15:12:17 OCA PAD AMENDMENT - PROJECT HEADER INFORMATION 06/11/91

Active

Project #: E-20-835 Cost share #: Rev #: 4
Center # : T5202-0A0 Center shr #: OCA file #: 90
Work type : PUB SER
Contract#: TASK ORDER 17/BOA DTD 871109 Mod #: LTR DTD 910604 Document : TO
Prime #: Contract entity: GTRC

Subprojects ? : Y CFDA:
Main project #: PE #:

Project unit: CIVIL ENGR Unit code: 02.010.116
Project director(s):
BARKSDALE R D CIVIL ENGR (404)894-6225

Sponsor/division names: GA DEPT OF TRANSPORTATION /
Sponsor/division codes: 300 / 035

Award period: 890103 to 911003 (performance) 911003 (reports)

Sponsor amount	New this change	Total to date
Contract value	0.00	133,216.00
Funded	0.00	133,216.00
Cost sharing amount		0.00

Does subcontracting plan apply ?: N

Title: EVALUATION OF AGGREGATE PROPERTIES OF RUTTING & FATIGUE OF ASPHALT CONCRETE..

PROJECT ADMINISTRATION DATA

OCA contact: Brian J. Lindberg 894-4820

Sponsor technical contact	Sponsor issuing office
PETER MALPHURS	LAMAR CAYLOR
(404)363-7510	(404)363-7537
GA DOT - OFF OF MATERIALS & RESEARCH	GA DOT - OFF OF MATERIALS & RESEARCH
15 KENNEDY DRIVE	15 KENNEDY DRIVE
FOREST PARK, GEORGIA 30050-2599	FOREST PARK, GEORGIA 30050-2599

Security class (U,C,S,TS) : U ONR resident rep. is ACO (Y/N): N
Defense priority rating : N/A N/A supplemental sheet
Equipment title vests with: Sponsor X GIT
HOWEVER, NONE PROPOSED OR ANTICIPATED.
Administrative comments -
LETTER DATED 6/4/91 FROM PETER MALPHURS AUTHORIZES EXTENSION OF PROJECT THROUGH OCTOBER 3, 1991.

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

NOTICE OF PROJECT CLOSEOUT

Closeout Notice Date 09/08/92

Project No. E-20-835 Center No. T5202-0A0

Project Director BARKSDALE R D School/Lab CIVIL ENGR

Sponsor GA DEPT OF TRANSPORTATION/

Contract/Grant No. TASK ORDER 17/BOA DTD 871109 Contract Entity GTRC

Prime Contract No.

Title EVALUATION OF AGGREGATE PROPERTIES OF RUTTING & FATIGUE OF ASPHALT CONCRE

Effective Completion Date 911003 (Performance) 911003 (Reports)

Closeout Actions Required:	Y/N	Date Submitted
Final Invoice or Copy of Final Invoice	Y	
Final Report of Inventions and/or Subcontracts	Y	
Government Property Inventory & Related Certificate	N	
Classified Material Certificate	N	
Release and Assignment	N	
Other	N	

Comments

Subproject Under Main Project No.

Continues Project No.

Distribution Required:

Project Director	Y
Administrative Network Representative	Y
GTRI Accounting/Grants and Contracts	Y
Procurement/Supply Services	Y
Research Property Managment	Y
Research Security Services	N
Reports Coordinator (OCA)	Y
GTRC	Y
Project File	Y
Other	N
	N

NOTE: Final Patent Questionnaire sent to PDPI.

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

NOTICE OF PROJECT CLOSEOUT (SUBPROJECTS)

Closeout Notice Date 09/08/92

Project No. E-20-835 Center No. T5202-0A0

Project Director BARKSDALE R D School/Lab CIVIL ENGR

Sponsor GA DEPT OF TRANSPORTATION/

Project # G-35-810 PD POLLARD C O JR Unit 02.010.140 T
TO # TASK ORDER 17/BOA DT MOD# MEMO DTD 900814E & A SCI *
Ctr # T5202-0A1 Main proj # E-20-835 OCA CO BJL
Sponsor-GA DEPT OF TRANSPORT / 300/035
EVALUATION OF AGGREG
Start 890103 End 901002 Funded 28,244.00 Contract 28,244.00

LEGEND
1. * indicates the project is a subproject.
2. I indicates the project is active and being updated.
3. A indicates the project is currently active.
4. T indicates the project has been terminated.
5. R indicates a terminated project that is being modified.

RESEARCH PROJECT PROGRESS REPORT
DEPARTMENT OF TRANSPORTATION
STATE OF GEORGIA

Report No. 1	Date: 7/7/89
Report Period: from Jan. 3, 1989 to June 30, 1989	

·oject No.	Project Title
-835 /GDOT8812	Evaluation of the Effects of Aggregate Properties on Rutting and Fatigue of Asphalt Concrete

:search Agency(s)	Project Director:
:orgia Institute of Technology :lanta, Georgia 30332	Richard D. Barksdale School of Civil Engineering; Georgia Inst. of Technology

:arting Date	Completion Date	Total Months	Time Expended: months, percentage
ıary 3, 1989	October 2, 1990	21	6 29%

ınding Sources(s)	Funds Authorized Total	Funds Expended Report Period	Funds Expended Total
HPR	$133,216	$17,800	$17,800

·oject Objectives, Status, Progress

ıjectives

1. To determine the basic properties of aggregates from a number of different quarries. Properties to be determined include aggregate shape, surface area, free mica, surface roughness, and petrographic analysis. The aggregates are to be classified and generalized relations between aggregate characteristics and density determined.

2. Develop optimum asphalt mix designs for each aggregate class selected. Surface, binder and bare mixes are to be included in the study. Both rutting and fatigue are to be considered in developing the mix designs.

:atus

The aggregate shape, surface area, free mica and petrographic studies are almost complete. Surface roughness measurements are presently underway.

·ogress This Report Period

Aggregate Shape and Surface Area - A digitalizing technique has been developed for measuring the aggregate shape and surface area. The technique uses a digitalizer tablet and an IBM-XT computer. A spreadsheet is used for analyzing the data and making plots. Typical results are included for examination. The method used to estimate surface area has been found to agree reasonably well with a more precise method based on sterology.

Free Mica - A new technique is being developed to separate the free mica from the other minerals. This approach involves the use of an electromagnetic separator developed by the minerals extraction industry. Since the electro magnetic separator removes all magnetic materials, corrections have to be made to the results. A visual comparison

ld additional sheets as needed

:oject Objectives, Status, Progress (Continued)

will be made of the percent of non-mica in the magnetic portion. Also a special chemical has been obtained from Germany that separates the fractions based on specific gravity. This technique will be experimented with hopefully to provide a further positive refinement to the quantification of free mica.

Surface Roughness - All aggregate samples have been cast in epoxy and sections through them cut with a diamond saw. The sections have been photographed. The photographs are presently being used to measure the surface roughness. Surface roughness at a magnification of about 20 times is planned to be used. It is felt that a lower magnification is not sufficient, while a higher magnification would emphasize minute surface roughness features to too great of a degree.

Petrographic Examination - Thin sections have been prepared and examinations of all aggregates submitted (except four) have been performed. In addition to the thin section specimens, a hand specimen has also been performed. X-ray diffraction tests will be performed on the very fine grained samples such as the limestones; these specimens are considered too fine-grained to give a meaningful petrographic analysis.

Final Design and Recommendations - No activity

Implementation - No activity

Final Report - No activity

ɔrk Planned for Next Report Period

Aggregate Property Tests - Complete the basic aggregate property tests and lassify aggregates by groups

Mix Design - Begin the asphalt mix design phase of the study

Implementation - No activity scheduled

Final Report - No activity scheduled

ecommendations

None at this time

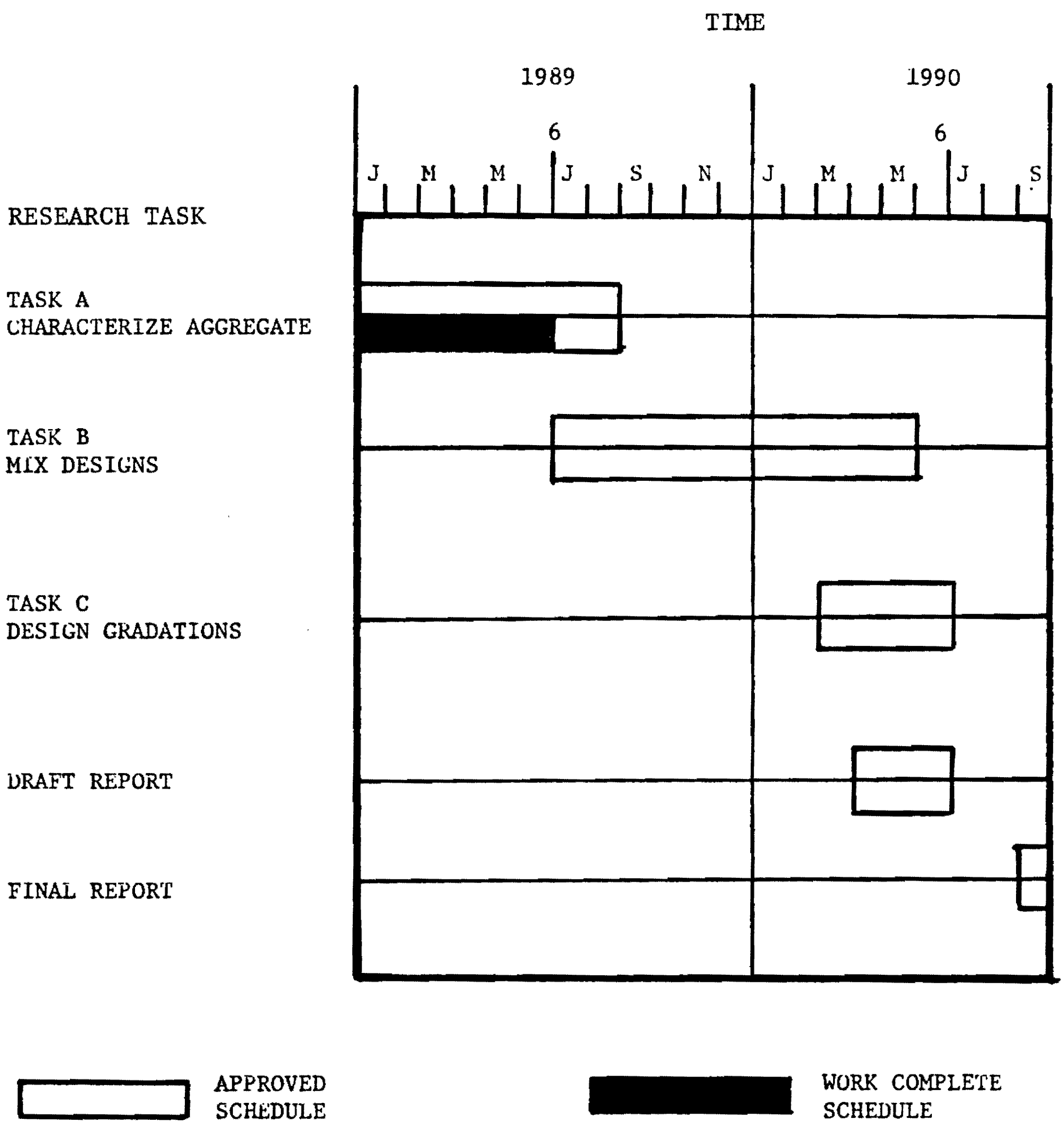
:oblems - None

Richard D. Barksdale
Project Director

WORK PLAN SCHEDULE

Evaluation of the Effects of Aggregate Properties on Rutting and Fatigue of Asphalt Concrete

GTRI Project No. E20-835



APPENDIX

Petrographic Examination Examples

Aggregate Shape and Surface Area Examples

ROCK DESCRIPTIONS

Sample Descriptions

ıple #	Description
ǀ-57A	Light colored medium grained granite with biotite disseminated throughout. Quartz and feldspars predominate although percentages vary. Quartz grains <5mm, Feldspars <10mm. Rare reddish brown rounded grains, possible garnet. Muscovite generally not distinguishable in hand specimen. Rock Type: Muscovite Biotite Granite
4-57A-1	Quartz 38% - Fractured grains ranging from 0.1-5mm. Feldspar 29% - Large, irregularly shaped grains up to 6 mm. Plagioclase 18% - Grains smaller than feldspars, 2-3 mm and less irregularly shaped. Biotite 10% - Occurs in clusters of crystals 1-2 mm in size. Little or no foliation noted. Muscovite 5% - Associated with the biotite clusters though not as common. Also occurs as very fine grained sericite associated with alteration of plagioclases.
4-57A-2	Quartz 18% - Occurs as very coarse grains, approximately 5 mm or much smaller grains of 0.5-1 mm. Large grains are often highly fractured. Feldspar 23% - Few grains present but those that are are relatively large, 3-4 mm. Plagioclase 50% - Medium to coarse grains, 1-5 mm, showing moderate alteration and some zonation. Biotite 8% - Medium grained, 1-2 mm, occuring in a few relatively large clusters. Muscovite 1% - Very highly eroded crystals approximately 1 mm in size associated with biotite.
.4-57A-3	Quartz 41% - Highly fractured medium to large grains 1-6 mm. Feldspar 17% - Anhedral crystals, few in number but relatively large 3-5 mm. Pericline twinning predominates with some Carlsbad. Plagioclase 33% - 2-3 mm crystals showing Albite twinning, often altered to sericite. Alteration concentrated in centers of crystals indicating some zoning of crystals. Biotite 9% - Crystals approximately 0.5 mm occur in clusters throughout the sample. Very small amounts of muscovite associated with these clusters along

with some sericite.

-57B Light colored medium grained with biotite throughout. Some samples show relatively high biotite content > 10%. There is some very light green staining possibly from the biotite weathering. Muscovite is present only in very small amounts.

Rock Type: Muscovite Biotite Granite

Dark gray to black, dark minerals > 60%, fine grained, thinly foliated. Foliation not perfect. Hornblende and biotite dominate.

Rock Type: Biotite Hornblende Amphibolite

-57B-1 Quartz 46% - Crystals range from 0.05-5 mm but avg 2-3 mm. Fracturing less intense than 014-57A but still present throughout.
Feldspar 21% - Occurs as small, irregular grains with occasional larger grains up to 2 mm.
Plagioclase 21% - Anhedral grains, 1-2 mm, showing zoned crystals whose centers are frequently fractured and altered to sericite along cleavage planes.
Biotite 6% - Crystals, <1 mm, occur in clusters sometimes associated with larger 2-3 mm muscovite and accessory calcite and hornblende.
Muscovite 4% - Larger crystals, 2-3 mm often associated with biotite clusters.
Epidote 1% - Occurs as single grains distributed sparsely throughout.
Opaque Trace

l-57B-2 Quartz 30% - Unfractured grains up to 0.2 mm but usually <0.1 mm. Size varies somewhat with location in sample, larger grains toward center.
Plagioclase 3% - Very small grains <2 mm dispersed throughout sample.
Hornblende 56% - Anhedral to euhedral crystals 0.02-0.5 mm. Some foliation defined by larger crystals in center of sample.
Biotite 11% - Crystals up to 0.5 mm help define foliation along with hornblende.

