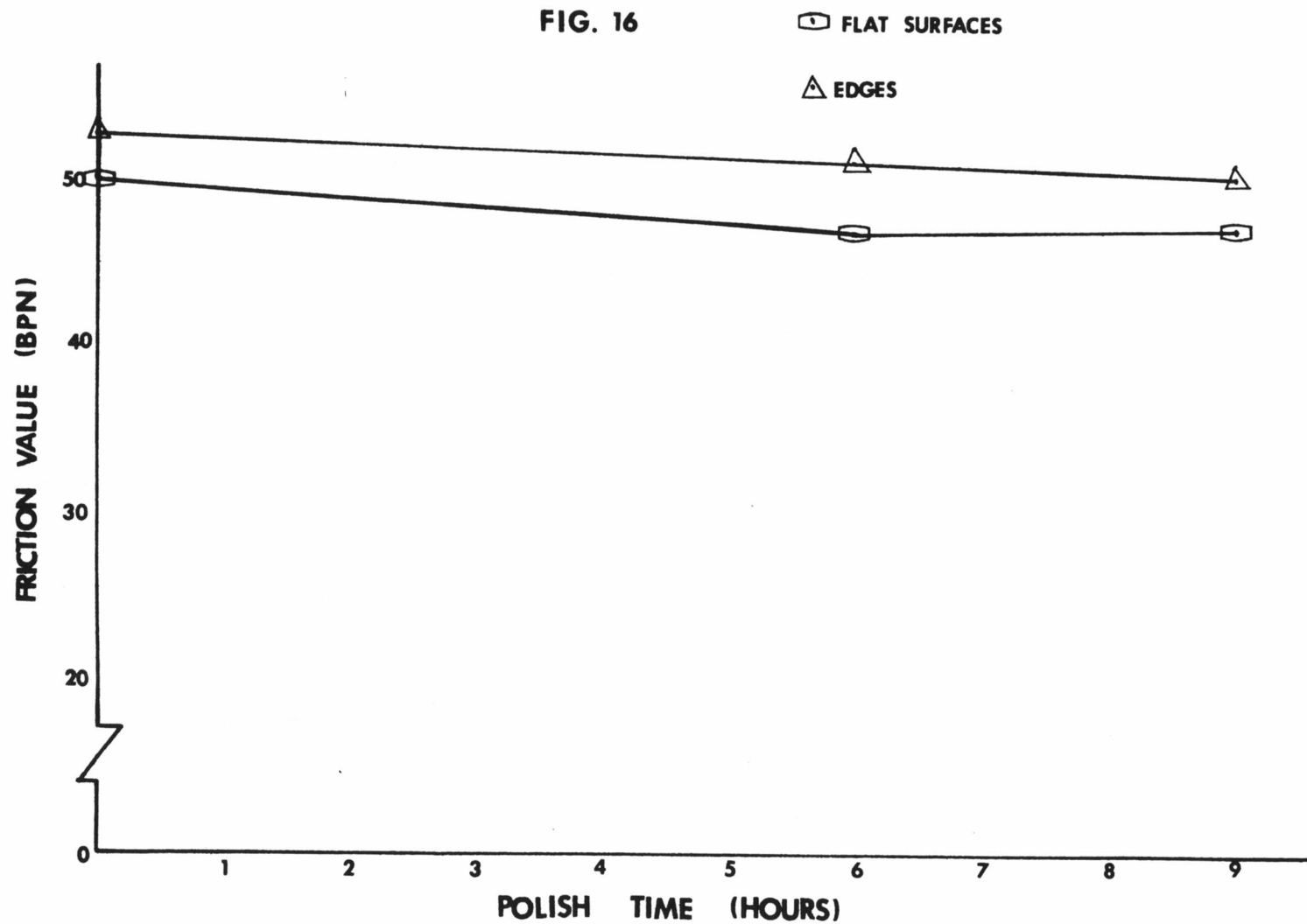
Wearability

The hard sharp aggregates performed far superior in wearability than the other test aggregates (Figures 18, 19, 20, and 21). As can be seen on the graphs, the difference in hardness of the silica and silicon carbide abrasives did not appreciably affect the wear characteristics of these aggregates.

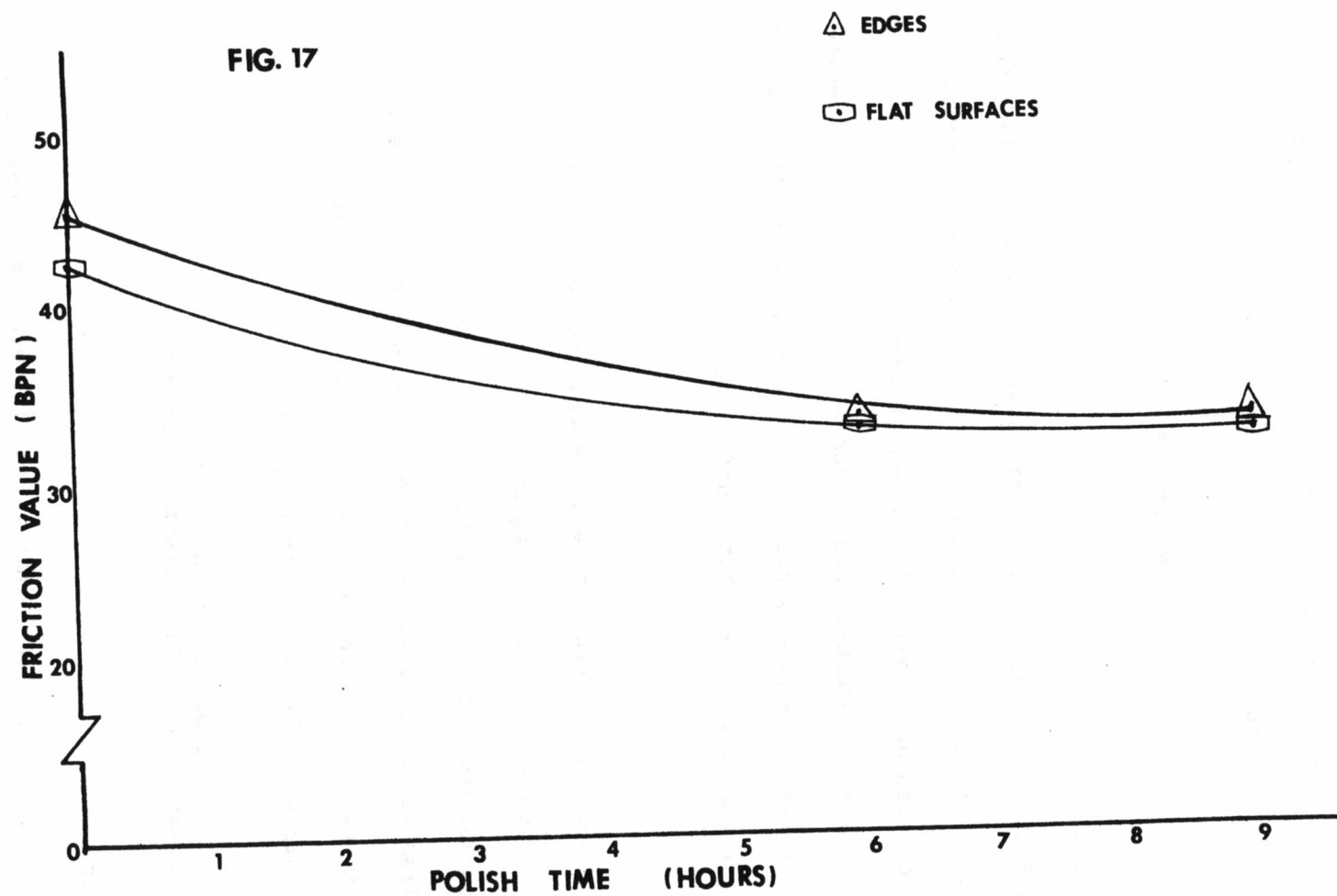


Relation of Edges, Surfaces, and Round Surfaces of Four Siliceous Gravels

FIG. 16



Comparison of Edges and Flat Surfaces of Two Sandstones



Comparison of Edges and Flat Faces of Two Limestones

The differential wear, Figure 12, between the hard materials and standard polish susceptible carbonate undoubtedly accounts for the high polish stone values of these aggregates in the 50 percent blend as can be seen in Figure 13. This development of "macrotexture" allows the rubber pad of the BPT to encounter some of the sharp edges of the aggregates and cause the high polish stone values.

Vesicular Materials

Polish Stone Values

The expanded shale test specimen exhibited an acceptable polish stone value (36.4 BPN). A microscopic examination of the specimen indicates that the numerous pores present convenient avenues of escape for water from the dynamic pressures exerted when rubber slides across the aggregate. Also, numerous thin walls between pores permit the material to fracture in an irregular angular manner and exhibit "surface renewal."

Wearability

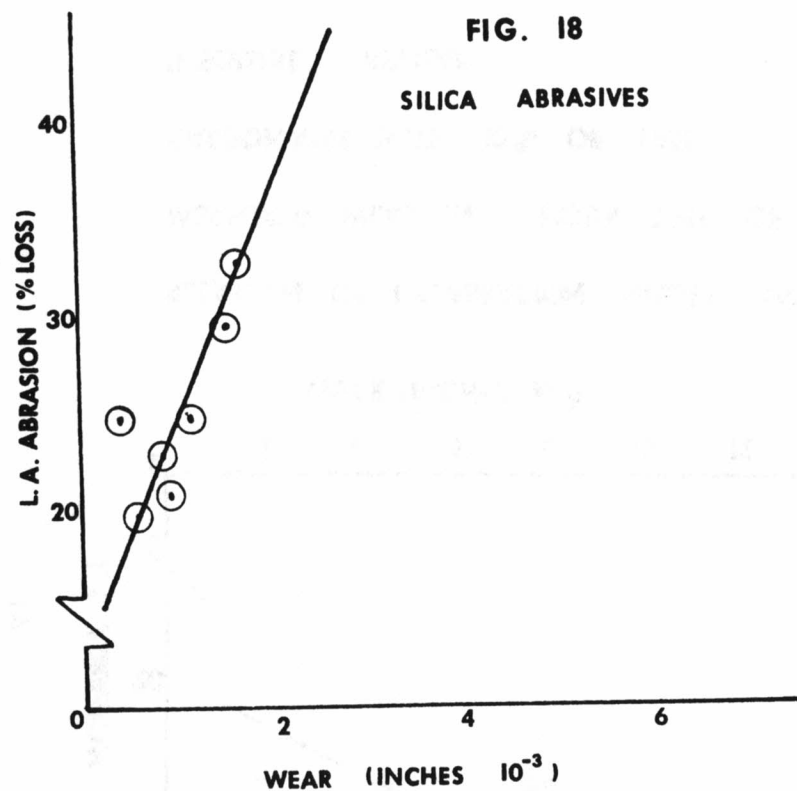
The expanded shale exhibited a greater resistance to wear than the standard polish susceptible carbonate aggregate, Figure 12.

The differential wear in the blend between the nonpolishing vesicular material and polish susceptible aggregate resulted in some "macrotexture" and higher frictional values than calculated from the linear relationship of polish stone values of the two aggregates, Figure 13 and 14.

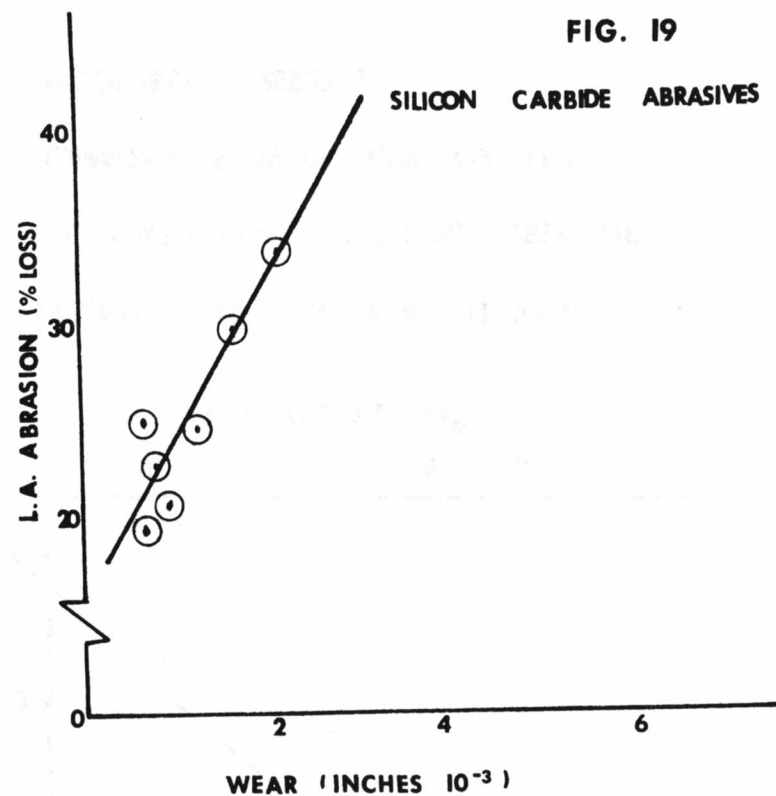
Carbonates Which Exhibit a Combination of Nonpolishing Attributes

Polish Stone Value

The good microtexture (crystallinity, fossils, etc.) developed during

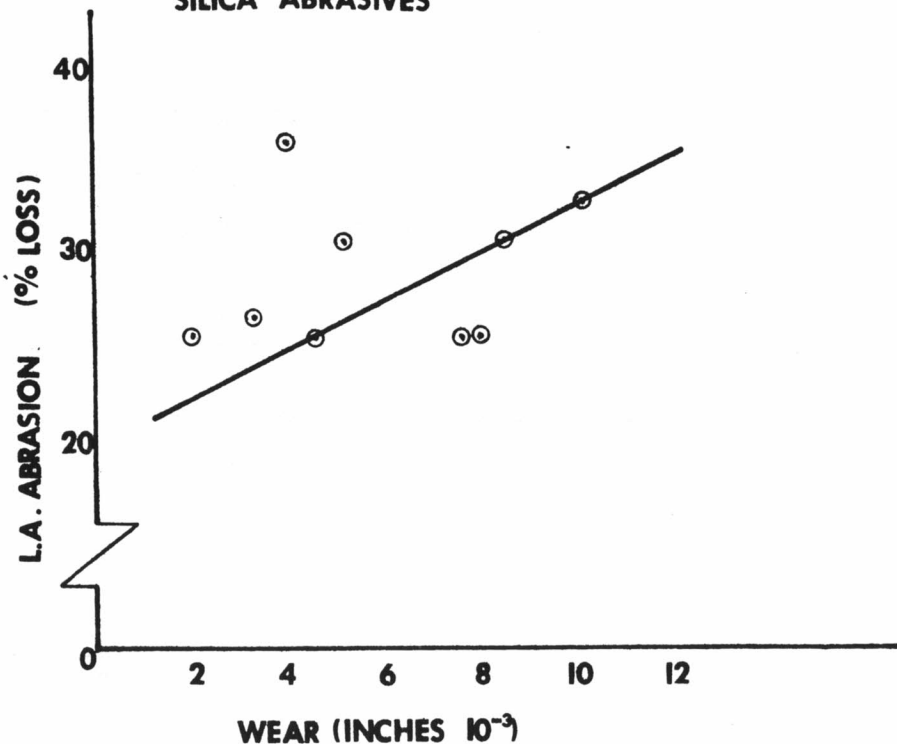


RELATION OF L.A. ABRASION VALUES
AND MEASURED WEAR VALUES IN 9 HOUR
TEST OF HARD MINERALS



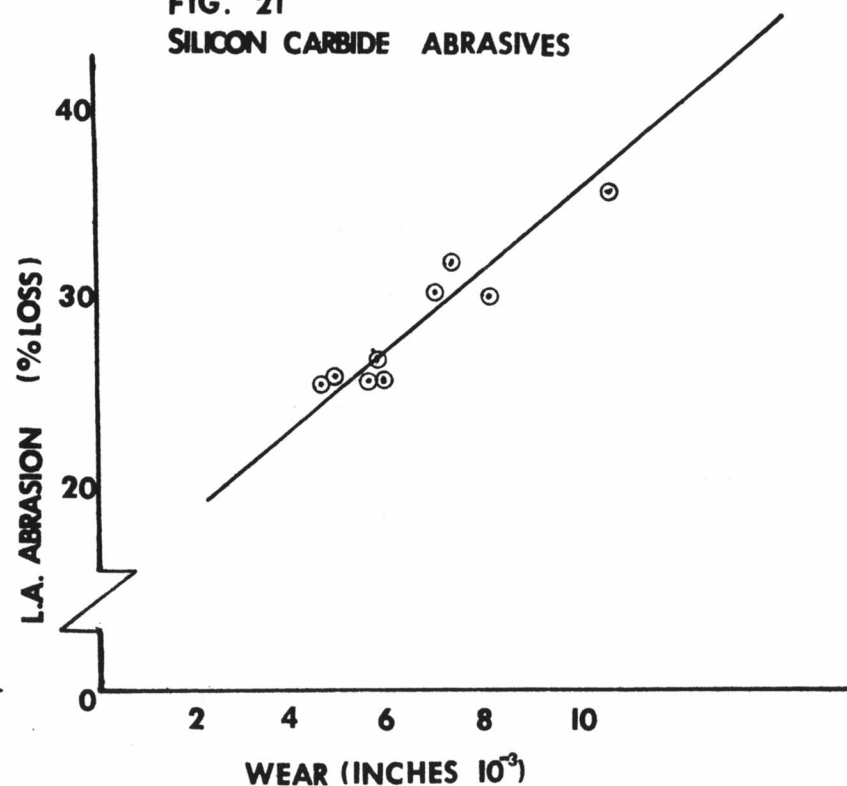
RELATION OF L.A. ABRASION VALUES
AND MEASURED WEAR IN 9 HOUR
TEST OF HARD MINERALS

FIG. 20
SILICA ABRASIVES



RELATION OF L.A. ABRASION VALUES AND
MEASURED WEAR IN 9 HOUR TEST OF
CARBONATES WITH 10% OR LESS
INSOLUBLE RESIDUE

FIG. 21
SILICON CARBIDE ABRASIVES



RELATION OF L.A. ABRASION VALUES AND
MEASURED WEAR IN 9 HOUR TEST OF
CARBONATES WITH 10% OR LESS
INSOLUBLE RESIDUE

crushing operations of carbonate aggregates were quickly worn and polished by the abrasives of the British Wheel test.

The polish stone values of the relatively pure carbonate aggregates (10 percent or less insoluble residue) were found to be dependent on both the amount of insoluble residue and the soundness of the aggregate(s), Figure 22. Those aggregates with acceptable polish stone values (34-39 BPN) either had L.A. abrasion wear loss values greater than 30 percent or contained five percent or more insoluble residue. These aggregates also were found by the petrographic examination (see Appendix B) and the chemical composition data (see Appendix D) to contain attributes which resist polishing. These attributes are partial silicification of calcite, insoluble residues which pass the No. 200 sieve and porosity. The more sound carbonates in this classification which had an L.A. abrasion wear loss value of less than 30 percent and contained less than five percent insoluble residue exhibited low polish values, see Figure 22.

Blends containing carbonate aggregates with acceptable polish stone values and the polish susceptible carbonate aggregate exhibited frictional values very close to a linear relationship, see Figure 13 and 14. This linear polish value relationship of the blends appears to be related to the approximate equal hardness of the stone as both aggregates in the blend are dominantly calcium carbonate.