5-57A Light colored fine to medium grained. Biotite content varies widely within sample from < 5% to about 15%. High biotite samples exhibit good foliation and schistose texture, low biotite samples show no foliation and granitic texture. Hornblende content varies between 0-20%. Substantial muscovite content in several samples. Some samples show contact between rock types.

Rock Type: Biotite Granite
Biotite Hornblende Granite
Biotite Schist

-57A-1

Quartz 38% - Anhedral, unfractured grains <1 mm.
Feldspar 24% - Anhedral grains showing polysynthetic twinning, up to 2mm located primarily at one end of sample
Plagioclase 27% - Small to medium size grains 0.5-2 mm, albite twinned, present throughout sample.
Biotite 4% - Present throughout sample in very small laths, <0.5 mm.
Muscovite 7% - Uncommon but relatively large grains, 1-2 mm, with some embayed grains present.

-57A-2

Quartz 45% - Anhedral, unfractured grains <1 mm, similar to 015-57A-1 but with higher percentage of
er grains.
Feldspar 20% - Irregularly shaped grains disseminated throughout showing polysynthetic twinning.
Plagioclase 28% - Small to medium sized grains 0.5-2 mm showing pericline twinning and less ordered albite twinning.
Biotite 7% - More abundant and slightly larger grains than 015-57A-1 but with very rare muscovite.
Epidote Trace.

-57A-3

Quartz 36% - More common on one half of slide, <1 mm rounded grains.
Plagioclase 30% - Small to medium sized grains 0.5-2 mm showing albite twinning.
Hornblende 20% - Present throughout but much more common in dark half of slide. Small to medium grains 0.5-2 mm.
Biotite 11% - Present throughout but concentrated along with the hornblende.
Opaques 3% - Fine grained 0.05-0.5 mm present primarily in dark half of sample.

5-57B

Light colored fine to medium grained quartz rich with some accessory pyrite and garnet. Biotite content varies considerably from 1-10%. Biotite rich samples show some foliation. One biotite rich sample contained approximately 5% of a light green glassy mineral, possibly epidote. Others show same as rare grains. Some samples contain significant hornblende, up to 20%.

Rock Type: Biotite Granite
Biotite Hornblende Granite

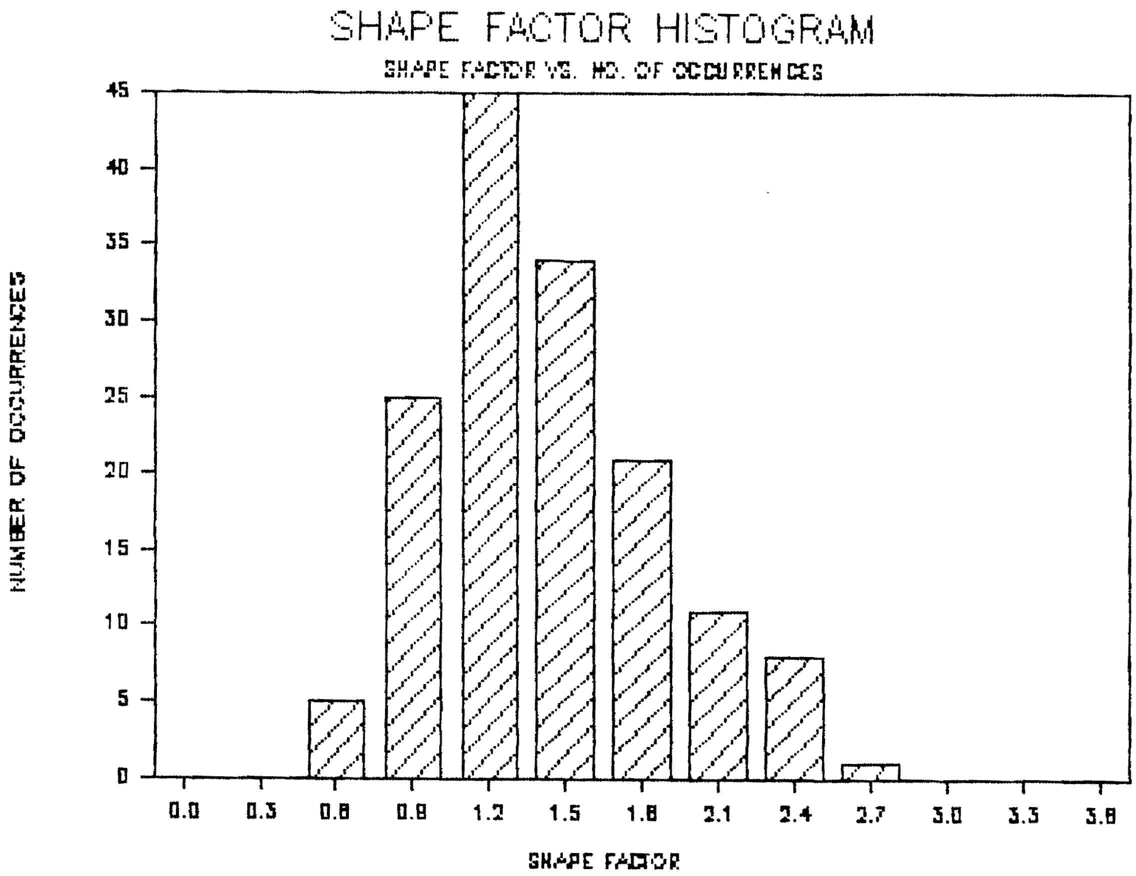
AGGREGATE SHAPE AND SURFACE AREA

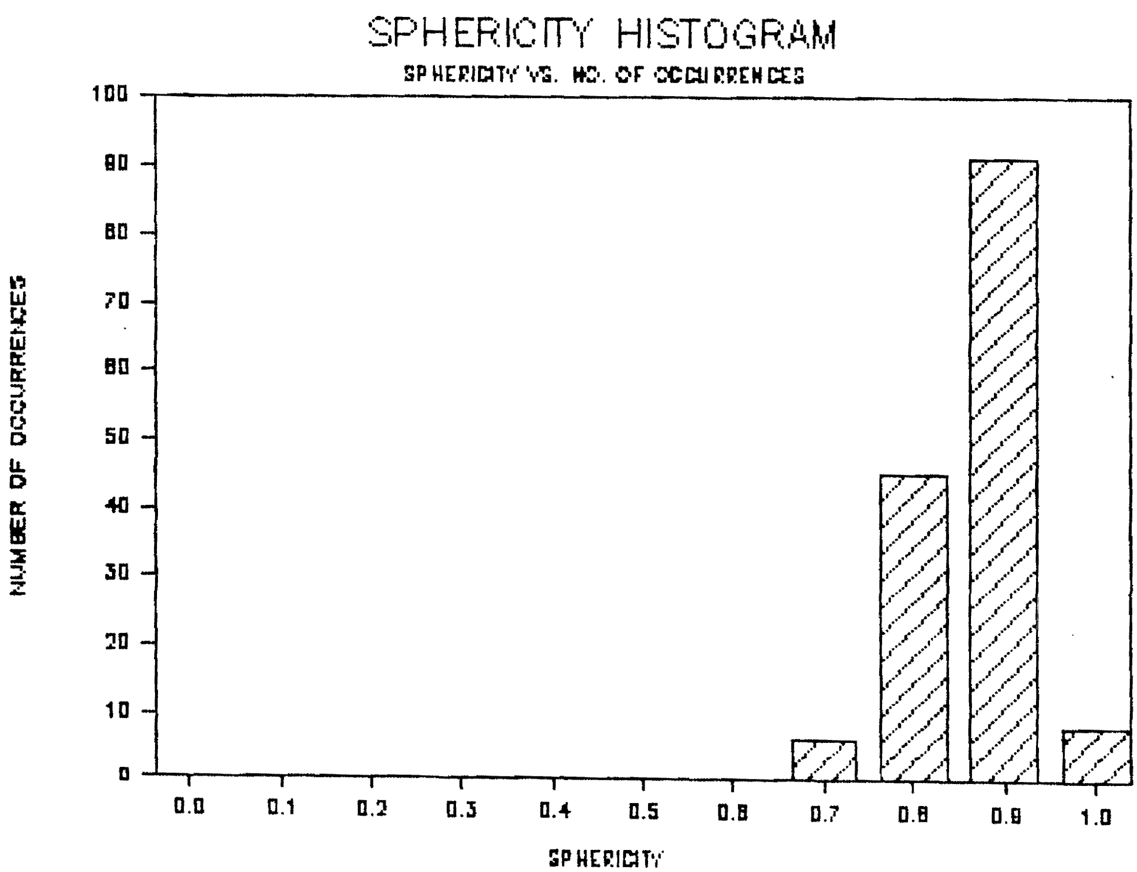
Florida Rock Industries
(GADOT Quarry No. 015)

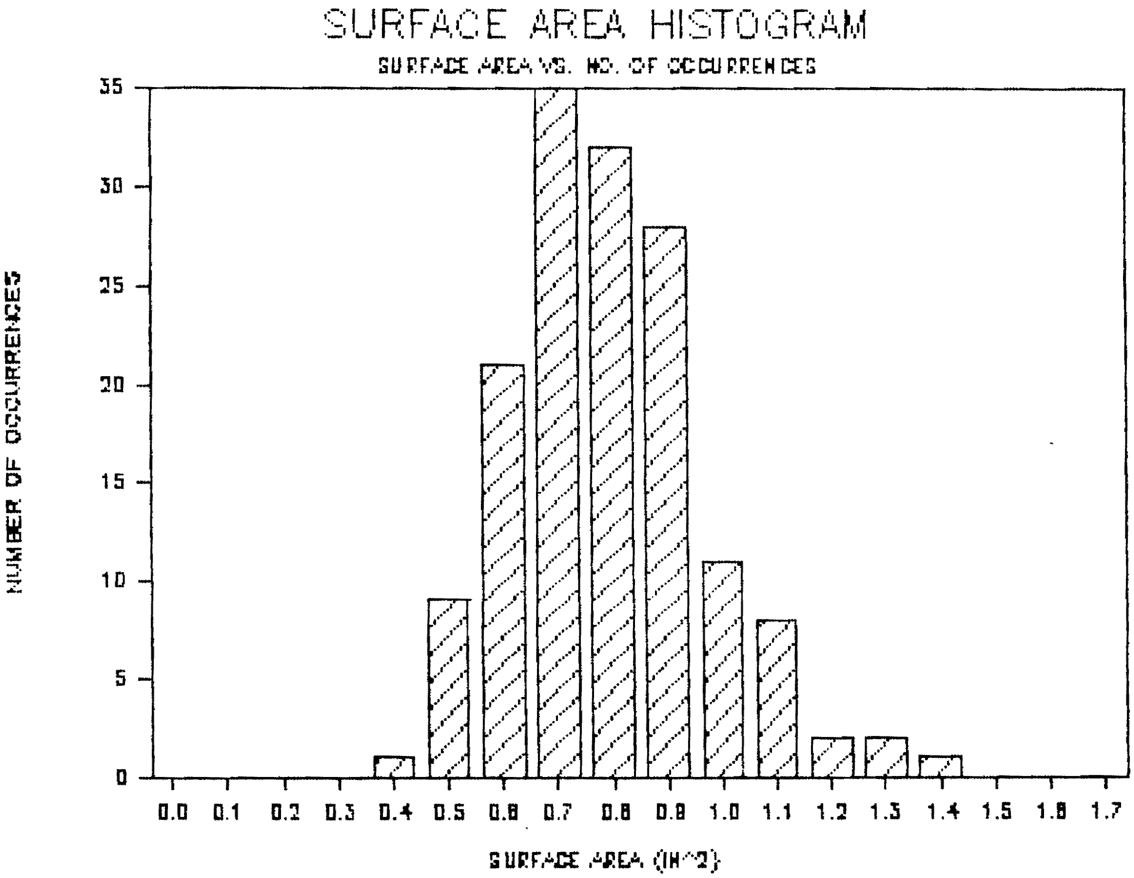
A Sample

-1/2 to +3/8 Size

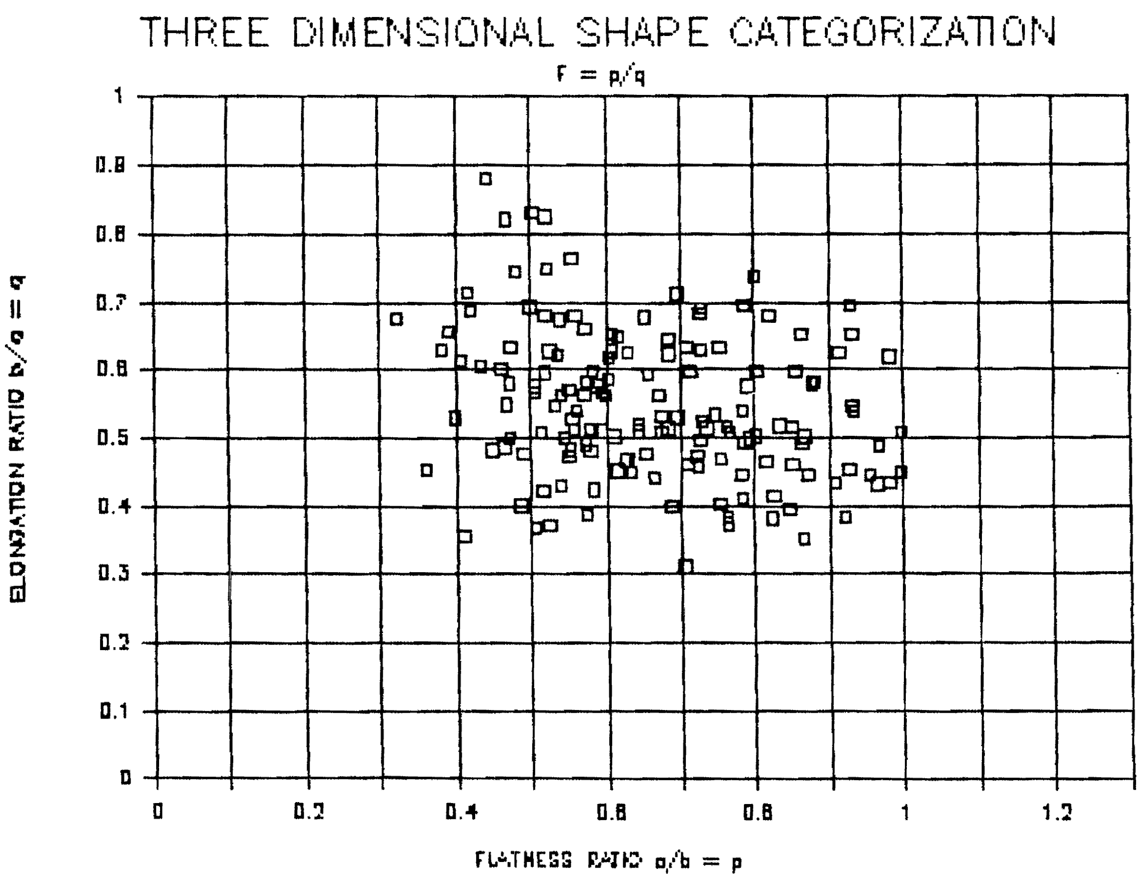
Aggregate


SHAPE FACTOR HISTOGRAM
SHAPE FACTOR VS. NO. OF OCCURRENCES
NUMBER OF OCCURRENCES
0
5
10
15
20
25
30
35
40
45
0.0
0.3
0.6
0.9
1.2
1.5
1.8
2.1
2.4
2.7
3.0
3.3
3.6
SHAPE FACTOR