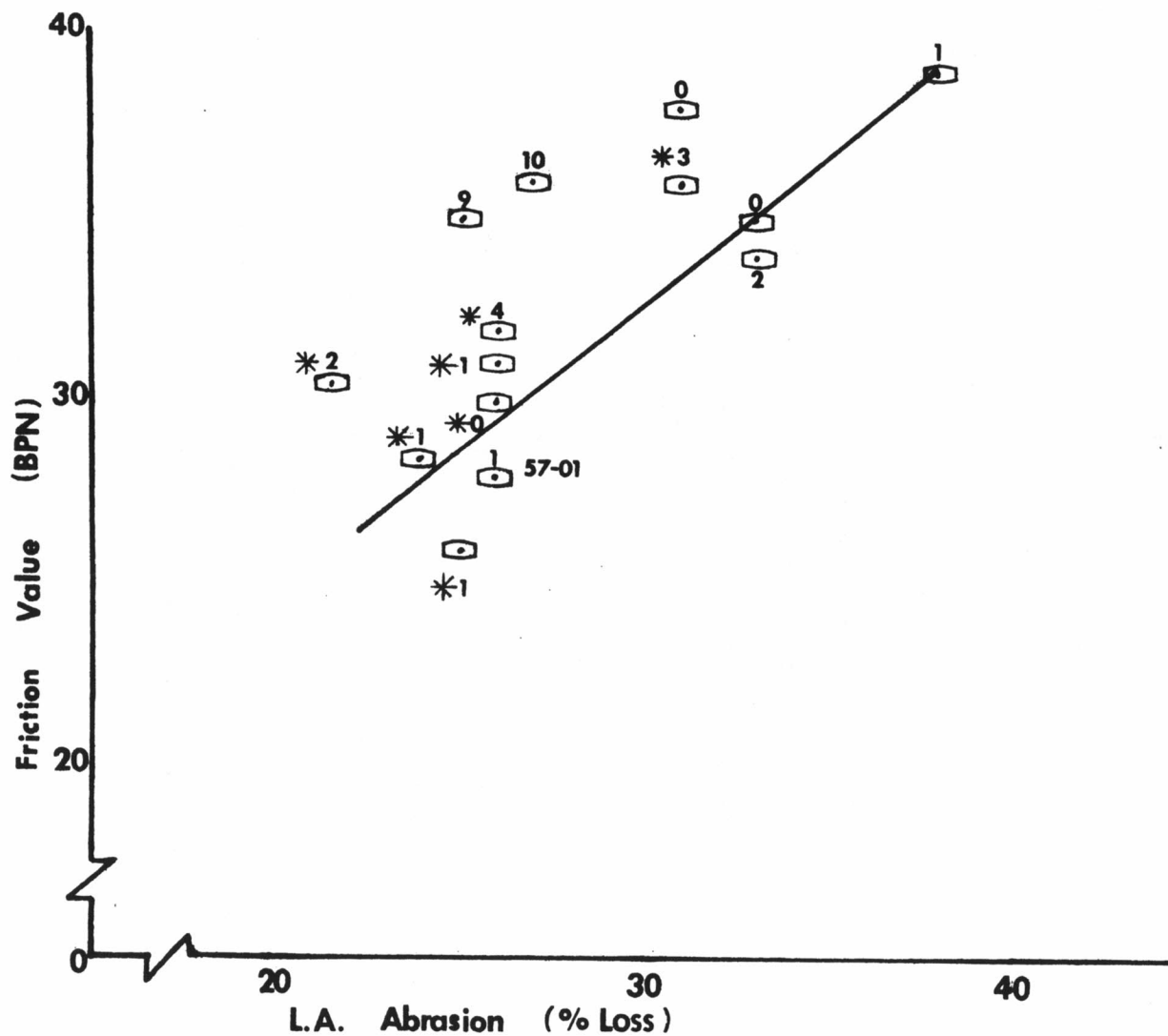
Wearability

"Nonpolishing" carbonates with a greater L.A. abrasion loss than the polish susceptible aggregate were found in the laboratory to also generally exhibit a greater measured wear loss than the polish susceptible aggregate, see Figure 12. Although these "nonpolishing" carbonate aggregates

FIG. 22

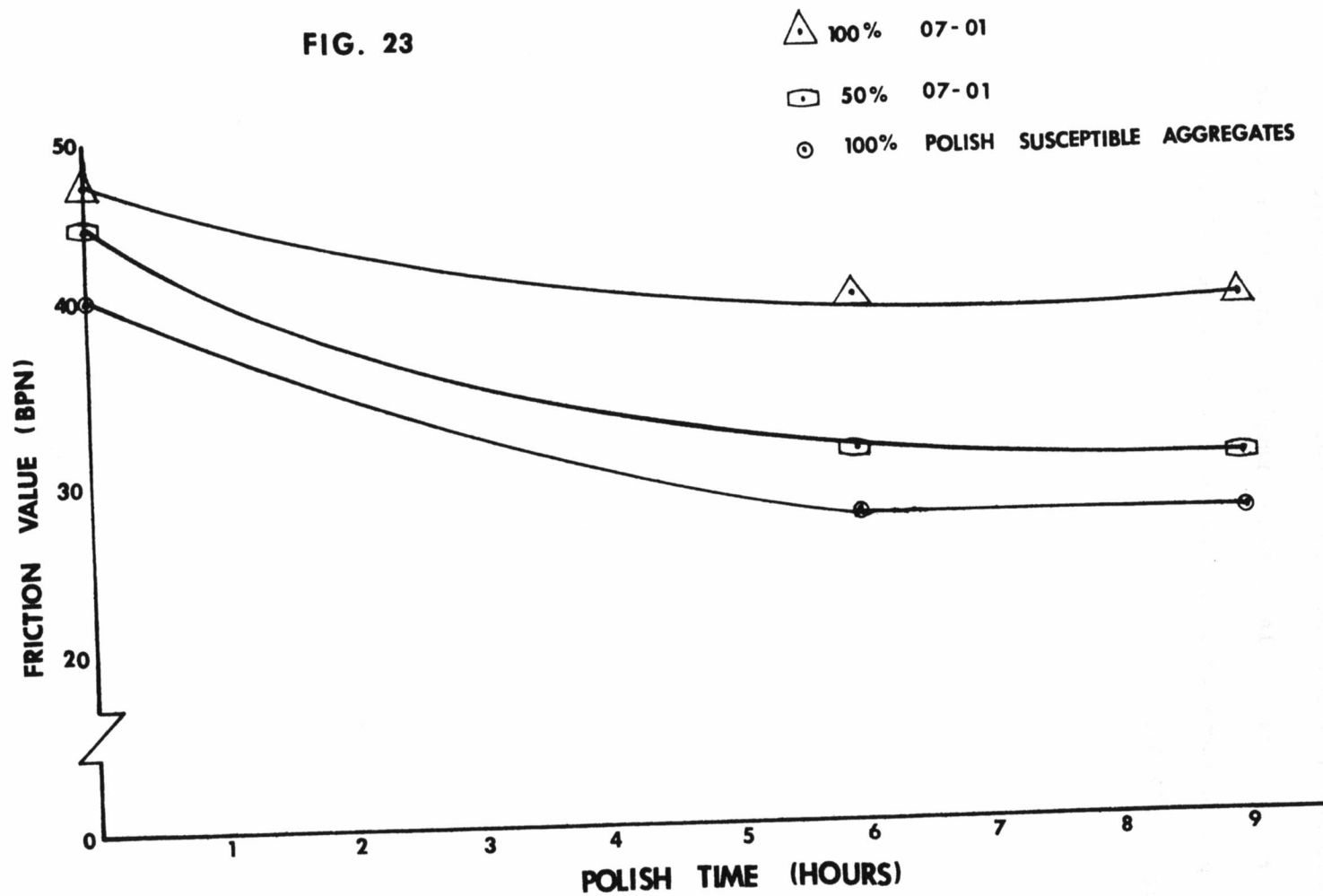
* VALUES DERIVED FROM SPECIMENS OTHER
THAN STUDY SPECIMENS

#- PERCENT INSOLUBLE RESIDUE



Comparison of Soundness of Relatively Pure Carbonates (10% or Less Insoluble Residue) and Polish Stone Values

FIG. 23



Relation of Polish Stone Values of Limestone 07-01 and Polish Susceptible Aggregate

may exhibit adequate polish stone values and be acceptable as the coarse aggregate portion of a bituminous mix, their inability to resist abrasive wear make them undesirable for blending with polish susceptible coarse aggregates as this would permit the readily polishable aggregates to be exposed to the vehicle tire. A laboratory example of this type of wear may be shown in the polish stone value of the 50 percent blend, Figure 23, of limestone source No. 07-01.

CORRELATION OF PAVEMENT "FRICTIONAL VALUES" WITH LABORATORY "POLISH STONE VALUES"

Underwood, Hankins, and Garana (11) of Texas established a minimum "polish value" of 29 BPN specification near the end of their study with the British Wheel which represented a $Sn_{40} = 32$ (0.32 coefficient of friction as measured by a skid trailer at 40 mph). This specification has since been upgraded to require a "polish value" of 34 BPN which conforms with an approximate $Sn_{40} = 40$. The change in specification complies more with Kummer and Meyer (1) NCHRP Report No. 37 which recommended that pavements nationally have a minimum $Sn_{40} = 37$.

Carbonate Aggregates

Polish Stone Values

An analysis of skid trailer tests on asphalt concrete pavements in Oklahoma with over four million vehicular passes (no differentiation between trucks and automobiles) revealed that carbonate aggregates (< 10 percent insoluble residue) with a laboratory polish stone value of 33 to 34 BPNs exhibited a range of $Sn_{40} = 34 - 41$.

Wearability

The range in skid numbers ($Sn_{40} = 34 - 41$) may partially be attributed to macrotexture and the type of fine aggregate used in the bituminous mix. A textural examination of 12 projects using limestone in the fine aggregate portion

revealed that the average macrotexture height exhibited by the limestone coarse aggregate was 0.43 mm. A similar examination of ten projects in which siliceous material was used for the fine aggregate portion, the average macrotexture exhibited by the limestone coarse aggregate was 0.72 mm. The lack of differential wear between the limestone coarse and limestone fine aggregate probably helps produce lower skid numbers.

The differential wear or greater macrotexture exhibited by the siliceous fine aggregate and limestone coarse aggregate occurs primarily from the difference of stability of the bituminous mixes. Rounded (siliceous) fine aggregates provide less strength than crushed fine aggregates (limestone) (18). Photographs reveal that round sand grains also tend to pluck from the pavement surface as the pavement ages.

Hard Sharp Materials

Polish Stone Values

An analysis of skid trailer tests on seven asphalt concrete pavements (specifications of 50 percent fractured faces) with four plus million vehicular passes containing quartz or chert as the coarse aggregate revealed that these pavements exhibited a range of $Sn_{40} = 42 - 52$. The polish stone values for fractured faces of these aggregates exhibited a low range of values, 29 - 33 BPN. As mentioned previously, the excellent values obtained in testing edges of these aggregate specimens plus their resistance to wear are their main contributions to skid resistance. Therefore, these siliceous aggregates should be subjected to specifications relating to a high percentage of fractured faces instead of the British Wheel Test, see Figure 15. Also, the more dense graded bituminous mixes with these aggregate as the coarse aggregate portion should exhibit high skid resistance values

due to the great number of edges, but in a coarse bituminous mix (assuming the same type of roller and techniques are used) these aggregates may exhibit somewhat less skid resistance values due to the less number of edges and a proportionally greater amount of flat surfaces exposed with a lack of adequate microtexture.

Wearability

A textural examination of the seven asphalt concrete pavement projects revealed an average macrotextural height of 0.72 mm.