SPHERICITY HISTOGRAM
SPHERICITY VS. NO. OF OCCURRENCES
NUMBER OF OCCURRENCES
0
10
20
30
40
50
60
70
80
90
100
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
SPHERICITY



SURFACE AREA HISTOGRAM
SURFACE AREA VS. NO. OF OCCURRENCES
NUMBER OF OCCURRENCES
0
5
10
15
20
25
30
35
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7
SURFACE AREA (IN^2)



THREE DIMENSIONAL SHAPE CATEGORIZATION
F = p/q
ELONGATION RATIO b/a = q
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
0.2
0.4
0.6
0.8
1
1.2
FLATNESS RATIO c/b = p

AGGREGATE SHAPE AND SURFACE AREA

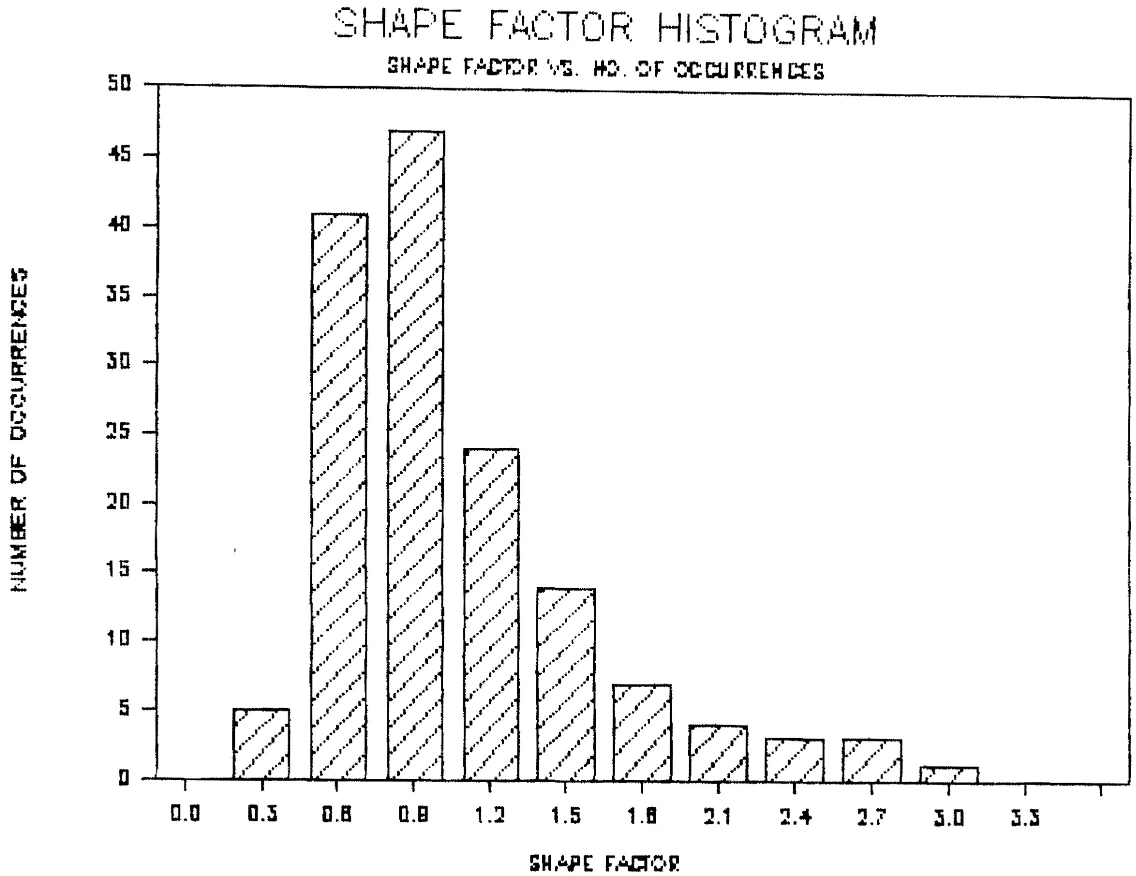
Florida Rock Industries

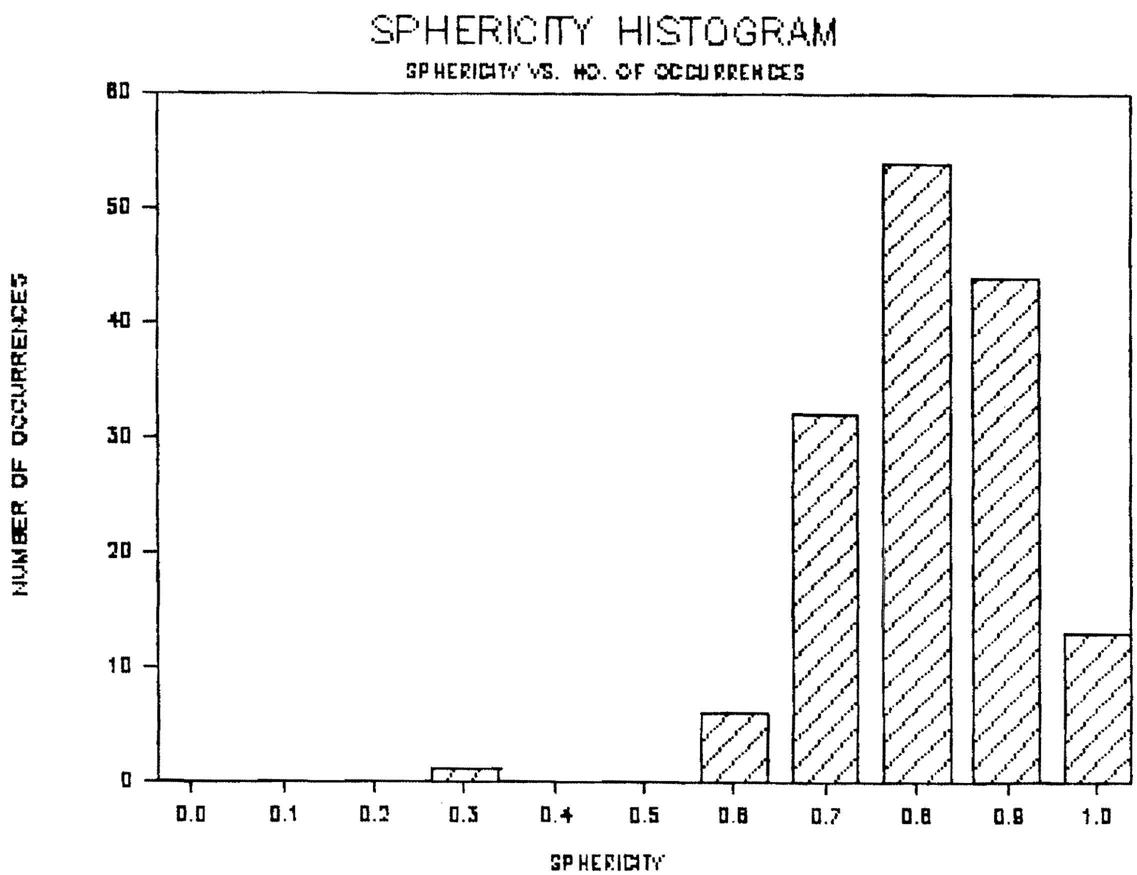
(GADOT Quarry No. 015)

A Sample

-No. 4 to +No. 8

Aggregate


SHAPE FACTOR HISTOGRAM
SHAPE FACTOR VS. NO. OF OCCURRENCES
NUMBER OF OCCURRENCES
50
45
40
35
30
25
20
15
10
5
0
0.0
0.3
0.6
0.9
1.2
1.5
1.8
2.1
2.4
2.7
3.0
3.3
SHAPE FACTOR


SPHERICITY HISTOGRAM
SPHERICITY VS. NO. OF OCCURRENCES
NUMBER OF OCCURRENCES
60
50
40
30
20
10
0
0.0
0.1
0.2
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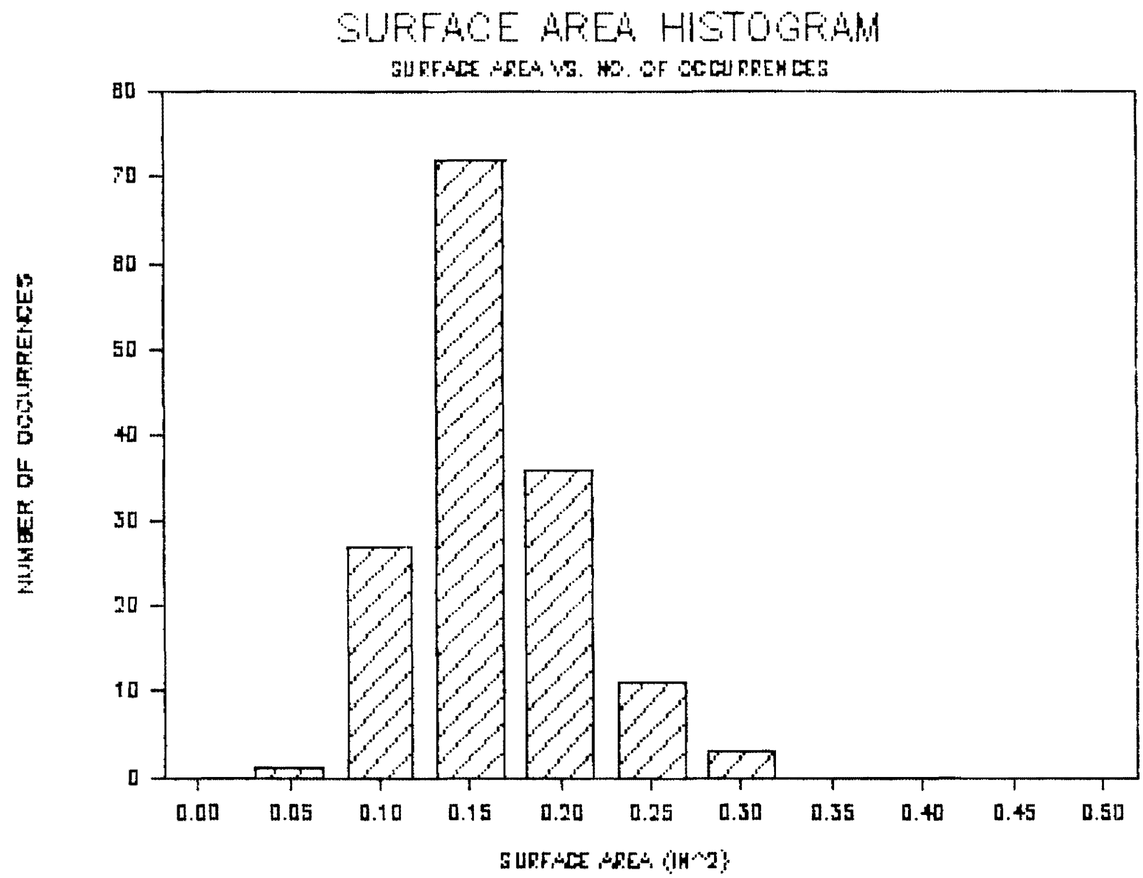
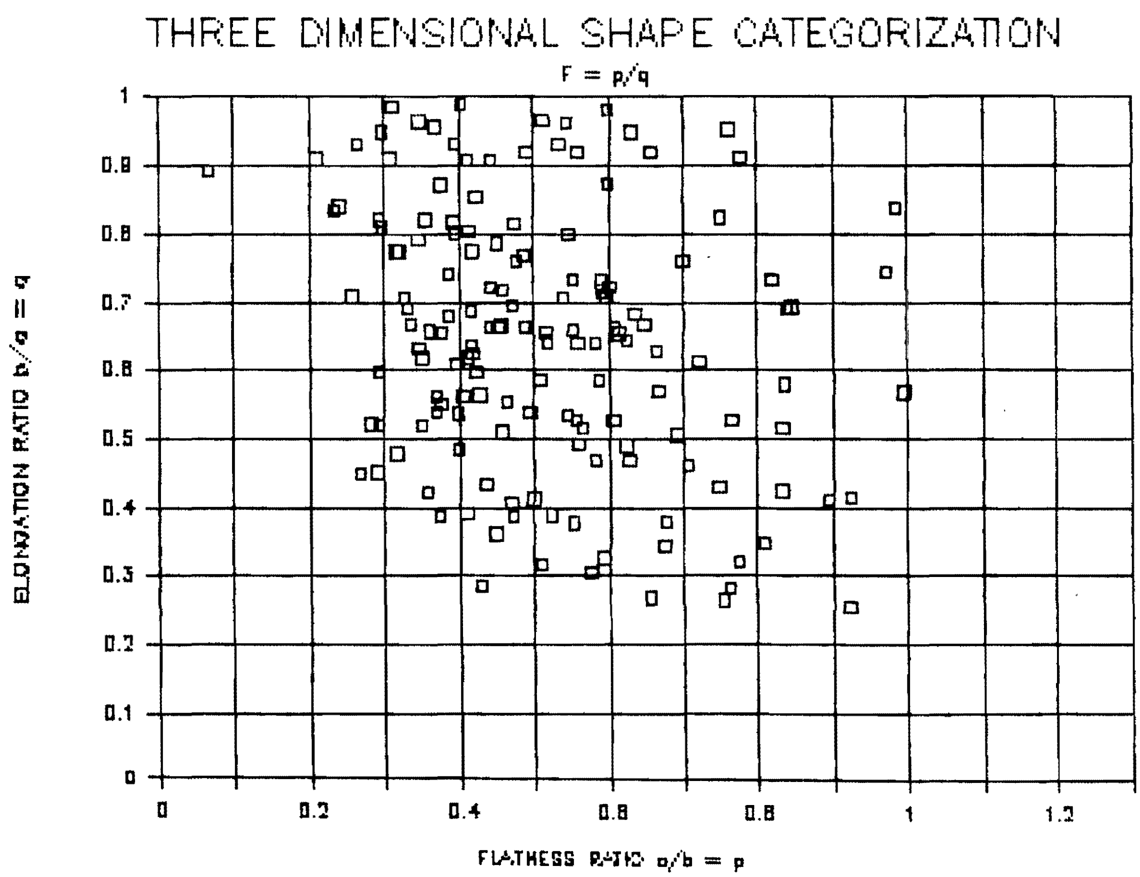
0.4
0.5
0.6
0.7
0.8
0.9
1.0
SPHERICITY


SURFACE AREA HISTOGRAM
SURFACE AREA VS. NO. OF OCCURRENCES
NUMBER OF OCCURRENCES
SURFACE AREA (IN^2)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50


THREE DIMENSIONAL SHAPE CATEGORIZATION
F = p/q
ELONGATION RATIO b/a = q
FLATNESS RATIO c/b = p

RESEARCH PROJECT PROGRESS REPORT DEPARTMENT OF TRANSPORTATION STATE OF GEORGIA	Report No. 2 Date: 1/11/90 Report Period: from July 1, 1989 to Jan. 31, 1990

ɔject No.	Project Title
35/GaDOT 8812	Evaluation of the Effects of Aggregate on Rutting and Fatigue of Asphalt Concrete

ɛearch Agency(s)

Georgia Institute of Technology
Atlanta, Georgia 30332

Project Director: Richard D. Barksdale
School of Civil Engineering
Georgia Tech

ɪrting Date	Completion Date	Total Months	Time Expended: months, percentage
anuary 3, 1989	October 2, 1990	21	12 months; 57%

nding Sources(s)	Funds Authorized Total	Funds Expended Report Period	Funds Expended Total
HPR	$133,216	$39,277	$57,077 (43%)

oject Objectives, Status, Progress

jectives

1. To determine the basic properties of aggregates from a number of different quarries. Properties to be determined include aggregate shape, surface area, free mica, surface roughness, and petrographic analysis. The aggregates are to be classified and generalized relations between aggregate characteristics and density determined.
2. Develop optimum asphalt mix designs for each aggregate class selected. Surface, binder and bare mixes are to be included in the study. Both rutting and fatigue are to be considered in developing the mix designs.

Status

The aggregate shape, surface area, free mica and petrographic studies are now complete. Significant progress has been made on determining the Talbot gradation (n-value) that gives maximum dry density. Tests are being performed on selected aggregates from each tentative grouping for both the surface and base mix sizes.

A general Lotus macro has been developed for analyzing all data for placing each quarry into a grouping. General grouping requirements were established at the September 7 meeting with the Georgia DOT. Free mica work was just completed in late December and this data is now being prepared for input into the macro.

The sliding plate, wheel tracking rutting device is now operational and works very well. Molds have been fabricated and procedures developed to prepare 3-1/2 in. thick, 5 in. wide by 10 in. long specimens. Routine testing of beams in rutting is now ready to begin.

dd additional sheets as needed

Progress This Report Period

Aggregate Shape and Surface Area - Measurements were completed for all size ranges and the results put into a macro written for Lotus 1-2-3. Variability of shape and surface area results was found to be greater for the two finer aggregate sizes.

Free Mica - The original mica contents originally determined by magnetic separation have now been corrected. Glass slides were made of representative samples from both the magnetic and non-magnetic portions of separated material. Counts were then made to determine the percent minerals in each fraction which should not be present. Considering only actual totally free mica in the two coarse sizes will give significantly smaller percent mica than originally reported.

Surface Roughness - Surface roughness measurements were completed during this report period.

Petrographic Examination - The petrographic examination was completed during this report period. These results will be given to the Georgia DOT at the next meeting.

Maximum Density - The gradation which gives maximum density is being determined using primarily a vibrating table. Optimum Talbot's n-values have been developed for aggregates from most of the projected groups for surface mix gradations. The Talbot n-value is typically between 0.4 and 0.50. A few type aggregates, however, appear to have optimum n-values less than 0.4 which result in a gradation with a quite high fines content.

Rutting Test - The rutting apparatus has been developed and sample preparation procedures established. Production work will begin on rutting early in January, 1990.

Fatigue Test - A computer program was written to predict the fatigue behavior of each asphalt mix.

Diametral Test - The apparatus was developed during this report period and the electronics are presently being installed.

Final Design and Recommendations - No Activity.

Final Report - Significant work was accomplished in getting the aggregate properties data into a form suitable for the final report.

Work Planned for Next Report Period

Group Quarries - Finish the classification system and place each quarry in a group. A meeting with the Georgia DOT will be held as soon as this is completed.

Rutting Tests - Begin the production wheel tracking rutting tests. Develop optimum gradation for rut resistance from rut test results.

Diametral Tests - Begin production testing for resilient modulus.

Fatigue Tests - Begin fatigue tests for selected materials and gradations.

Implementation - No Activity Scheduled.

Final Report - No Activity Scheduled.

Recommendations

None at this time

Problems

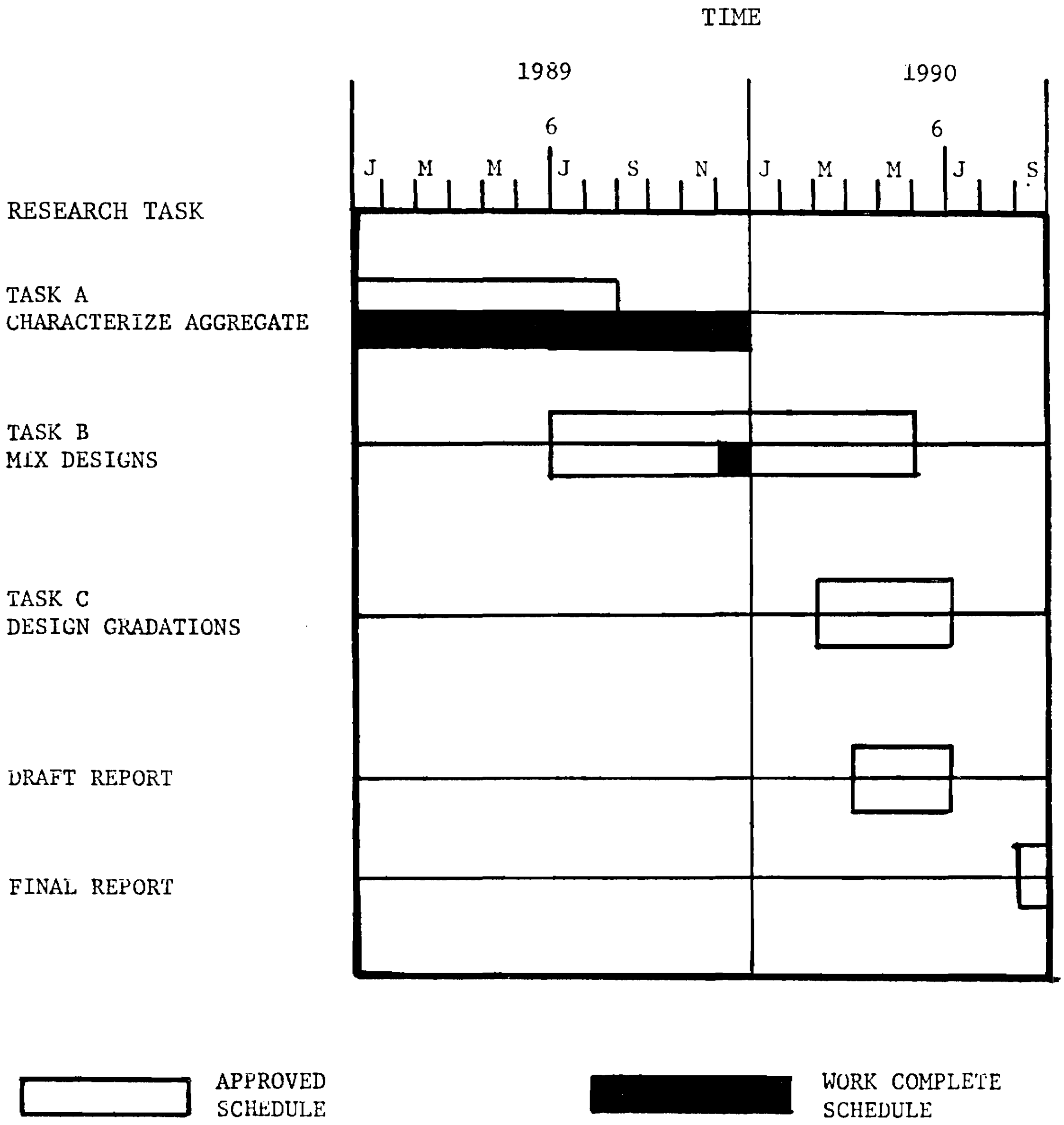
No significant problems to report at this time.

Richard D. Barksdale
Project Director

WORK PLAN SCHEDULE

Evaluation of the Effects of Aggregate Properties on Rutting and Fatigue of Asphalt Concrete

GTRI Project No. E20-835



RESEARCH PROJECT PROGRESS REPORT DEPARTMENT OF TRANSPORTATION STATE OF GEORGIA		Report No. 3 Date: 7/3/90 Report Period: from Jan. 1, 1990 to June 30, 1990	
oject No. 35/GaDOT 8812	Project Title	Evaluation of the Effects of Aggregate on Rutting and Fatigue of Asphalt Concrete	
search Agency(s) rgia Institute of Technology anta, Georgia 30332		Project Director: Richard D. Barksdale School of Civil Engineering Georgia Tech	
arting Date . 3, 1989	Completion Date Oct. 2, 1990	Total Months 21	Time Expended: months, percentage 18 months; 86%
nding Sources(s) HPR	Funds Authorized Total $133,216	Funds Expended Report Period $19,005	Total $76,113 (57%)

oject Objectives, Status, Progress

Objectives

1. To determine the basic properties of aggregates from a number of different quarries. Properties to be determined include aggregate shape, surface area, free mica, surface roughness, and petrographic analysis. The aggregates are to be classified and generalized relations between aggregate characteristics and density determined.

2. Develop optimum asphalt mix designs for each aggregate class selected. Surface, binder and base mixes are to be included in the study. Both rutting and fatigue are to be considered in developing the mix designs.

Status

The focus of work on the project shifted during this report period from measuring aggregate properties to evaluating rutting of asphalt mixes. Approximately 54 beam specimens were tested for rutting during this semi-annual report period.

Rutting Resistance - Almost all of the rutting tests were performed on specimens prepared using the standard Georgia DOT mix design gradations. Comparisons with "improved" gradations were made only for base mixes for White and Kennesaw material. Both the coarser and finer improved White base mixes performed significantly better than did the standard Georgia DOT mix design (Table 1). The finer improved gradation mix for Kennesaw, however, did not do as well as for the standard gradation. Rutting tests on the coarser improved mix will be performed as soon as more Kennesaw large size aggregate is received.

Fatigue Resistance - The microcomputer program for calculating fatigue life was made operational. This program is written in BASIC language and uses the methods of the Asphalt Institute and the University of Nottingham for predicting fatigue life. For the White base mix, the coarse and fine improved gradation mixes both had fatigue lives reasonably close to the standard Georgia DOT mix as summarized

l additional sheets as needed

in Table 2. The coarse improved gradation, as previously discussed, showed a marked improvement in rut resistance. Probably great difficulty would be encountered in developing a mix with improved rut resistance that at the same time has better fatigue resistance. The very small reduction in fatigue life of the coarse gradation, improved White mix compared to the standard mix is not considered to be significant.

The fatigue resistance value given above is the fatigue life in terms of repetitions of load for an applied strain of $200x10^{-6}$ in./in. These numbers are the average of four theoretically calculated values using (1) two different theoretically calculated stiffness values and (2) two different methods for predicting fatigue life. Theoretical fatigue lives for most of the asphalt mix design received from the Georgia DOT have now been calculated. A limited number of laboratory fatigue tests are also being conducted.

Diametral Test - The diametral test apparatus was calibrated and put into routine operation during this report period. Resilient moduli are now being evaluated for the mixes.

Planned Work Next Quarter

1. Continue testing for rut resistance standard Georgia DOT mix designs. Begin testing routinely the improved gradation mixes. To accomplish this we will have to be supplied with improved mix designs more rapidly than in the past.

2. Continue to perform diametral tests on a routine basis. Also perform a limited series of fatigue tests to compare theory with laboratory performance.

WORK PLAN SCHEDULE

Evaluation of the Effects of Aggregate Properties on Rutting and Fatigue of Asphalt Concrete

GTRI Project No. E20-835

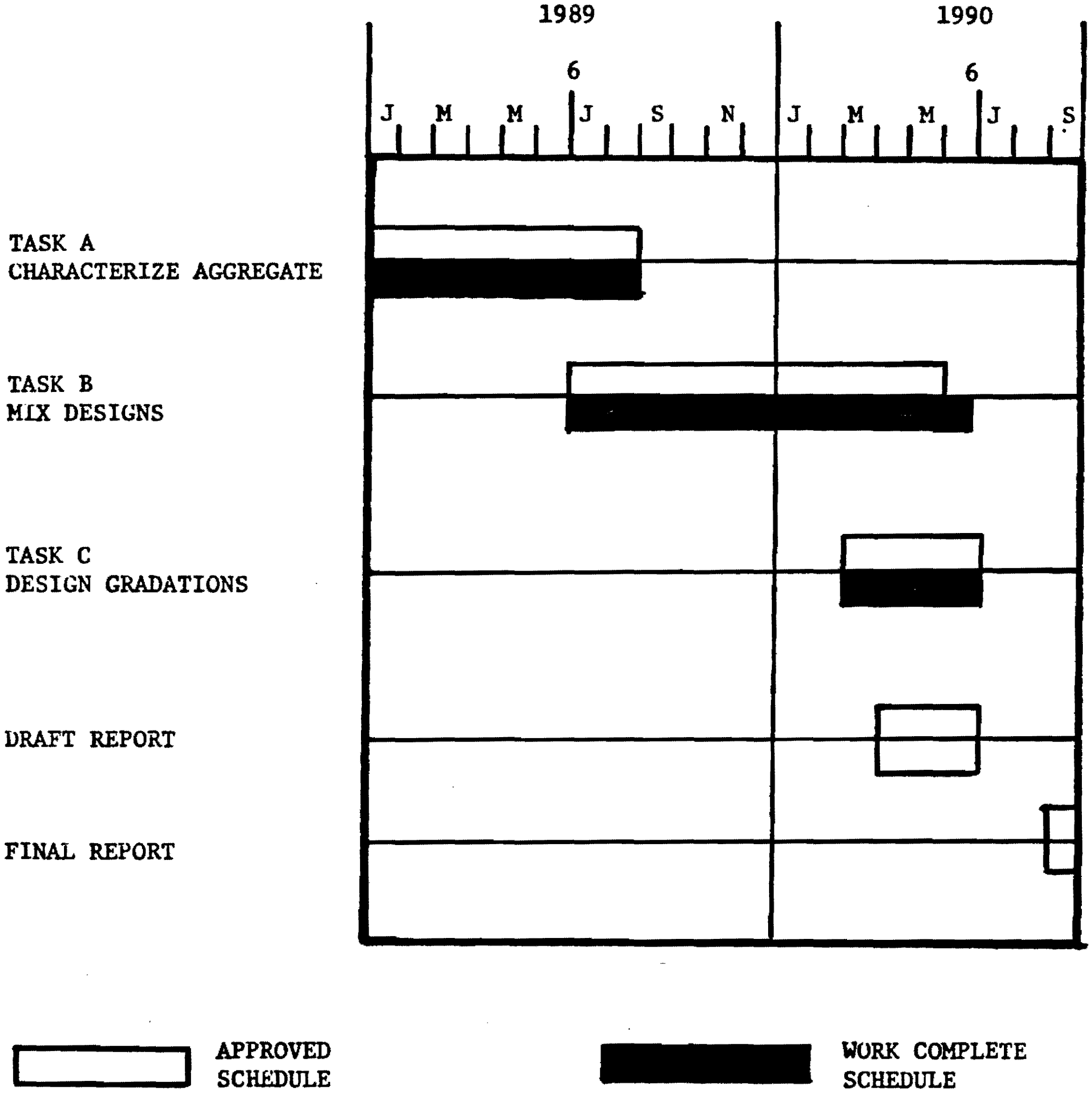


Table 1. Comparison of Rutting Performance for Standard Georgia DOT Mix Design with Trial Improved Gradations