Sandstones and Quartz Sandy Limestones

Polish Stone Values

An analysis of skid trailer tests on four asphalt concrete pavements with four plus million vehicular passes revealed a range of high skid resistance values, $Sn_{40} = 51 - 67$. These values corresponded with high laboratory polish stone values of 39 and 49 BPN.

Aggregates which contain excellent microtexture should function best as the coarser aggregate portion of a bituminous mix and in coarse graded bituminous mixes.

Wearability

Three of the four skid tested pavements contained source No. 46-01 as the coarse aggregate, and it exhibited an average macrotextural height of 0.2 mm. The one pavement which contained source No. 08-01 as the coarse aggregate exhibited a macrotextural height of 0.5 mm and a $Sn_{40} = 55$.

Stereo Photograph Correlation

Stereo photograph concepts developed by R. Shonfeld (21) for analyzing microtexture of pavements were unsuccessfully used in an attempt to correlate microtextural values (degree of polish) of coarse aggregates which have undergone polishing in pavement surfaces with stones polished by the British Wheel Test.

Laboratory molds with known polish stone values were photographed and analyzed by the same concepts as pavements. The polish stone values of molds which exhibited the same stereo microtextural values were divided into groups of three BPN's. The correlation showed that only 70 percent of the stereo microtextural values fell within the predicted BPN groupings. The use of stereo photographs were discontinued from the study due to this poor correlation.

Factors which hampered the correlation were the small polished area ($1\frac{1}{2}'' \times 3\frac{1}{2}''$) of the laboratory test specimens for analyzation, the proximity of the aggregates to each other, lack of destruction of the original rugosity of some aggregates, tilted aggregates, and the qualitative designation of microtextural values by stereo photographs. Also, aggregates in the pavement were found to be devoid of initial rugosity, generally very flat, and exhibit a greater degree of polish than those subjected to the British Wheel Test.

CONCLUSIONS

1. Crystallinity, granularity, mineralogy, cementing strengths, and other petrographic features of aggregate specimens definitely affect the wearing performance of coarse aggregates, but one must classify the aggregate sources petrographically for proper analysis.

2. Sandstones and quartz sandy limestones exhibit the highest polish stone values primarily due to "surface renewal" of microtexture by unpolished sand grains. The test specimens with weaker cementing strengths and high L.A. abrasion wear loss values exhibit the highest polish stone values. Other petrographic features such as packing of grains, angularity of grains, grain size, and stratification of soft and hard minerals also affect the polish stone value. The use of these aggregates in blends appear to be limited to those aggregates which exhibit a L.A. abrasion wear loss of 40 percent or less. These aggregates with excellent microtexture are best suited in the coarse aggregate portion ($3/4''$ - $3/8''$) of bituminous mixes or as seal coat aggregate(s) ($3/4''$ - No. 4 sieve) because of the area of exposure of these larger aggregates in the pavement's surface.

3. Chert and quartz exhibit generally low polish stone values due to lack of initial rugosity, but edges and resistance to wear are their main contributors to skid resistance. The British Wheel Test eliminates proper evaluation of these aggregates since a flat face is required for

RECOMMENDATIONS

Based on the results of this study, the following is recommended:

1. It is recommended that specifications and a test procedure employing the "polish stone value" for coarse aggregates and blending of coarse aggregates be used on experimental construction projects for optimum economic and safety benefits.

2. Specifications requiring a high percentage of fractured faces more aptly applies to hard (> 5 Mohs' scale) aggregates such as chert and quartz. These aggregates should be exempted from the British Wheel Test.

3. It is recommended that continued research effort be given to the amount of fractured faces required in hard materials to improve blends.

4. It is recommended that existing pavements with coarse aggregate blends (based on insoluble residue data) be monitored for greater verification of laboratory "polish stone values."

5. It is recommended that periodic skid measurements (performance records) be maintained for the surfaces of construction projects utilizing the results of the British Wheel Test. Revised design procedures and related information can be developed from this information.

13. Giles, C. G.; Sabey, B. E.; and Cardew, K. H. T.; "Development and Performance of the Portable Skid-Resistance Tester", ASTM Special Technical Publication No. 326, 1962, pp. 50-75.
14. Schneider, A. G., "First Results of a Study on Aggregate Wear and Polishing", Pennsylvania State University, Report No. 13, 1966.
15. Kummer, H. W. and Meyer, W. E., "Measurement of Skid Resistance", ASTM Special Technical Publication No. 326, 1962, pp. 3-28.
16. Maclean, D. J. and Shergold, F. A., "The Polishing of Roadstones in Relation to Their Selection for Use in Road Surfacing", First International Skid Prevention Conference Proceedings, Part II, Virginia Council of Highway Investigation and Research, 1959.
17. Sherwood, W. C. and Mahone, D. C., "Predetermining the Polish Resistance of Limestone Aggregates", Virginia Highway Research Council, 1970.
18. Herrin, Moreland, and Goetz, "Effect of Aggregate Shape on Stability of Bituminous Mixes", Highway Research Board Proceedings, Volume 33, 1954, pp. 293-308.
19. Kummer, H. W., "Correlation Study", Tappahannock, Virginia, September, 1962, p. 42.
20. Rowland, T. L., "Lithostratigraphy and Carbonate Petrology of the Morrow Formation (Pennsylvanian) Braggs-Cookson Area, Northeastern Oklahoma", Doctor of Philosophy Dissertation, University of Oklahoma, Norman, OK, 1970.
21. Schonfeld, R., "Skid Numbers from Stereo-Photographs", Department of Highways, Ontario, Report No. RR 155, January, 1970.

APPENDIX A

Method of Test for Total Insoluble Residue in Coarse Aggregates

OHD-L-25

SCOPE: This method of test is intended for the determination of acid insoluble material in aggregates used in asphalt concrete.

APPARATUS: The apparatus for this test will consist of the following:

- (a) Half-gallon jars
- (b) Hydrochloric acid - Technical Grade
- (c) Evaporating dishes (Vycor 350 ml)

PROCEDURE: (a) Crush sample so that all material is less than one-half inch.

(b) Split the sample to approximately 200 grams, weigh accurately, and place in clean, labeled half-gallon jar.

(c) Add 400 ml water and slight excess of concentrated hydrochloric acid (approximately one ml per gram of rock) over amount needed to react with available carbonate. Stir mixture over a period of days until all reaction ceases.

(d) Wash the insolubles free of excess ions by filling jar with tap water, allowing all of the material to settle (about 48 hours) and pour off the clear solution. Procedure is repeated three times.

(e) After the third wash cycle, wash the insolubles into an evaporating dish, dry at 100-105°C and weigh.

REPORT: Report insoluble residue percents retained on the No. 200 sieve of the total sample.

The ledge rock specimen consists of 42 percent subround to subangular, well sorted, loosely packed quartz grains cemented by sparry calcite. The grains range in size from 0.3 mm to 0.02 mm with a median size of 0.15 mm. Technical name of specimen: Recrystallized, quartz sandy calcarenite.

No. 11-02 - A tan to gray slightly weathered quartz sandy fossiliferous limestone (Pennsylvanian) obtained from exposures along the flanks of the Ozark Uplift in northeastern Oklahoma.

Three ledge rock specimens show that 45 percent of the source consists of poorly sorted, overly close packed, stratified, subangular quartz grains, and grains of skeletal fossils which contain moderate silicification of calcite. The amount of quartz grains range from 13 to 36 percent in specimen. They range in size from 0.4 mm to 0.02 mm with a median size of 0.17 mm. Fossil grains range in size from 2.0 mm to 0.15 mm with a median size of 0.6 mm. Sparry calcite comprises the matrix (55 percent) of the specimen. Technical name of specimen: Bryozoan, pelmatozoan, quartz sandy calcarenite.

No. 11-03 - A tan, moderately weathered quartz sandy fossiliferous limestone (Pennsylvanian) obtained from exposures along the flanks of the Ozark Uplift in northeastern Oklahoma.

The ledge rock specimen shows that 33 percent of the specimen consists of subangular, poorly sorted, overly close packed, locally stratified, with siliceous cemented clusters of quartz grains. The grain sizes range from 0.25 mm to 0.02 mm with a median size of 0.15 mm. Fossil grains with micritic rims comprise 23 percent of the specimen and consist of sparry calcite. Sparry calcite comprise the matrix (44 percent). Technical name of specimen: Bryozoan, pelmatozoan, quartz sandy calcarenite.

No. 31-01 - A gray siliceous sandstone (Pennsylvania) obtained from the Arkhoma Basin of eastern Oklahoma. The ledge rock specimen consists of 80 percent quartz grains. The grains are subangular, well sorted, overly close packed, and range in size from 0.4 mm to 0.05 mm with a median size of 0.2 mm. Chert and some chalcedony comprise the cementing matrix or 18 percent of the specimen. Technical name of specimen: Sandstone (orthoquartzite).

No. 46-01 - A gray siliceous sandstone (Pennsylvanian) obtained from the Arkhoma Basin of eastern Oklahoma.

The ledge rock specimen consists of 68 percent quartz grains. The grains are subangular, well sorted, overly close packed, and range in size from 0.35 mm to 0.05 mm with a median size of 0.15 mm. Chert and some chalcedony comprise the cementing matrix or 31 percent of the specimen. Carbonaceous material occurs in striations and comprises one (1) percent of the specimen. Technical name of specimen: Sandstone (orthoquartzite).

No. 68-02 - A gray to tan quartz sandy fossiliferous limestone (Pennsylvanian) obtained from exposures along the flanks of the Ozark Uplift in northeastern Oklahoma.

The ledge rock specimens show that 37 percent and 38 percent, respectively, of the specimen consists of subangular to subround well sorted, overly close packed, stratified quartz grains. The grains in some of the stratifications are siliceous cemented or intergrown to form clusters. The grain size ranges from 0.5 mm to 0.07 mm with a median size of 0.2 mm. Fossil grains comprise 18 percent and 17 percent, respectively, of the specimens and consist of sparry calcite. Moderate silicification of calcite is prevalent in many of these grains. The cementing matrix consists of sparry calcite. Technical name of specimen: Skeletal, quartz sandy calcarenite.

Hard Minerals

No. 12-01 - A brown, fairly homogeneous, chert gravel obtained from terrace deposits (Quaternary) of southeastern Oklahoma.

An analysis of the gravel aggregates shows the deposit consists of 95 percent chert and 5 percent quartzite. The aggregates are well rounded and exhibit very little microtexture before crushing.

No. 35-02 - A light pink granite (Precambrian) obtained from the Arbuckle Mountains of south-central Oklahoma.

The ledge rock specimen consists of 22 percent quartz, 78 percent orthoclase feldspar, and traces of biotite, hornblende, and other minerals. Average grain size of the quartz is approximately 2 mm. Average size of the orthoclase feldspar is about 3 mm. Technical name of specimen: Coarse grained granite.

No. 45-01 - A light brown heterogeneous siliceous gravel obtained from alluvial deposit (Quaternary) of southeastern Oklahoma.

An analysis of the gravel aggregates shows the deposit consists of 50 percent quartz, 24 percent chert, 21 percent quartzitic sandstone, and 4 percent metamorphic rocks. The aggregates are subround and exhibit some microtexture before crushing.

No. 58-01 - A whitish gray chert (Mississippian) obtained from a zinc mine crushing operation in northeastern Oklahoma.

An analysis of the aggregates shows the deposit to consist of 92 percent chert, 6 percent limestone, and 2 percent dolomite, zinc, iron, and accessory minerals.

No. 63-01 - A whitish pink to brown, fairly homogeneous, chert gravel obtained from a conglomerate (Permian) of the Prarie Plains Homocline in central Oklahoma.

An analysis of the aggregates show the deposit consists of 94 percent banded chert and 6 percent cherty limestone. Leaching of calcium carbonate is prevalent in many of the cherty limestone aggregates.

No. 01-01C - A white to dark gray dominantly quartz gravel obtained from a terrace deposit (Quaternary) in southeastern Colorado.

An analysis of the aggregates show the deposit consists of 75 percent quartz and quartzite, 10 percent sandstone, 5 percent limestone, 6 percent basalt, and 4 percent metamorphic rocks.

No. 01-01T - A tan to brown heterogeneous gravel obtained from a terrace deposit (Quaternary) in northwestern Texas.

An analysis of the aggregates showed the deposit consists of 44 percent quartz and quartzite, 21 percent sandstone, 18 percent limestone, 6 percent basalt, 5 percent granite, 5 percent caliche, and 1 percent chert.

Limestones

No. 07-01 - A white chalky limestone (Cretaceous) obtained from the Gulf Coastal Plain of southeastern Oklahoma.

The ledge rock specimen consists of 37 percent fossil grains which which contain moderate local silicification of the sparry calcite fossils. The fossil grains are closely packed, skeletal-fragmented to round, poorly sorted, and range in size from 4.0 mm to .01 mm with median size of 0.3 mm. The matrix of the specimen consists of micrite and contains numerous pores and a few scattered very fine quartz, pyrite, and dolomite grains. Technical name of specimen: Skeletal, calcarenitic mudstone.

No. 11-01 - A dark gray to gray fossiliferous limestone (Pennsylvanian) obtained from the flanks of the Ozark Uplift of northeastern Oklahoma.

The ledge rock specimen consists of 59 percent sparry calcite grains which are present in the form of fossils and void fillings. Micrite rims comprise the fossil boundaries. The fossil grains are overly close packed, well sorted, rounded, and range in size from 2.5 mm to 0.1 mm with a median size of 0.4 mm. Moderate silicification of calcite occurs locally. Dolomite grains comprise four percent of the specimen and occurs as replacement of sparry calcite. A few pyrite grains are scattered throughout the specimen. Pseudospar forms the matrix.

The rock generally crushes around fossils and along cleavage planes to form aggregates with angular microtexture. Technical name of specimen: Oolitic calcarenite.

No. 15-01 - A gray fine-grained limestone (Ordovician) obtained from the Arbuckle Mountains of south-central Oklahoma.

Two ledge rock specimens consist of 81 and 87 percent micrite, respectively, which occurs as matrix or in pelletoid form. Sparry calcite comprises 5 to 18 percent. Dolomite and chert occurs in thin bands in the specimens. Technical name of specimen: Mudstone.

No. 50-02 - A gray fine-grained limestone (Ordovician) obtained from the Arbuckle Mountains of south-central Oklahoma.

The ledge rock specimen consists of 68 percent micrite with zones and veins of pseudospar (15 percent), microspar (3 percent), and dolomite (8 percent). Chert grains (1 percent) are present in silt size. Clay, iron, and carbonaceous material (5 percent) are present in stylolites. The rock often crushes along calcite veins. Technical name of specimen: Stylitic, dolomitic mudstone.

No. 61-01 - A gray to dark gray fossiliferous limestone to cherty limestone (Pennsylvanian) obtained from the Ouachita Mountains of southeastern Oklahoma.

Three ledge rock specimens show the material source to be variable lithologically. One specimen contains 95 percent micrite and represents beds 69 feet thick. The other two specimens represent beds 85 feet thick. These specimens consist of 11 percent and 63 percent, respectively, fossil grains. The fossils are composed of sparry calcite which are highly silicified locally. The fossils are overly close packed to seldom touching, well sorted, and range in size from 4.0 mm to .05 mm with median size of 2.0 mm. Glauconite and quartz grains are scattered throughout the matrix. The matrix is composed of microspar which is silicified locally. Technical name of specimen:

- No. 1 - Mudstone
- No. 2 - Calcarenitic mudstone
- No. 3 - Pelmatozoan calcarenite

No. 72-01 - A light gray and gray limestone (Pennsylvanian) from the Prairie Plains Homocline of northeastern Oklahoma.

The ledge rock specimen consists of 33 percent pseudospar grains or void fillings with moderate silicification. The grains are angular, poorly sorted, and range in size from 2.0 cm to 0.03 mm with a median size of 1.0 mm. Fossils composed of sparry calcite comprise 9 percent of the specimen. Micrite (58 percent) comprises the matrix. Technical name of the specimen: Recrystallized, calcarenitic micrite.

No. 74-01 - A light gray to buff gray, fine-grained limestone (Pennsylvanian) obtained from the Prairie Plains Homocline of northeastern Oklahoma.

The ledge rock specimen consists of 21 percent pseudospar which has filled fossil molds and voids. The pseudospar has undergone moderate

silicification. The angular pseudospar ranges in size from 1.0 mm to 0.01 mm with a median size of 0.02 mm. The matrix comprises 79 percent of the specimen and consists of micrite. Technical name of specimen: Recrystallized mudstone (microsparite).

Vesicular Material(s)

Shale - A dark gray expanded shale obtained from north-central Texas. This lightweight aggregate is formed by subjecting shales or clays to extremely high temperatures (2000+°F) for approximately one hour. The high temperature converts the moisture inside the material into steam. The expansion of the steam and other trapped gases results in a highly vesicular aggregate or clinker. The clinker may then be screened or crushed to specifications. Technical name of specimen: Expanded shale.

No. 57-01, Standard Polish Susceptible Aggregate - A gray, fine grained limestone (Pennsylvanian) obtained from the Prairie Plain Homocline of north-central Oklahoma.

Two ledge rock specimens consist of 75 percent and 99 percent micrite, respectively. Fossils composed of pseudospar comprise 25 percent and 1 percent, respectively, of the specimens.

The mudstone specimen represents 20 feet of the 30 feet thick rock quarry. Technical name of specimen:

- No. 1 - Calcarenitic mudstone
- No. 2 - Mudstone

APPENDIX C

The following classification of carbonate rocks by Dr. T. L. Rowland (20) was used in the study of test specimens and is suggested as a feasible classification for other carbonate researchers.

Classification of Carbonate Rocks

In recent years, a number of major contributions have been made to the understanding of carbonate sedimentation. Numerous classification schemes for carbonate rocks have been proposed and several of the more significant ones were published by the American Association of Petroleum Geologists (Ham, et al., 1962). An excellent discussion of the parameters of classification and the different classification schemes is given in the first article by Ham and Pray.

Most of the classifications have used basically the same parameters but have arrived at different names. If the proper information is present so the reader will have a clear understanding of how particular rocks are treated, it does not matter what classification scheme is used.

Carbonate rocks are the dominant lithologic types encountered in the dissertation area. These rocks are classified using a modified combination of those proposed by Folk (1959, 1962), Dunham (1962), and a classification scheme used by W. E. Ham in a course in carbonate petrology at the University of Oklahoma. For the details of classifications by Folk and Dunham, the reader is referred to their original articles. The classification utilized in this report appears in Table I.

Terms and notes for the working usage of this classification appear below so that a full meaning of how the rocks are treated is conveyed.

Terms

Mud or micrite	- calcite up to 4 microns in size. Folk (1962).
Microspar, pseudospar	- calcite from 4 to 60 microns. Folk (1959, 1962, and 1965). Used in conjunction with recrystallization fabrics.
Sparry calcite cement	- void- and pore-filling calcite. Folk (1959, 1962)
Sparites and micrites	- terms for rock names with proper prefixes attached, such as biosparite for rocks that are sparry calcite cemented and with skeletal debris as the main grain constituents. See Folk (1959, 1962).
Wackestone, grainstone, packstone, boundstone	- terms for rock names utilizing depositional textures. See Dunham (1962).
Grain support	rocks in which the grains are so abundant as to support one another. Dunham (1962).

1) If the rock contains more than 10 percent terrigenous material or authigenic constituents, "quartz sandy" or "quartz silty", an appropriate modifier prefixes the rock name.

2) If the rock contains more than ten percent replacement dolomite, the term "dolomitic" prefixes the rock name.

3) Rocks with obvious structures have appropriate modifiers such as "burrowed."

TABLE I

Carbonate Rock Classification

Category	Rock Name	Size (Microns)	
		Grains	Matrix
Non-muddy, grain supported limestones; < 10% mud matrix	Grainstones		
	Calcarenite	62-2000	< 4-2000
	Calcisiltite	10- 62	10- 62
	Sparite	62-2000	< 4-2000
	Sparrudite	>2000	< 4-2000
	Calcirudite	>2000	< 4-2000
Recrystallized equivalents	Microsparites	62-2000	4- 60
Muddy, grain supported limestones; > 10% mud matrix	Packstones		
	Muddy calcarenites	62-2000	4 or less
	Muddy calcisiltites	10- 62	44 or less
	Sparites	62-2000	4 or less
	Sparrudites	>2000	4 or less
	Muddy calcirudites	>2000	4 or less
Recrystallized equivalents	Microsparites	62-2000	4- 60
Muddy, non-grain supported limestones; > 10% grains	Wackestones		
	Calcarenitic mudstone	62-2000	4 or less
	Mudstone	62-2000	4 or less
	Micrite	62-2000	4 or less
< 10 %grains	Mudstones		
	Calcilutite	<4-2000	4 or less
	Micrite	<4-2000	4 or less
Recrystallized equivalents	Microsparites	62-2000	4- 60
Dolomitized equivalents of all the above.			
Special Types	Boundstones		

4) If the rock has undergone recrystallization and the degree is severe or extensive, recrystallized is prefixed and Folk's term "microsparite" is applied to those rocks.