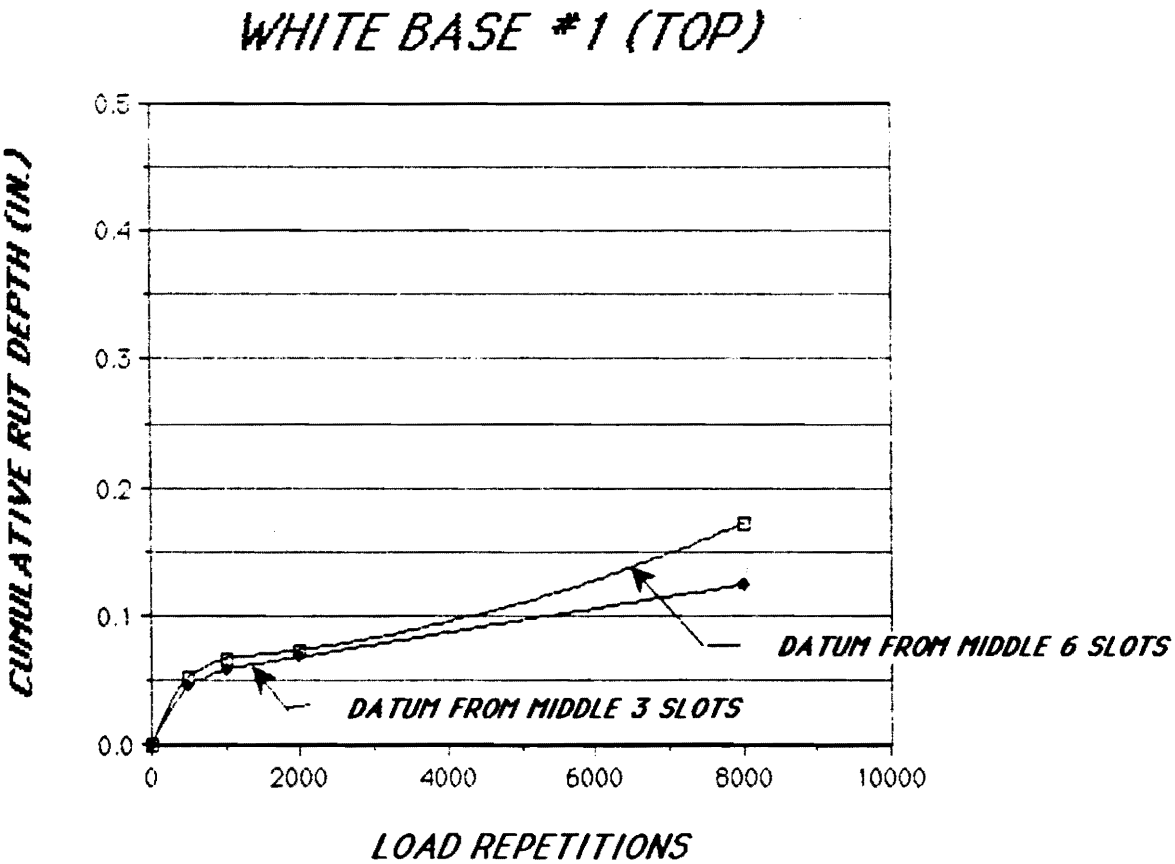
Base Source	Gradation	Wheel Load Tester Rutting Avg. of 2 or 3 tests (load repetition)
1. White	Standard GA DOT	0.138
	Improved Coarse	0.070
	Improved Fine	0.072
2. Kennesaw	Standard GA DOT	0.094
	Improved Fine	0.133

Table 2. Theoretical Fatigue Resistance

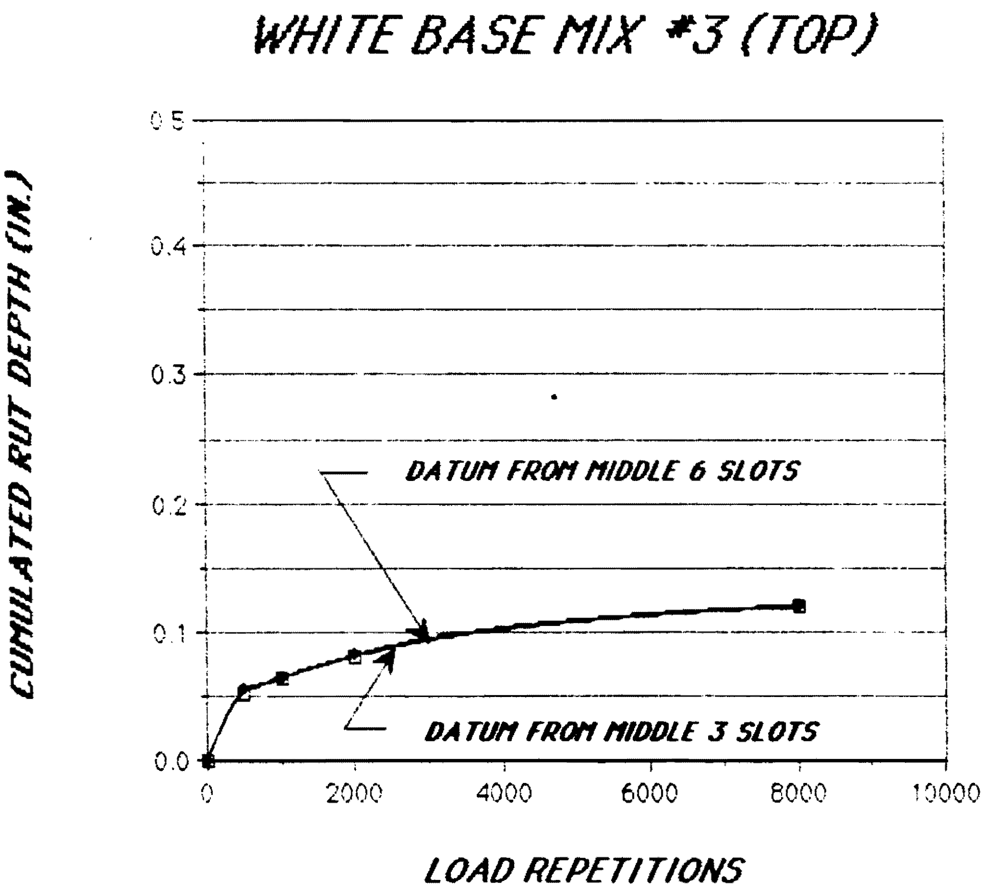
Base Mix	Gradation	Average Fatigue Life (inches)
White	GA DOT	1,209,000
	Improved Coarse	1,064,000
	Improved Fine	994,000

Appendix A

Selected Rutting Test Results

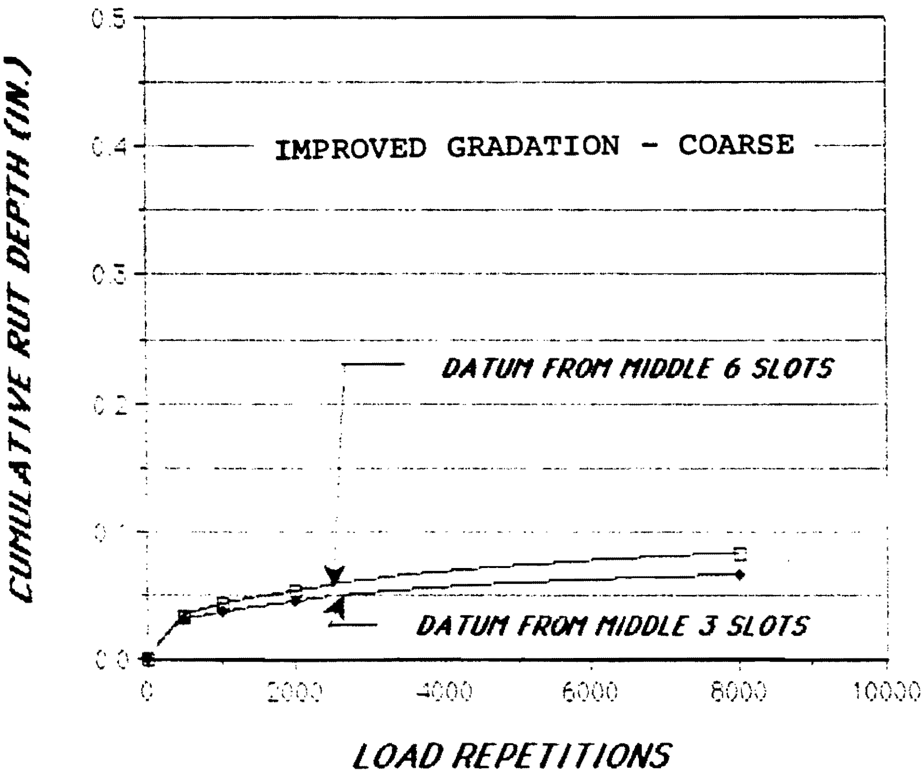


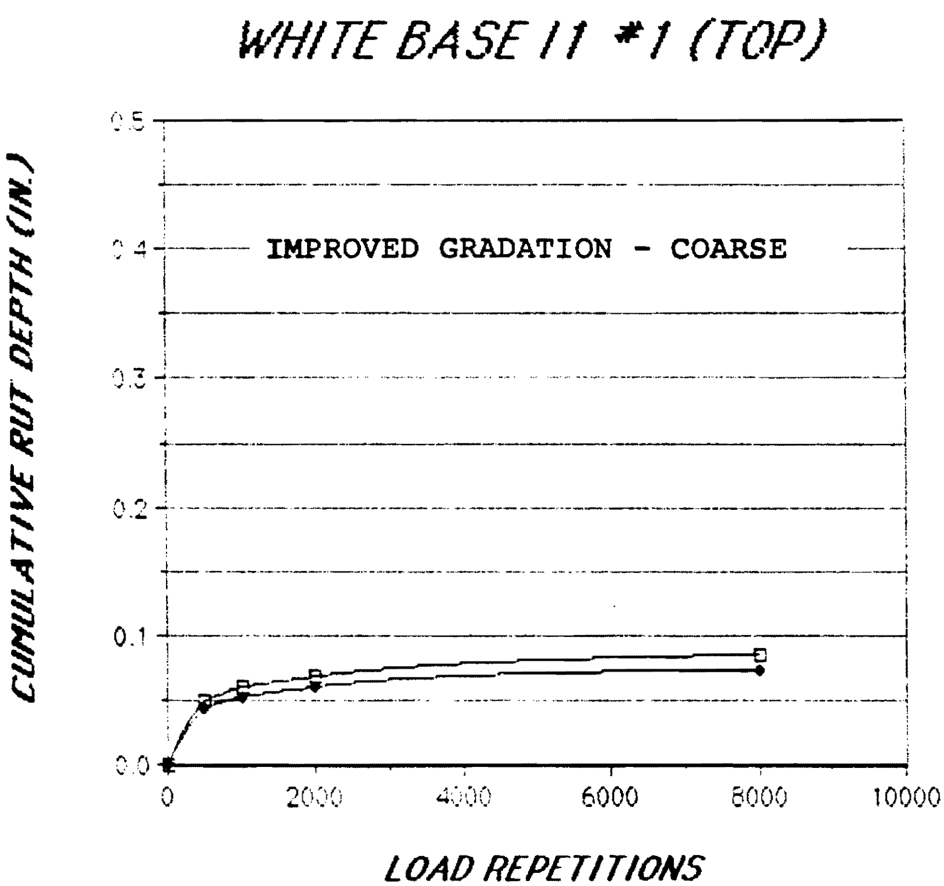
WHITE BASE #1 (TOP)
0.5
0.4
0.3
0.2
0.1
0.0
0
2000
4000
6000
8000
10000
CUMULATIVE RUT DEPTH (IN.)
LOAD REPETITIONS
DATUM FROM MIDDLE 6 SLOTS
DATUM FROM MIDDLE 3 SLOTS



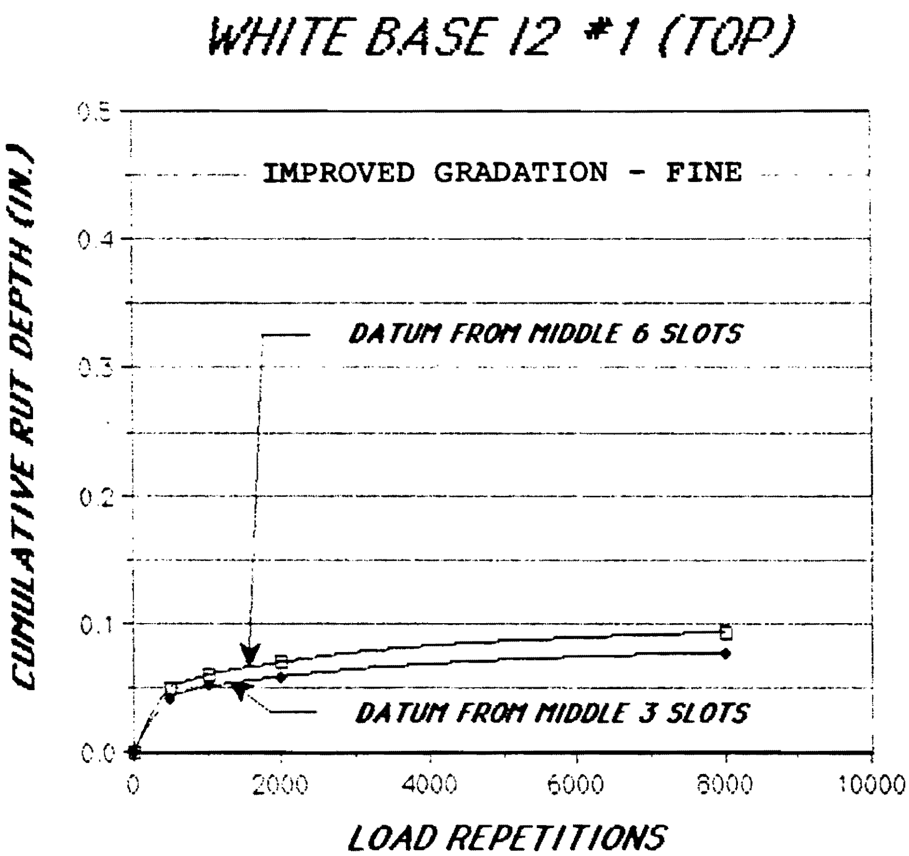
WHITE BASE MIX #3 (TOP)
CUMULATED RUT DEPTH (IN.)
0.5
0.4
0.3
0.2
0.1
0.0
0
2000
4000
6000
8000
10000
DATUM FROM MIDDLE 6 SLOTS
DATUM FROM MIDDLE 3 SLOTS
LOAD REPETITIONS