5) If the rock contains more than ten percent fossil debris, the term "skeletal" is used as a modifier. If one faunal element is dominant, it replaces the term "skeletal."

6) In prefixing modifiers, the one closest to the rock name is the most abundant (e.g. bryozoan, pelmatozoan, calcarenite; bryozoan content is less than pelmatozoan).

Several examples to clarify usage are presented below.

Fine- to very coarse-grained, bryozoan, pelmatozoan calcarenite; biosparite (grainstone). The rock is grain supported, dominated by bryozoans and pelmatozoans, sparry calcite cemented and the grains are in the 62-2000 micron size. It may contain up to ten (10) percent micrite matrix.

Fine- to very coarse-grained, pelmatozoan, muddy calcarenite; poorly washed biosparite (packstone). The rock is grain supported, dominated by pelmatozoans, contains more than ten percent mud and the grains are in the 62-2000 micron size.

Fine- to very coarse-grained, bryozoan, calcarenitic mudstone; biomicrite (wackestone). The rock is mud supported, dominated by bryozoans, has more than ten percent grains in the 62 2000 micron size.

Fine- to very coarse-grained, algal calcilutite; biomicrite (mudstone). The rock is mud supported, dominated by algae, but has less than ten percent grains in the 62 - 2000 micron size.

Fine-grained, bryozoan, recrystallized calcarenite; biomicrosparite (recrystallized grainstone). The rock is dominated by bryozoan debris, and is extensively recrystallized.

The scheme is such that the reader has a choice of three rock names to choose and to add the appropriate modifiers. Examining the first case; fine- to very coarse-grained, bryozoan, pelmatozoan calcarenite; biosparite (grainstone). If the name "biosparite" is used, it would be as follows: fine- to very coarse-grained, bryozoan, pelmatozoan biosparite; if the term "grainstone" is used, the rock would be a fine- to very coarse-grained, bryozoan, pelmatozoan grainstone.

Perhaps no classification scheme can be completely satisfactory because of the gradational series existing in carbonate rocks. The scheme presented here offers the reader a choice of three possible classifications which are mostly descriptive but weighted heavily with genetic implications.

References Cited

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- Folk, R. L., 1959, Practical Petrographic Classification of Limestones: American Association of Petroleum Geologists, Bull., v. 43, p. 1-38.

APPENDIX D

Chemical Analysis Of Test Specimens

Chemical composition of crusher run aggregates from several test sources are listed. Sieve size determinations were not made on the samples

Percent	(CaCO ₃	MgCO ₃	SiO ₂	Al ₂ O ₃	Total Fe (as FeO)	H ₂ O	P ₂ O ₅	K ₂ O	Na ₂ O	S	Recovery	CO ₂	Insols)
Sample#													
07-01	94.28	1.48	2.17	0.40	0.62	0.11	.032	.064	.079	.12	99.36	41.92	3.30
08-01	22.10	15.37	59.22	2.62	0.68	----	.078	.161	.080	.11	100.00	17.44	60.48
11-01	90.86	1.83	4.02	1.16	0.86	0.25	.136	.089	.041	.26	99.51	40.36	5.94
15-01	78.84	2.56	16.12	0.60	0.51	0.10	.038	.061	.059	.10	98.98	35.42	18.11
31-01	0.97	0.76	90.58	6.16	1.21	----	.046	.201	.056	.02	100.00	0.87	95.84
46-01	2.18	1.65	83.00	10.56	1.63	0.49	.082	.329	.057	.02	100.00	1.74	96.35
50-02	58.79	26.96	8.96	2.53	0.76	----	.044	.229	.058	.19	98.52	38.47	14.17
57-01	88.02	6.27	1.97	1.81	0.41	----	.026	.256	.056	.09	98.91	42.46	3.10
61-01	73.60	1.84	21.20	1.48	0.79	0.19	.068	.139	.076	.12	99.50	32.72	23.33
72-01	94.43	2.19	1.74	0.94	0.32	----	.047	.090	.065	.07	99.89	42.63	2.70
74-01	83.38	5.65	5.21	2.24	1.36	0.02	.171	.169	.063	.17	98.43	39.82	7.93

APPENDIX E

British Wheel Test

Accelerated Polish Test Method for Coarse Aggregate Used in Pavement Surfaces

Scope:

This test method describes procedures for determining a relative measure of the extent to which different types of aggregate in the wearing surface will polish under traffic.

Definitions:

The polish stone value is defined as the state of polish reached by each sample when subjected to accelerated polish by means of a special machine. The test is in two parts:

- (1) Samples of stone are subjected to an accelerated polishing action in a special machine.
- (2) The state of polish reached by each sample is measured by a British Portable Tester and expressed as the polish stone value.

Apparatus:

1. Accelerated Polishing Machine: A polishing device as shown in Figure 1. An accelerated polishing machine shall be mounted on a firm level and non-resilient base of stone or concrete and shall include:

- A. A wheel (referred to as the road wheel) having a flat periphery and of such size and shape as to permit 14 specimens described below to be clamped on the periphery so as to form a continuous surface of stone particles, 1 and 3/4 inches wide and 16 inches in diameter.
- B. A means of rotating the road wheel about its own axis at a speed of 315 to 325 revolutions per minute.

- C. A means of bringing the surface of a rubber tired wheel of 8 inch diameter and 2 inch width to bear on the stone surface of the road wheel with a total load of 88 ± 1 pound. The tire shall be an industrial 8 x 2 pneumatic four ply smooth hand truck tire, treated, if necessary, to obtain a true running surface. The tire shall be inflated to a pressure of 45 ± 2 pounds per square inch and shall be free to rotate about its own axis, which shall be parallel to the axis of the road wheel. The plane of rotation of the tire shall be in line with that of the road wheel. Before a new tire is used on a test, it shall be given a preliminary run of 6 hours with coarse silica abrasives using dummy specimens on the road wheel.
- D. A means to feed the silica abrasives at the rates shown in "Accelerated Polish Test Procedure" and in such a way that the abrasive is continuously and uniformly spread over the surface of the tire and the specimens where they are in contact. The grit shall be fed directly onto the road wheel near the point of contact with the rubber tired wheel.
- E. A means to feed the water at the rate shown in "Accelerated Polish Test Procedure" in such a way that the water is continuously and uniformly spread over the surface of the road wheel near the point of contact with the rubber tired wheel.

2. Metal Molds: The metal forming molds are shown in Figure 2. A number of accurately machine metal molds for preparing specimens of the dimensions specified in No. 4 - "Preparation of Test Specimen."

3. British Portable Tester: A friction measuring device shown in Figure 3. The British Portable Tester used shall conform to ASTM Designation E 303-66T with the following modifications:

- A. The slider contact path shall be $3" \pm 1/16"$.
- B. The slider width shall be 1 and $1/4"$.
- C. The rubber which is bonded to the slider shall conform to a $1/4"$ by 1" by 1 and $1/4"$ dimension.
- D. The rubber shall meet the requirements as specified in ASTM Specification E 249, for Standard Tire for Pavement Tests.
- E. The zero adjustment shall be checked before testing the fourteen specimens and after testing the specimens and as often as the operator deems necessary.

- F. Calibration procedures of ASTM E 303-66T shall be used; however, after calibration the small slider shall be inserted.

4. A supply of disposable cups and stirring rods for use in molding the specimens.

Materials:

1. Water: A supply of tap water to be spread on the road wheel during testing.

2. Fine Sand: A supply of fine sand for sifting in the aggregate interstices prior to the placement of the polyester bonding agent.

3. Mold Release Agent: A supply of polyester mold release agent used to prevent bond between the mold and polyester.

4. Silica Abrasives: A supply of approved coarse silica grit (70 to 140 sieve sizes*) and fine silica grit (No. 270 air-floated sieve size*) to be used as the polishing agents.

5. Polyester Bonding Agent: A supply of polyester resin and catalyst.

6. Coarse Aggregate: Approximately a one-half cubic foot supply of coarse aggregate to be tested. The aggregate shall be normal plant run and laboratory crushed material shall be tested.

Test Record Forms: Record test data on a appropriate work sheet.

Test Control: Three specially selected specimens shall be used for control and only these three specimens shall be used. The specimens shall be selected from those which have been previously polished for 9 hours conforming to the procedure herein established. The friction value (as determined from the British Portable Tester) of the specimens shall be in the following ranges:

Control Specimen # 1 - 10-20
Control Specimen # 2 - 20-30

Control Specimen # 3 - 30-40

The control specimens shall be tested with the British Portable Tester prior to measuring the polish stone values of the test specimens. Corrections to the polish value will be made on the basis of change in friction values found with the control specimens.

Preparation of Test Specimens:

1. The aggregate to be tested should pass the one-half inch sieve and be retained on the No. 4 sieve.

*ASTM Standard Sieves

2. Aggregate shall be clean and free of dust.
3. The mold shall be coated with an application(s) of mold release agent.
4. Each specimen shall consist of a single layer of particles and cover an area of 3.5" x 1.75".
5. The aggregate particles shall be placed as closely as possible in the molds with a flat surface against the bottom of the mold.
6. The interstices between the stones shall be filled with fine sand to 1/4 to 1/2 of the aggregate depth.
7. Weigh the polyester resin and catalyst into a disposable cup, add the resin to the catalyst and mix thoroughly. A mixture of 0.5 to 0.75 grams of catalyst to 50 to 57 grams of polyester resin yields sufficient material for one specimen and remains workable for 10 minutes.
8. The prepared mold is then filled to overflowing with the polyester bonding agent.
9. The consistency of the polyester should be such as to allow it to flow freely between the particles.
10. The mold is then left until the polyester has stiffened sufficiently to be struck off accurately, level with the curved sides of the mold.
11. The specimen is then left in the mold for three to four hours to allow sufficient hardening of the polyester in order that the specimen may be removed from the mold.
12. The excess sand is removed from the face of the specimen.
13. The specimen is then replaced in the mold for a curing period of four hours with a weight (conforming to the curved sides) on the mold to insure proper curvature of the specimen upon removal.