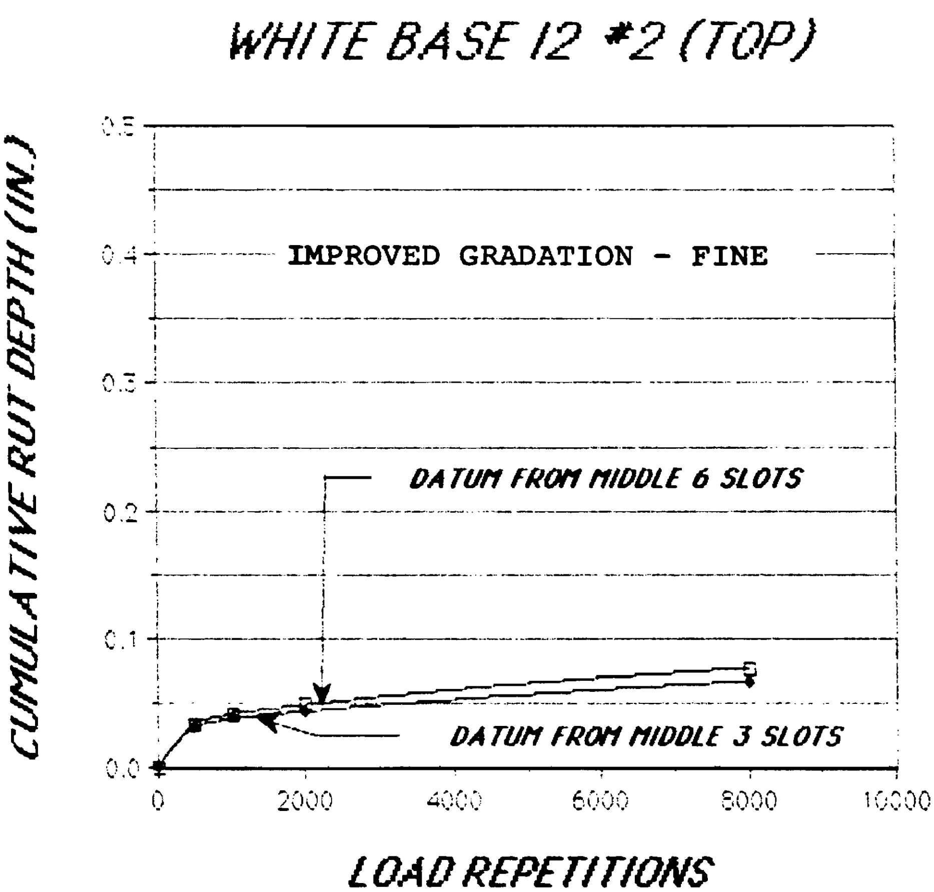
WHITE BASE II *2 (TOP)



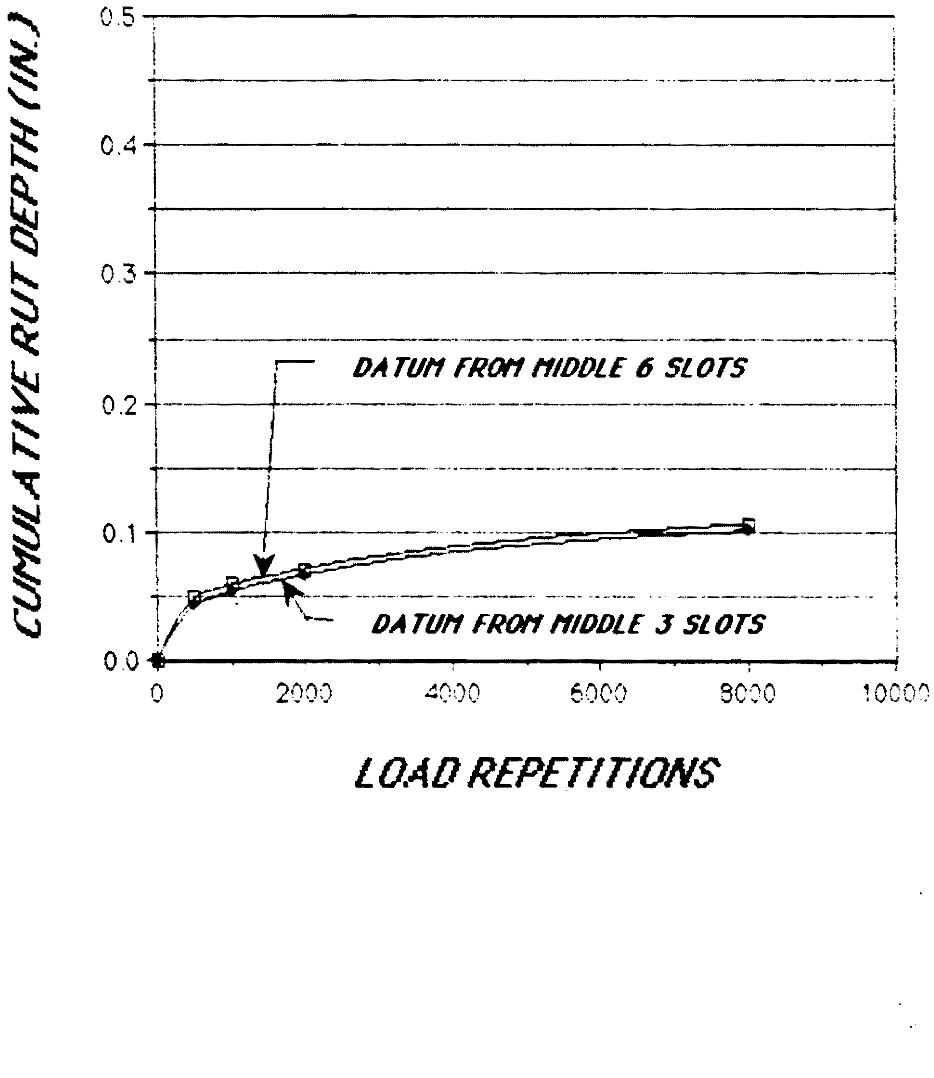


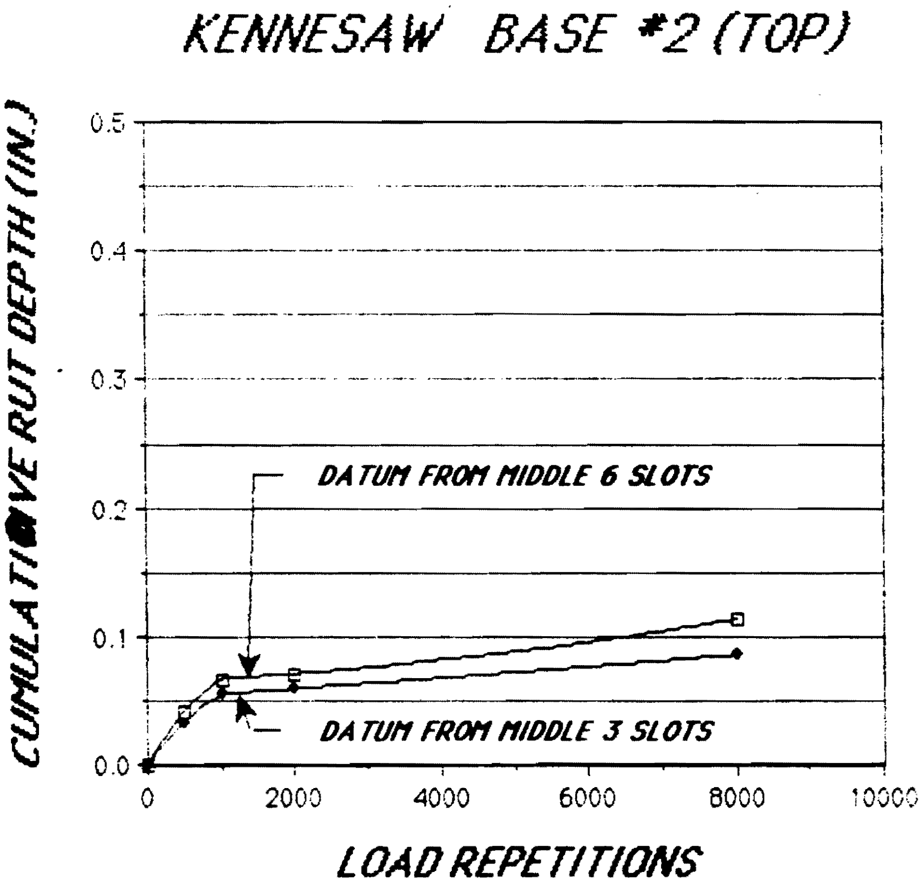
WHITE BASE 11 *1 (TOP)
CUMULATIVE RUT DEPTH (IN.)
IMPROVED GRADATION - COARSE
0.0
0.1
0.2
0.3
0.4
0.5
0
2000
4000
6000
8000
10000
LOAD REPETITIONS


WHITE BASE 12 #1 (TOP)
IMPROVED GRADATION - FINE
DATUM FROM MIDDLE 6 SLOTS
DATUM FROM MIDDLE 3 SLOTS
CUMULATIVE RUT DEPTH (IN.)
LOAD REPETITIONS
0.5
0.4
0.3
0.2
0.1
0.0
0
2000
4000
6000
8000
10000

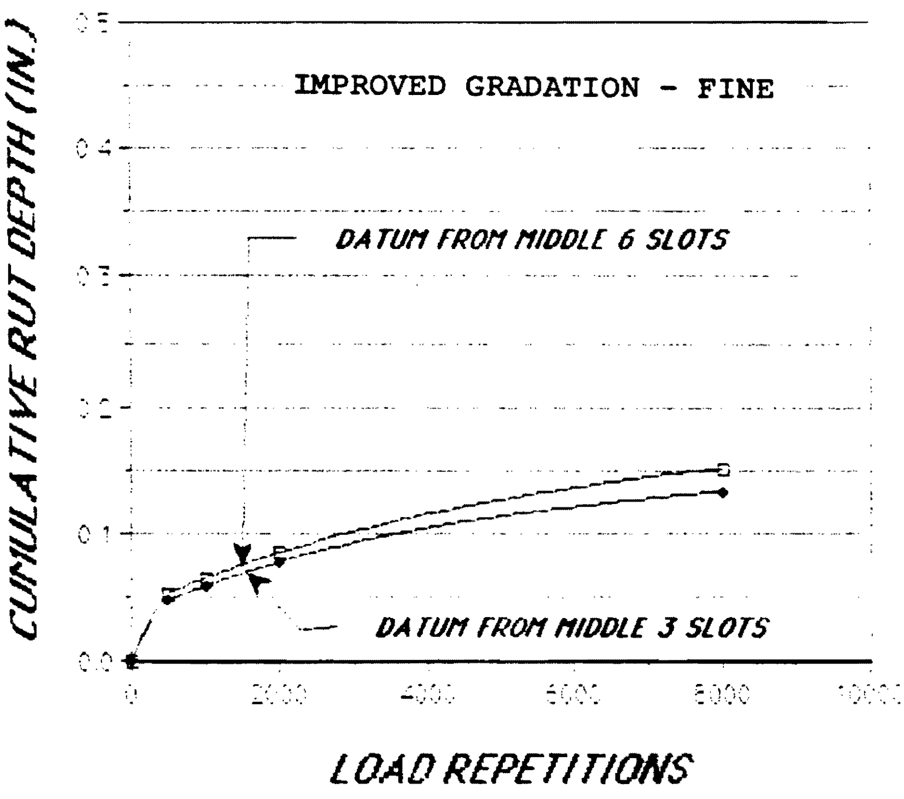

WHITE BASE 12 *2 (TOP)
CUMULATIVE RUT DEPTH (IN.)
0.5
0.4
0.3
0.2
0.1
0.0
IMPROVED GRADATION - FINE
DATUM FROM MIDDLE 6 SLOTS
DATUM FROM MIDDLE 3 SLOTS
0
2000
4000
6000
8000
10000
LOAD REPETITIONS

KENNESAW BASE #1 (TOP)




KENNESAW BASE #2 (TOP)
CUMULATIVE RUT DEPTH (IN.)
0.5
0.4
0.3
0.2
0.1
0.0
DATUM FROM MIDDLE 6 SLOTS
DATUM FROM MIDDLE 3 SLOTS
0
2000
4000
6000
8000
10000
LOAD REPETITIONS

KENNESAW BASE IMP. (FINER) #1 (TOP)



RESEARCH PROJECT PROGRESS REPORT
DEPARTMENT OF TRANSPORTATION
STATE OF GEORGIA

Report No. 4	Date: 1/16/91
Report Period: from July 1, 1990 to Dec. 30, 1990	

roject No.	Project Title
835/GaDOT 8812	Evaluation of the Effects of Aggregate on Rutting and Fatigue of Asphalt Concrete

esearch Agency(s)
Georgia Institute of Technology
Atlanta, Georgia 30332

Project Director: Richard D. Barksdale
School of Civil Engineering
Georgia Tech

tarting Date	Completion Date	Total Months	Time Expended: months, percentage
anuary 3, 1989	June 2, 1991	29	24 months; 83%

unding Sources(s)	Funds Authorized Total	Funds Expended Report Period	Funds Expended Total
HPR	$133,216	$23,518	$100,633

roject Objectives, Status, Progress

Objectives

1. To determine the basic properties of aggregates from a number of different quarries. Properties to be determined include aggregate shape, surface area, free mica, surface roughness, and petrographic analysis. The aggregates are to be classified and generalized relations between aggregate characteristics and density determined.

2. Develop optimum asphalt mix designs for each aggregate class selected. Surface, binder and base mixes are to be included in the study. Both rutting and fatigue are to be considered in developing the mix designs.

Status

General. Essentially all of the standard Georgia DOT E, F binder, and base mixes have now been tested in the wheel tracking machine. Also, essentially all of the improved base mixes have also been tested. The rate at which rut tests are performed during the next period will be dependent upon obtaining improved mix designs for the E and binder mixes since essentially all the standard mixes are finished. All diametral test samples have been tested, and fatigue life has been calculated of the mixes for which mix designs are available.