Accelerated Polish Test Procedure:

1. Determine the friction value of the control specimens for correction purposes as explained in the "Test Control" paragraph.
2. Determine the original friction number of the prepared test specimens as explained in ASTM Designation E 303-66T and modified by paragraph 3, "Apparatus."

3. Fourteen specimens shall be clamped around the periphery of the road wheel using rubber O-rings near the edges of the specimens.
4. The outer surface of the specimens shall then form a continuous strip of particles upon which the pneumatic-tired wheel shall ride freely without bumping or slipping.
5. The road wheel shall then be brought to a speed of 320 ± 5 revolutions per minute, and the pneumatic-tired wheel shall be brought to bear on the surface of the specimen with a total load of 88 ± 1 pounds.
6. Coarse silica grit shall be continuously feed at a constant rate of $25 \pm$ grams per minute for a period of 3 hours $\pm$ 5 minutes. Water shall be fed at the same rate as the coarse silica grit.
7. The coarse grit is then removed from the specimens and road wheel.
8. Fine silica grit shall be fed at a constant rate of 2 to 4 grams per minute for a period of 6 hours $\pm$ 5 minutes.
9. The specimens are then removed from the road wheel and washed thoroughly to remove grit.
10. Determine the friction value of the control specimens for correction purposes as explained in the "Test Control" paragraph.
11. After cleaning, the specimens shall be tested on the British Portable Tester to determine the "polish value" as explained in ASTM Designation E 303-66T and modified by paragraph, "Apparatus."

Silicon Carbide Abrasives

Nine hour tests were conducted on four molds.

<u>Before Polish</u>	<u>Polish Stone Value</u>	<u>Rock Type</u>	<u>Location</u>	<u>Producer</u>	<u>% Insoluble</u>	<u>L.A. Abrasion</u>
50.4	49.4	Sandstone	Onapa	H.D. Youngman	92	36
53.7	48.7	Qtz. Sdy. ls	Cherokee Co.	11-03 Ryder	45	54
50.1	45.8	Sandstone	Keota	H.D. Youngman	96	35
51.4	44.7	Qtz. Sdy. ls	Cherokee Co.	11-02 Qualls	25	40
46.9	42.9	Shale	Ranger, Tex.	Featherlite	-----	-----
49.6	42.7	Ls	Kenefic	Bryan Co. Ls Co.	1	37
46.0	42.2	Qtz. Sdy. ls	Sequoyah Co.	68-02 Smith Hollow	36	31
46.6	39.7	Sandstone	Cyril	Dolese	60	32
46.3	38.7	Gvl.	Broken Bow	Anderson-Dunhan	98	25
45.5	38.7	Ls	Bromide	Dolese	10	28
44.1	38.2	Gvl.	Canadian, Tex.	Kraft Mat.	99	28
44.0	37.4	Ls	Ft. Gibson	Arkholia	2	32
44.2	37.2	Ls	Richard's Spur	Dolese	6	26
42.9	36.9	Granite	Granite	Granite Sd. & Gvl.	99	-----
42.7	36.9	Gvl.	Baca. Co. Colo.	F & G Concrete	95	30
45.8	36.3	Ls	Gotebo (Abandoned)	Dolese	1	23
45.8	36.3	Ls	Pryor	Pryor Stone	3	30
46.9	36.1	Ls	Hartshorne	Dolese	23	25
47.0	36.0	Ls(Bad Sample)	Rayford	Dolese	40	23
43.8	36.0	Ls	Cooperton	Dolese	1	26

<u>Before Polish</u>	<u>Polish Stone Value</u>	<u>Rock Type</u>	<u>Location</u>	<u>Producer</u>	<u>% Insoluble</u>	<u>L.A Abrasion</u>
45.1	35.8	Ls	Bartlesville	Readi Mix	1	30
45.0	35.6	Dol.	Drumwirght	Quapaw	1	24
45.7	35.6	Ls	Tulsa	Anchor Stone	0	33
42.8	35.5	Ls	Big Canyon	Dolese	9	25
46.8	35.2	Ls	Nowata	Leco Mat.	7	26
40.0	34.5	Gvl.	McLean, Tex.	Western Sd. & Gvl.	87	29
37.4	34.1	Granite	Mill Creek	Century Granite	99	34
44.9	34.1	Ls	Burbank	Standard Ind.	2	31
39.6	33.8	Gvl.	Borger, Tex.	Western Sd. & Gvl.	98	----
42.7	33.7	Gvl.	Gore	Jeffries	98	19
46.1	33.7	Ls	Ardmore	Dolese	3	26
44.9	33.7	Ls	Coleman	Dolese	2	23
44.0	33.4	Ls	Davis	Sooner Rock	4	27
39.5	33.3	Gvl.	Tascosa, Tex.	Western Sd. & Gvl.	77	25
47.2	33.0	Ls	Wewoka	Capitol Mat.	-----	31
42.8	32.7	Ls	Pawhuska	Sadan Ls Co.	1	26
43.5	31.6	Ls	Konawa	Dolese	0	26
41.8	30.0	Gvl.	Asher	Corff Constr.	100	20
41.1	30.0	Chat	Pitcher	Eagle-Pitcher	95	21
42.7	29.7	Cherty ls	Stringtown	Trinity Concrete	73	20
41.4	28.9	Ls	Pawnee	M.E. Stewart	1	25
35.9	28.3	Gvl.	Hugo	Choctaw Mat.	99	25

Silica Abrasives

<u>Before Polish</u>	<u>Polish Stone Value</u>	<u>Rock Type</u>	<u>% Insoluble +200 Sieve</u>	<u>L.A. Abrasion</u>	<u>Location</u>	<u>Producer</u>
50.4	49.4	Sandstone	92	36	Onapa	H.D. Youngman ✓
54.2	46.8	Qtz. Sdy. ls	45	54	Cherokee Co.	11-03 Ryder ✓
49.9	44.4	Sandstone	96	35	Keota	H.D. Youngman ✓
53.0	42.6	Qtz. sdy. ls	25	40	Cherokee Co.	11-02 Qualls ✓
47.6	39.4	Ls	1	37	Kenefic	Bryan Co. Ls Co. ✓
46.1	39.3	Sandstone	60	32	Cyril	Dolese Bros. ✓
48.7	39.3	Qtz. sdy. ls	36	31	Sequoyah Co.	68-02 ✓
47.3	38.5	Gravel	98	25	Broken Bow	Anderson Dunhan ✓
46.0	38.8	Ls (Bad Sample)	40	23	Rayford	Dolese Bros. ✓
47.1	38.1	Ls	1	30	Bartlesville	Readi-Mix ✓
48.3	37.2	Ls	23	25	Hartshorne	Dolese Bros. ✓
51.0	36.9	Ls (Depleted)	1	23	Gotebo	Dolese Bros. ✓
47.1	36.4	Lightweight Shale	----	----	Ranger, Tex.	Featherlite ✓
45.7	36.0	Ls	3	30	Pryor	Pryor Stone ✓
50.3	36.0	Ls	10	28	Bromide	Dolese Bros. ✓

<u>Before Polish</u>	<u>Polish Stone Value</u>	<u>Rock Type</u>	<u>% Insoluble +200 Sieve</u>	<u>L.A. Abrasion</u>	<u>Location</u>	<u>Producer</u>
45.5	35.2	Ls	0	33	Tulsa	Anchor Stone ✓
43.7	35.1	Ls	9	25	Big Canyon	Dolese Bros. ✓
42.9	34.9	Qtz. Gravel	99	28	Canadian, Tex.	Kraft Mat. ✓
42.9	34.4	Qtz. Gravel	95	30	Baca Co.	F & G Concrete ✓
42.6	34.0	Ls	2	32	Ft. Gibson	Arkholia ✓
45.0	33.8	Ls	7	26	Nowata	Leco Mat. ✓
43.1	33.1	Chert	95	21	Miami	Eagle-Pitcher ✓
44.8	32.7	Gvl.	87	29	McLean, Tex.	Western Sd. and Gvl. ✓
42.4	32.8	Granite	99	----	Granite	Granite Sd. and Gvl. ✓
42.8	32.6	Granite	99	34	Mill Creek	Century Granite ✓
42.9	32.3	Ls	6	26	Richard's Spur	Dolese Bros. ✓
44.0	32.2	Ls	4	27	Davis	Sooner Rock ✓
42.9	32.2	Chert Gvl.	100	20	Asher	Corff Constr. ✓
41.3	32.0	Gvl.	77	25	Tascosa, Tex.	Western Sd. and Gvl. ✓
43.3	31.8	Cherty Ls	73	20	String town	Trinity Concrete ✓
42.4	31.8	Ls	1	26	Cooperton	Dolese Bros. ✓
41.4	31.7	Gvl.	98	-----	Broger, Tex.	Western Sd. and Gvl.
44.9	31.1	Ls	0	26	Konawa	Dolese Bros.
40.3	31.0	Gvl.	98	19	Gore	Jeffries
42.6	30.7	Ls	1	26	Pawhuka	Sedan Ls

<u>Before Polish</u>	<u>Polish Stone Value</u>	<u>Rock Stone</u>	<u>% Insoluble +200 Sieve</u>	<u>L.A. Abrasion</u>	<u>Location</u>	<u>Producer</u>
46.5	30.6	Ls	2	23	Coleman	Dolese Bros.
44.6	30.1	Ls	3	26	Ardmore	Dolese Bros.
43.3	28.9	Dolomite	1	24	Drumwright	Quapaw
40.7	27.8	Ls	2	31	Burbank	Standard Ind.
35.5	27.5	Chert Gvl.	99	25	Hugo	Choctaw Mat.
47.9	27.8	Ls	----	31	Wewoka	Capital Mat.
41.9	26.1	Ls	1	25	Pawnee	M.E. Stewart

Tests were conducted on four molds with ^{American} English Rubber. Molds were introduced to silica abrasives (coarse) with the following gradation (retained on #70-13.79%, #100-34.62%, #140-39.1%, #200-11.04%, through 1.35%) for ⁹ ~~these~~ hours. After the coarse abrasives, the molds were subjected to six hours of silica abrasives (fine) which passes the #200 sieve and has about 15% pass the #270 sieve. The polished stone values (9 hours) correlated very closely with British emery and emery flour with six hours of polish.