Diametral Test. The diametral test equipment is working very well and good results are being obtained. An attempt is being made to correlate resilient modulus with other variables. Correlations with Marshall stability, flow, and stability/flow are shown in Figures 1, 2 and 3. From these figures flow appears to give the best correlation. However, a statistical analysis will be performed to evaluate interactions and attempts to develop a predictive model.

add additional sheets as needed

Theoretical Fatigue Prediction. A computer program has been developed, verified, and is being used to predict fatigue life. Some typical results are tabulated in Table 1 for base mixes. As can be seen in the table, the slightly coarser gradation used in the improved mix gives, as expected, a slightly reduced fatigue life partly because of the use of a lower asphalt content in the mix. The computer simulation developed to model fatigue life has proved to be a very useful tool in evaluating new mix designs.

Rutting. An interesting summary of rutting obtained from the wheel tracking tests is given in Table 2 for 7 base mixes. Use of the coarser mix reduced rutting by 12 to 49% in 5 out of the 7 mixes. For the Kennesaw mix, both a coarser and finer mix than presently used resulted in an increase in rut depth of about 50%. Use of a slightly coarser Norcross base mix resulted in about the same rut depth as the standard mix. A more complete summary of rutting test data is given in Table 3. All of these data are presently being put in a similar form as given in Table 2.

A statistical analysis is currently being made to determine the parameters that affect the rutting potential of base mixes. Base mixes are being studied at the present time because both the standard GaDOT mixes and improved mixes have been essentially completed. Other mixes will be included in the statistical study later. The parameters included in the analysis are: roughness classification, surface area classification, percent air voids in the mix, shape classification, density of the mix, mica content, overall quarry classification, asphalt content and density of the unbound aggregate. Preliminary results show that the density of the asphalt mix is the most important factor affecting the rutting behavior of asphalt base mixes. Results also show that the combined average shape classification and adjusted surface area of material passing the No. 8 sieve and retained on the No. 120 sieve are not correlated to the rutting potential. The other variables appear to have a relatively low correlation with the rutting behavior of asphalt base. The most accurate relationship used to explain the observed rutting behavior use: density, roughness, mica content, and surface area. The coefficient of determination (r^2) of this relationship is about 53.9%. Plots showing relationships between rutting and density is shown in Figure 4 and between rutting and classification in Figure 5.

Planned Work Next Period

1. Complete all rutting and diametral tests.

2. Perform statistical analyses to develop, if possible, predictive models for rutting and resilient modulus.

3. Prepare the project report.

WORK PLAN SCHEDULE

Evaluation of the Effects of Aggregate Properties on Rutting and Fatigue of Asphalt Concrete

GTRI Project No. E20-835

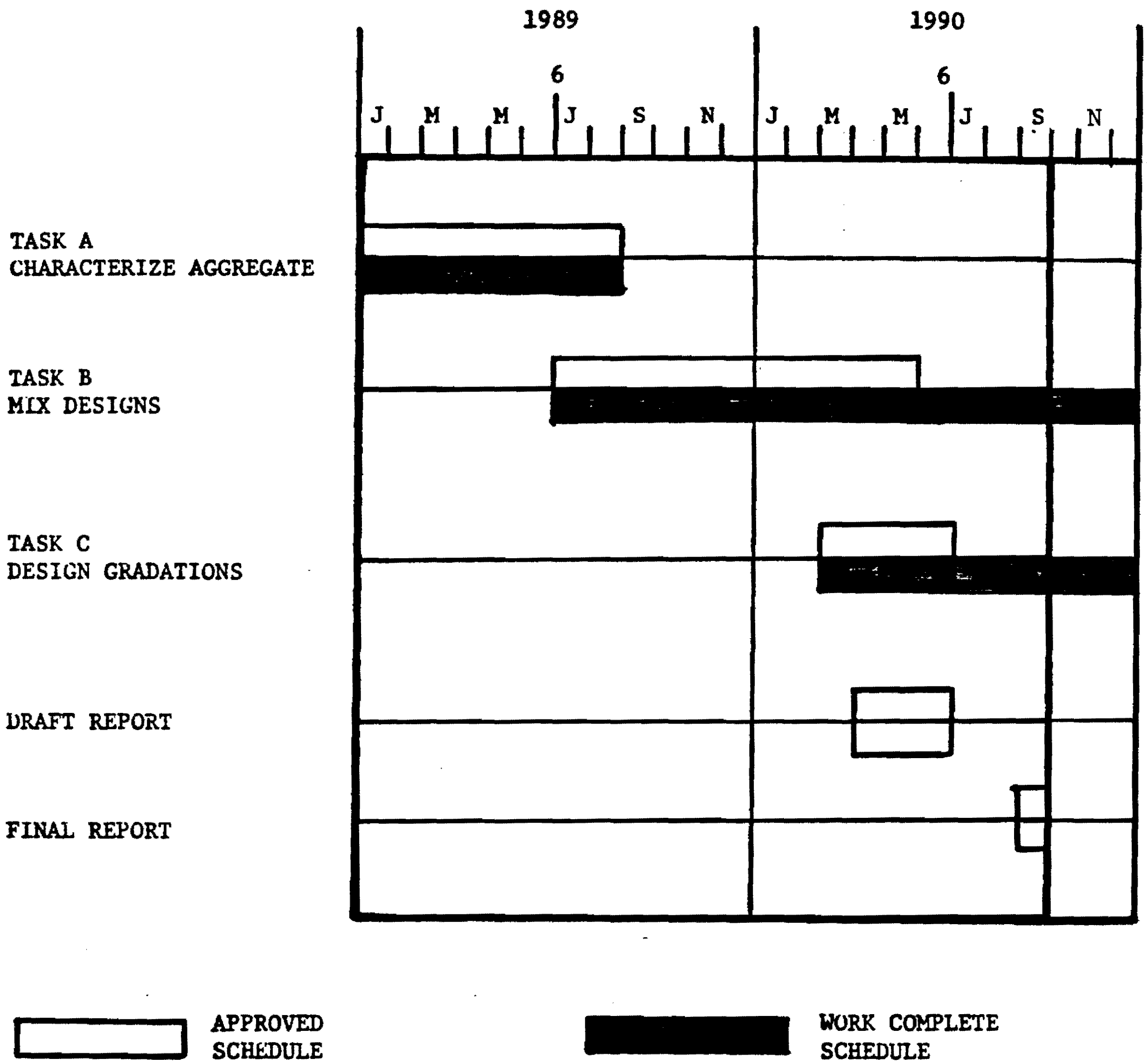


Table 1. Summary of Typical Calculated Fatigue Life Results for Selected Standard and Improved Base Mixes.

Quarry	Fatigue Life: Standard Mix		Improved Mix[1]	
	Method 1	Method 2	Method 1	Method 2
White	995,500	1,590,000	874,400	1,390,000
Kennesaw	1,437,000	2,479,000	1,029,000	1,950,000
Stockbridge	1,548,000	2,345,000	1,227,000	2,258,000
Lithonia	1,118,000	1,797,000	882,830	1,788,000
Norcross	1,298,000	2,367,000	870,200	1,660,000

Note: (1) Coarse Mix

Table 2. Wheel Track Test Rutting Results: Comparison of Standard Georgia DOT Mixes with Improved Mixes - Base.

Quarry	Standard DOT Design(1) $\delta_{average}$ (in.)	Coarse Mix Improved Design(1) $\delta_{average}$ (in.)	Fine Mix Improved Design(1) $\delta_{average}$ (in.)
White	0.1379	0.0699 (-49.31%)(2)	0.0724 (-47.49%)
Lithonia	0.14405	0.12625 (-12.36%)	0.09785 (-32.07%)
Kennesaw	0.0938	0.1409 (+50.21%)	0.14575 (+55.38%)
Barin	0.18445	0.14685 (-20.38%)	-
Palmer Station	0.212167	0.1147 (-45.94%)	-
Norcross	0.1835	0.1792 (- 2.34%)	-
Stockbridge	0.1562	0.1310 (- 16.1%)	-

Notes: 1. Average of two tests
2. The numbers in parentheses indicate the percent reduction in rutting compared to the standard Georgia DOT gradation.

Table 3. Summary of Rutting Test Results - 8,000 Load Repetitions.

QUARRY	SA. NO.	MIX TYPE - F MIX TOP	F MIX BOTT.	BASE MIX TOP	BASE MIX BOTT.	BASE IMP. TOP	BASE IMP. BOTT.	BASE IMP. (F) TOP	BASE IMP. (F) BOTT.	BINDER MIX TOP	BINDER MIX BOTT.	E MIX TOP	E MIX BOTT.
DIXIE	1	.3121	.3491										
	2	.3090	.2894										
	3	.3375	.4090										
	avg	.3195	.3492										
WHITE	1	.0934	.0792	.1243	.1402	.0735	.0905	.0777	.0602	.1151	.1487		
	2	.0736	.1879	.1685	.3322	.0663	.0847	.0670	.0529	.1096	.1208		
	3			.1209	.0900								
	avg	.0835	.1336	.1379	.1875	.0699	.0876	.0724	.0566	.1124	.1348		
BARIN	1	.1225	.1321	.1826	.2559	.1634				.1424	.2765	.1421	.2020
	2	.2113	.2352	.1863	.2636	.1303				.1958	.2257	.3107	.4659
	3											.2181	.3860
	avg	.1669	.1837	.1845	.2598	.1469				.1691	.2511	.2236	.3513
KENNES.	1			.1012	.1041	.1630		.1333		.1627	.1955	.1740	.2293
	2			.0864	.1256	.1188		.1582		.1472	.1917	.1249	.1930
	avg			.0938	.1149	.1409		.1458		.1550	.1936	.1495	.2112
STOCKBRI.	1			.1243	.2374					.1657	.2029	.1201	.1839
	2			.1881	.1181					.1728		.1461	.1949
	avg			.1562	.1778					.1693		.1331	.1894
LITHONIA	1			.1414		.1083		.0740		.2169		.2637	
	2			.1467		.1442		.1217		.1601		.1414	
	avg			.1441		.1263		.0979		.1885		.2026	
NORCROSS	1			.1537		.2034				.2136		.1962	
	2			.2133		.1550				.2144		.1910	
	avg			.1835		.1792				.2140		.1936	
PALMER STATION	1			.2604		.1270				.2318		.4817	
	2			.1644		.1024				.1786		.4636	
	avg			.2124		.1147				.2052		.4727	
BALL GROUND	1			.1681		.1701	.0927			.1810		.0832	
	2			.0948		.0519	.0320			.2070		.1554	
	avg			.1315		.1109	.0624			.1940		.1155	

Table 3 (continued). Summary of Rutting Test Results - 8,000 Load Repetitions.

QUARRY	SA. NO.	MIX TYPE: BASE	MIX TYPE: IMP. BASE	MIX TYPE: BINDER
ATHENS	1	.1464		.1814
	2	.2361		.2329
	AVG	.1913		.2072
CANDLER		TOP / BOTTOM		
	1	.1274 / .1201	.2274	.2616
	2	.1612 / .1897	.1937	.2424
	AVG	.1443 / .1549	.2105	.2520
MT VIEW		TOP / BOTTOM	TOP / BOTTOM	
	1	.1161	.1433 / .1104	.1558
	2	.2240	.2260 / .1961	.1922
	AVG	.1700	.1846 / .1532	.1740
TYRONE		TOP / TOP / BOTTOM		
	1	.1950 / .2473 / .2639	.1909	.2191
	2	.2050 / .1998 / .2754	.1369	.2268
	AVG	.2000 / .2236 / .2696	.1639	.2230
BUFORD	1	.1900	.1370	.1847
	2	.1968	.0630 .1902	.1268
	AVG	.1934	.1300	.1558
CUMMING	1	.1710		.3702
	2	.1286		.3067
	AVG	.1498		.3385

Table 3 (continued). Summary of Rutting Test Results - 8,000 Load Repetitions.

QUARRY	SA. NO.	MIX TYPE: BASE	MIX TYPE: IMP. BASE	MIX TYPE: BINDER
GRIFFIN	1	.1760		.1930
	2	.2199		.1670
	AVG	.1980		.1800
DAN		TOP / BOTTOM		
	1	.2273 / .0598	.1165	.1913
	2	.1511 / .1163	.1511	.1401
	AVG	.1892 / .088	.1338	.1657
RUBY	1	.1521		.1128
	2	.1090		.1218
	AVG	.1306		.1173
DALTON	1	.1021		.1290
	2	.1346		.0708
	3	---		.0901
	AVG	.1184		.0966
LITHIA SPR				TOP / BOTTOM
	1		.1201	.2023 / .1355
	2		.1825	.2470 / .1494
	AVG		.1513	.2246 / .1425
POSTELL	1	.1360		.2511
	2	.1321		.1950
	AVG	.1341		.2231

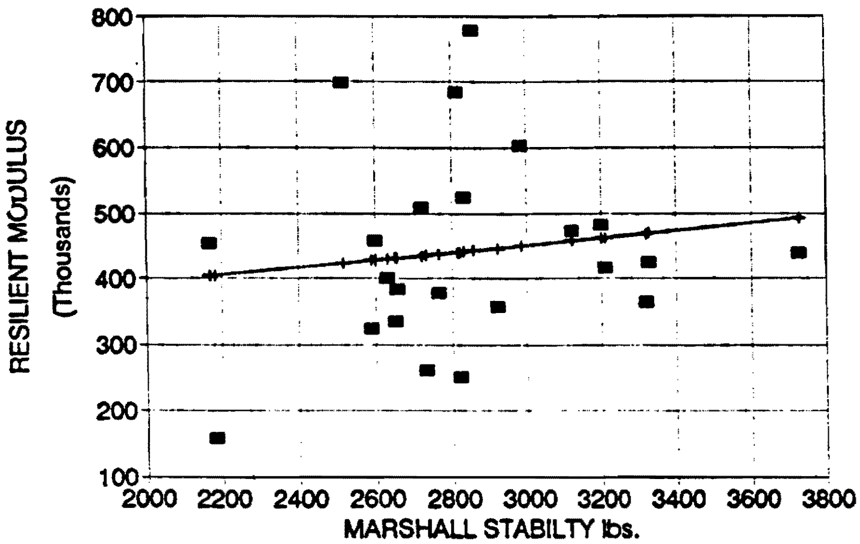


Figure 1. Resilient Modulus as a Function of Stability for All Quarries and Mixes.