Wet Moulds Correlation

7-16-71
English Rubber vs American Rubber

	English BPN	ave.	American BPN	ave.
2:19-01:1 (26)	27 26 26 26 26 *	26.0	31 30 29 29 29	29.8
6:67-01:3 (27)	30 29 29 28 28	28.3	31 30 30 30 30	30.2
2:38-01:2 (28)	27 27 27 27 27	27.0	31 30 30 29 29	29.8
1A:19-01:1 (29)	29 29 29 29 28	28.7	31 30 30 30 30	30.2
2:38-01:1 (30)	30 30 30 29 29	29.3	33 32 32 31 31	31.8
2A:16-01:1 (31)	31 31 31 31 30 *	30.7	33 33 33 32 32	32.2
3:50-02:1 (32)	33 33 33 33 32	32.7	38 37 36 36 36	36.6
3:15-01:2 (33)	34 33 33 33 32	32.7	37 36 36 35 35	35.6
3A:15-01:4 (34)	36 35 35 34 33	34.0	36 35 34 33 33	33.6
5:46-01:1 (35)	36 35 35 35 35 *	35.0	40 40 40 39 39	39.6
4:46-01:3 (36)	34 33 33 33 33	33.0	40 39 39 39 38	38.6
3A:07-01:3 (37)	38 38 37 37 36	36.7	41 40 40 40 39	39.6
4:31-01:2 (38)	40 40 40 39 39	39.3	45 44 44 44 44	44.2
4:31-01:1 (39)	40 40 40 40 39 *	39.7	44 43 43 43 43	43.2
6:31-01:3 (40)	42 42 42 41 41	41.3	45 45 44 44 44	44.2
5:31-01:3 (41)	41 41 40 40 40	40.0	45 44 44 44 44	44.2
4:31-01:4 (42)	41 41 41 40 40	40.3	45 45 45 45 45	45.0
6:31-01:1 (43)	42 42 42 42 41	41.7	46 45 45 45 45	45.0
4:08-01:3 (44)	43 43 43 43 42 *	42.7	48 48 48 48 48	48.0
5:08-01:4 (45)	45 45 45 45 45	45.0	50 50 49 50 49	49.3
6:08-01:2 (46)	45 45 44 44 44	44.0	49 48 48 48 48	48.0
#25 BPN (before)	25 25 25 24 24	24.4	26 25 25 25 25	25.0
#48 BPN (before)	36 35 35 34 34	34.3	39 38 38 38 38	38.0
#25 BPN (after)				
#48 BPN (after)				
13:08-01E:2 (50)	51 50 50 49 49 *	49.3	51 50 50 50 51	50.3
13:31-01:1 (47)				

OKLAHOMA DEPARTMENT OF HIGHWAYS
SPECIAL PROVISION
FOR
MINERAL AGGREGATES
PLANT MIX BITUMINOUS BASES & SURFACES

708-4(a)
9-1-73

The Standard Specifications, Edition of 1967, Section 708.01(a) is amended as follows:

Section 708.01 Mixtures for Asphalt Concrete

(a) Materials 2. Mineral Aggregate. (Change the first and second paragraphs as follows:) The mineral aggregate shall be composed of coarse aggregate, fine aggregate, and mineral filler.

The coarse aggregate shall be that part of the aggregate retained on the No. 10 sieve and shall consist of clean, tough, durable particles. It shall be practically free from clay, organic, or other injurious matter occurring either free or as a coating on the aggregate. At least 70 percent of all aggregate retained on the No. 4 sieve in the combined mix shall be crushed stone or mechanically crushed gravel having two or more fractured faces and shall contain less than 5 percent of flat, elongated, soft and disintegrated pieces. (See Note 1.) If necessary, as determined by the engineer, a washing operation shall be used to provide complete separation of all fines which may be stuck to the gravel prior to crushing.

NOTE 1. A flat or elongated piece is one in which the length is greater than 5 times the average thickness.

When used in the wearing course, shoulders excepted, the coarse aggregate shall contain not less than 30% insoluble residues. Aggregate sources and percentage of blends must be approved on a project basis by the Materials Engineer. Because of performance history and/or known characteristics of certain aggregates, the Materials Engineer may determine that an approved anti-stripping agent will be required as part of certain mixes.

708.01(d) Sampling and Testing (Add) Aggregate

Insoluble Residues - - - - - OHD L-25

OKLAHOMA DEPARTMENT OF HIGHWAYS
SPECIAL PROVISIONS
FOR
MIXTURES FOR ASPHALT CONCRETE

This Special Provision amends and where in conflict supersedes the applicable portion of Section 708.01 of the Standard Specifications, 1967 Edition.

(b) Composition of Mixtures

TABLE OF MIXTURES

Mixture	Type A	Type B	Type C
Asphalt	<u>Percent by Weight of Total Mix</u>		
Soluble in Solvent	3.6-6.5	4.4-7.5	4.4-7.5

Method of Test for
Total Insoluble Residue in Coarse Aggregate

6-29-70

OHD-L-25

cdh
JS

SCOPE: 1. This method of test is intended for the determination of acid insoluble material in aggregates used in asphaltic concrete.

APPARATUS: 2. The apparatus for this test will consist of the following:

- (a) Half-gallon jars
- (b) Hydrochloric Acid Technical Grade
- (c) Evaporating Dishes (Vycor 350 ml)

PROCEDURE: 3. (a) Crush sample so that all material is less than one-half inch.
(b) Split the sample to approximately 200 grams, weigh accurately, and place in clean, labeled half-gallon jar.
(c) Add 400 ml of water and slight excess of concentrated hydrochloric acid (approximately one ml. per gram of rock) over amount needed to react with available carbonate. Stir mixture over a period of days until all reaction ceases.
(d) Wash the insolubles free of excess ions by filling jar with tap water, allowing all of the material to settle (about 48 hours) and pour off the clear solution. Procedure is repeated three times.
(e) After the third wash cycle, wash the insolubles into an evaporating dish, dry at 100-105 °C and weigh.

REPORT: 4. Report insoluble residues as retained on the #200 sieve as percent of total sample used.



100

Run 1, 2, 3, 4, 5, 6, ~~7~~ comparison of values
derived from, emory, silicon carbide, and
silica abrasives.

Run 7 & 8 cherts

Run 9 & 10 ls.

Run 11 & 12 50%

Run 13 & 14 edges



mostly siliceous

used Run 1 Emery - 7 ls 07-01, 11-01, 15-01, 16-01, 19-01, 38-01, 45-01

used Run 2 silica 7 ls

used Run 3 silicon carbide 7 ls

used Run 4 Emery 4 ls & 3 ss 50-03, 67-01, 72-01, 74-01 & 08-01, 31-01, 446-01

used Run 5 silica 4 lb & 3 ss

used Run 6 silicon carbide 4 ls & 3 ss

used Run 7 silica 6 cherts & 75% density 45-01 + 100% density 12-01, 45-01, 58-01, 63-01, 01-01C, 01-01T

Run 8 silicon carbide 6 cherts & 75% density 45-01

Run 9 silica 7 ls 10-01, 38-02, 49-02, 50-01, 53-01, 57-01, & 57-02

Run 10 silicon carbide 7 ls

Run 11 silica 50% density cherts & 100% density 03-01 & 50% densities 61-01 (crushed faces) [63-01, 01-01T, 12-01, 58-01, 01-01C]

Run 12 silicon carbide same as Run 11 molds

Run 13 silica edges of aggregates 58-01, 03-01, 38-01, 11-01,
used. Edges 46-01, 31-01, & 45-01

Run 14 silicon carbide edges of aggregates
Last Run that Ron Wollman completed.

Run 15 silica Rounded chert gals. Also, baked shale &
Round Surfaces white bauxite. (2 molds) 2 molds ^{Newoka} 67-02
12-01, 45-01, 63-01, 01-01C, & 01-01T

Run 16 silicon carbide same as molds in 15

* Run 17 Blend 50% flat surfaces of 07-01, 08-01, 31-01,
used Blends 46-01, 45-01, and edges of 58-01 and 01-01C with
50% standard polish susceptible limestone
(Pawhuska). Graph 14

* Run #18 Blend 50% of 74-01, 61-01, 15-01, 72-01, 50-02,
used Blends 16-01, and 49-01 in molds with 50% standard limestone
Graph 14

Run #19 Make molds (100% flat faces) of 11-03, 68-02, 11-02, 35-02,
Edges and 35-01 and edges of 12-01 and 63-01 (no blends)

Run #20 silicon carbide same molds as in 19 ^{rounded edges.}

Run #21 Molds with edges of 01-01C, ^{rounded edges.} flat crushed faces of
edges 38-03, 59-01, 68-01, 02-01T, 03-01T, and 04-01T.

Run #22 silicon carbide Abrasives same molds as in 21.
Cahill started Run 23B

* Run #23 Blend 50% of 68-02, 11-02, 11-03, 35-02, baked
used Blends shale (Texas), 08-01, and 46-01 with 50% of Pawhuska
(all flat surfaces). Molds made by Jim. Graph #14

* Run #24 Blend 25% of 08-01, 45-01, 31-01, 46-01, 11-02, 11-03, and
No Good! 68-02 with 57-01 limestone (75%).
used 24R Graph #15

Run #25 Blend 25% of 07-01, 61-01, 15-01, 50-02, 74-01,

Run no 72-01, and shale with 75% of 57-01.
good cocked aggregates

Used 25 R Graph #15

Run #26 Make molds with gaps to form 50% void space and blend equally 08-01, 11-03, 31-01, 11-02, 68-02, 46-01, and shale with 57-01.
This will give 25% of each nonpolishing source to the total mold.

50% Voids

Run #27 Blend 50% of 12-01, 63-01, 01-01C, 01-01T, 58-01, and 45-01 with standard polishing limestone (all flat crushed faces).
Also, blend 75% of 45-01 with the limestone.
Compare with 50% density graphs. Graph 14

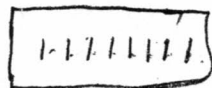
used

Run #28 Make molds with gaps to form 50% void space and blend equally 07-01, 61-01, 15-01, 50-02, 72-01, and 74-01 with 57-01; also, same type of mold with 50% void & 50% 57-01.

50% voids

Run #29 Make molds with 50% 58-01, 12-01, 03-01, 63-01, 45-01, 01-01C, and 01-01T edges and 50% 57-01 flat surfaces.

N W W V



edges in middle of mold.

Run #30 Make molds with 50% 07-01, 15-01, 11-01, 16-01 50-02, 72-01, and 74-01 edges with 50% 57-01 flats, surfaces.

Mike only
57-01

Run #31 Make molds with 50% voids & 50% 08-01, 11-02, 11-03, 31-01, 46-01, 68-02, and shale (all flat surfaces). (Compare with Run #23)

used Run # 24 Redid. Graph 15
Run # 25 Redid. " "