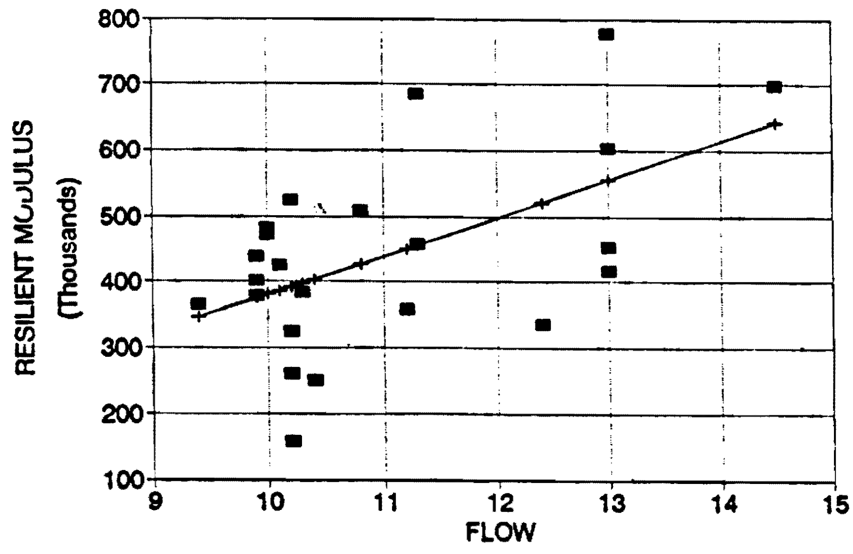


Figure 2. Resilient Modulus as a Function of Flow for All Quarries and Mixes.

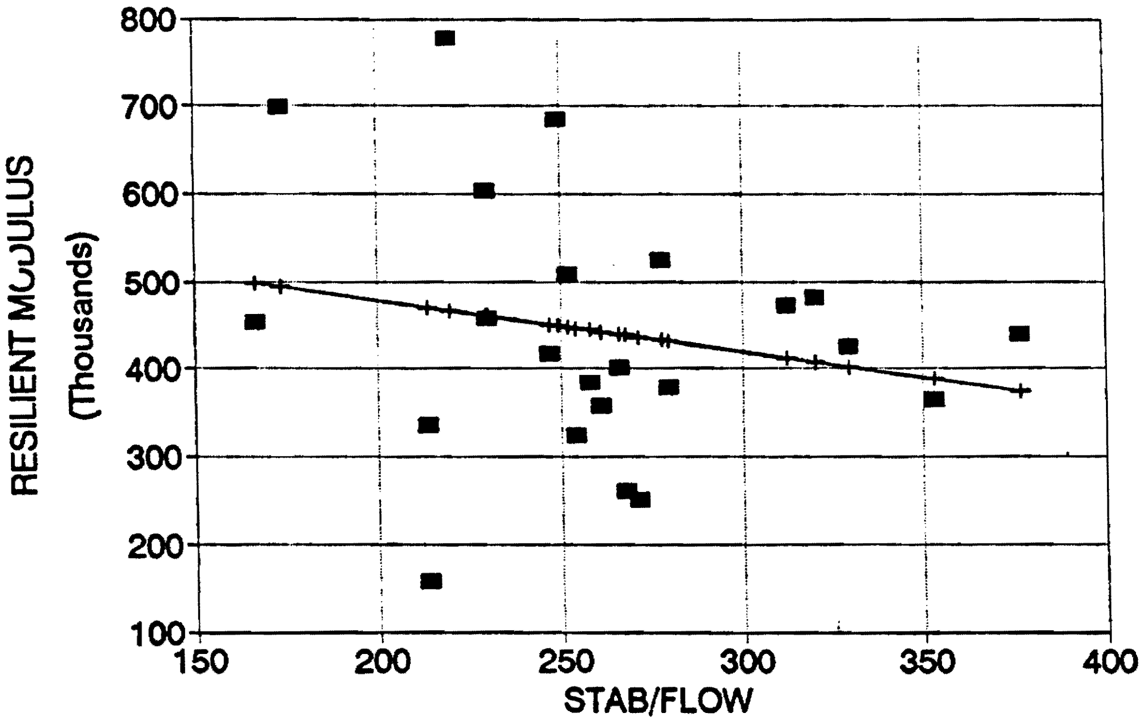


Figure 3. Resilient Modulus as a Function of Stability/Flow for All Quarries and Mixes.

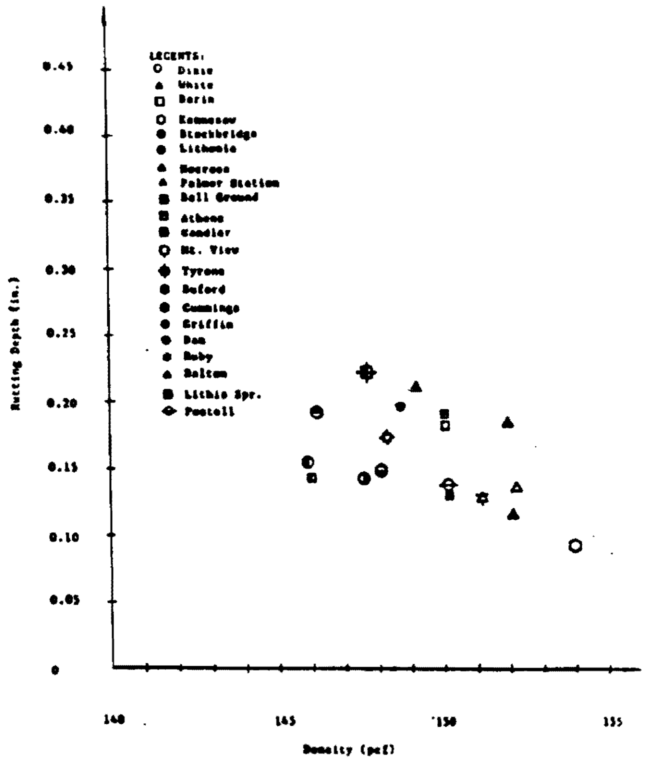


Figure 4. Rut Depth as a Function of Density for Base Mix.

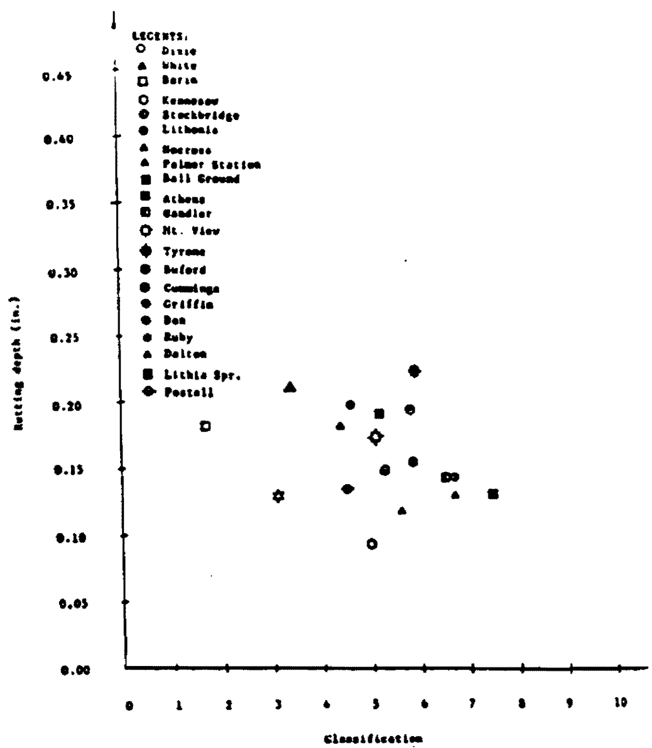


Figure 5. Rut Depth as a Function of Classification for Base Mix.

RESEARCH PROJECT PROGRESS REPORT DEPARTMENT OF TRANSPORTATION STATE OF GEORGIA	Report No.5 Date: 7/23/91 Report Period: from Jan. 1, 1991 to June 30, 1991

Project No.	Project Title
)-835/GADOT 8812	Evaluation of the Effects of Aggregate on Rutting and Fatigue of Asphalt Concrete

Research Agency(s)

Georgia Institute of Technology
Atlanta, Georgia 30332

Project Director: Richard D. Barksdale
School of Civil Engineering
Georgia Tech

Starting Date	Completion Date	Total Months	Time Expended: months, percentage
January 3, 1989	October 3, 1991	33	30 months 91%

Funding Sources(s)	Funds Authorized Total	Funds Expended Report Period	Funds Expended Total
HPR	$133,216	$28,694	$132,414

Project Objectives, Status, Progress

Objectives

1. **To determine the basic properties of aggregates from a number of different quarries. Properties to be determined include aggregate shape, surface area, free mica, surface roughness, and petrographic analysis. The aggregates are to be classified and generalized relations between aggregate characteristics and density determined.**

2. **Develop optimum asphalt mix designs for each aggregate class selected. Surface, binder and base mixes are to be included in the study. Both rutting and fatigue are to be considered in developing the mix designs.**

Status

The project is in the final stages of completion with only tests on the E-mixes (both DOT and improved mixes to be prepared and tested at the same time) to be completed. Also, a few additional diametral tests will be performed as specimens are obtained from the DOT. A large number of rutting tests (two series) have been performed on the B-mix and improved B-mix (the base mix was used) looking for a more rut resistant B-mix. The most recent series of tests involved comparing the standard GaDOT B-mix with the coarser GaDOT base mix. Specimens (2 each) for each mix were prepared from aggregate sieved at the same time and the resulting blended material split. The results show that on the average the B-mix is as rut resistant as the GaDOT base mix as shown on the attached table. The overall difference in the two mixes was only +4% neglecting the Lithonia mix. This overall finding is in agreement with the earlier findings clearly indicating the currently used B-mix is a good one which is relatively rut resistant. A limited amount of additional work will be conducted to try and find an improved B-mix.

Work Next Quarter

All testing will be completed and work will begin in August on preparing the final report.

add additional sheets as needed

RO

Comparison Standard Georgia DOT
Base Mixes with Standard B-Mixes

QUARRY NAME	SAMPLE No	BASE Stand. DOT Mix (in)		BINDER Stand. DOT Mix (in)		PERCENTAGE of Base (%)	
		TOP	BOTTO	TOP	BOTTO	TOP	BOTTO
CUMMING	1	0.2884		0.3978			
	2	0.3776		0.3378			
	AVG	0.3330		0.3678		-10.5	
DAN	1	0.1785		0.1413			
	2	0.1792		0.1596			
	AVG	0.1789		0.1505		15.9	
GRIFFIN	1	0.1943		0.2135			
	2	0.2235		0.2216			
	AVG	0.2089		0.2176		-4.1	
LITH. SP	1	0.2471					
	2	0.2773					
	AVG	0.2622					
LITHONIA	1	0.1937		0.4208			
	2	0.1786		0.2896			
	AVG	0.1862		0.3552		-90.8	
MT. VIEW	1	0.2263		0.2786			
	2	0.2723		0.3209			
	AVG	0.2493		0.2998		-20.2	
NORCROSS	1	0.2701		0.1468			
	2	0.2482		0.1998			
	AVG	0.2592		0.1733		33.1	
PALMER STATTION	1	0.2147		0.1996			
	2	0.2560		0.2185			
	AVG	0.2354		0.2091		11.2	

Final Report

Georgia DOT Project [illegible]
GaTech Project [illegible]-635

EVALUATION OF THE EFFECTS OF [illegible] ON [illegible]
AND [illegible] OF ASPHALT

Prepared for

Georgia Department of Transportation

by

Michael D. [illegible]
Professor [illegible]
[illegible]
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([illegible] Research Assistant)

and

[illegible]
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(Formerly Graduate Research Assistant)

School of Civil Engineering
Georgia Institute of Technology

February, [illegible]

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ACKNOWLEDGEMENTS

The [illegible] cooperation given by the Georgia Department of Transportation personnel, too numerous to acknowledge individually, is gratefully appreciated. Special acknowledgement is given to Mr. Pete Malphurs, former State Materials and Research Engineer, and to Mr. Ronald Collins, the new State Materials and Research Engineer, for their part in initiating and carrying out this research and to Larry Taylor who carefully monitored the study. Special appreciation is extended to the Georgia Crushed Stone Association for the financial support provided for Bill Sheffield. Georgia Tech provided support for [illegible] to conduct the statistical analyses. Appreciation is also expressed to Bill Sheffield, Mike Kemp, Tim Mirocha, and Jon Cheng who all worked on the project as Graduate Research Assistants. Dr. Lynn Pollard and Anna Butler performed the [illegible] content studies while [illegible] performed the thin section work. All of the petrological work was performed under the immediate direction of Dr. Pollard.

Chapter 1

INTRODUCTION

Asphalt concrete surface, binder and base courses are critical components of a flexible pavement. Therefore, rutting and cracking of these layers must be limited to a tolerable level. To meet varying needs, the Georgia Department of Transportation uses surface, binder, and base asphalt concrete mixes in flexible pavement construction. In recent years greater tire pressures and higher temperatures have, in some instances, resulted in rutting problems in these mixes.

Presently, mix designs are prepared considering primarily the influence of the asphalt content, percent voids, mineral filler, and the characteristics of bitumen binder. Laboratory tests and previous experience show, however, aggregate characteristics also influence the behavior of the mix [1-5].[1] Aggregate variables of importance appear to include mineral composition, shape, surface area, surface texture, and angularity. Filler content, in the both [illegible] states, and the presence of filler may have serious detrimental effects on the fatigue and/or rutting performance of asphalt concrete mix.

Unfortunately, very little research involving the effect of quantifiable aggregate characteristics has been conducted on asphalt mixtures in general and in specific those used in Georgia. Furthermore, asphalt mixes are presently often designed using about the same gradation regardless of aggregate characteristics.

---

[1] The numbers in brackets indicate references given at the end of this report.

OBJECTIVES OF RESEARCH STUDY

The overall purpose of this study is to determine the role that aggregate characteristics play in the rutting of asphalt concrete mixes and to develop more rut resistant asphalt concrete surface, binder, and base mixes for use in Georgia. The resulting mix designs must be durable, have optimum resistance to rutting under high tire pressures and temperatures, and also show reasonably good fatigue behavior.

Specific objectives of this project are as follows:

1. Develop suitable test methods and use to evaluate characteristics of aggregates from selected quarries. Aggregate properties studied include shape, surface area, surface texture, mineral composition, free mica content, and gradation-density characteristics.
2. Categorize the aggregates from the quarries tested for design purposes based on their physical characteristics.
3. Develop new gradation-based asphalt mix designs as alternates to existing ones. Compare their rutting, fatigue, and moisture behavior with existing mix designs. Surface, binder, and base mixes are all studied using The Loaded Wheel Tester to evaluate rutting. Previously developed theoretical expressions are used to quantify probable fatigue behavior.
4. Develop asphalt mix designs for each aggregate and type mix. These designs are to optimize rutting

and fatigue properties.

[illegible] Specific Aggregates [illegible] Included in Study

Aggregates obtained from the 21 quarries summarized in Table 1 were included in this study. More detailed testing was performed on aggregate from primary quarries, which are indicated in the table by an asterisk; the remaining ones are designated as secondary quarries. Granite gneiss aggregate comprised 76 percent of the different aggregate sources included in the study. A specific breakdown by geologic aggregate classification is as follows: granite gneiss (16 sources), limestone (3 sources), injected quartzite (1 source), alluvial sand and gravel (1 source). Detail descriptions of the tests performed during this study are given in a series of Masters Special Research Problem reports [6-12].

Originally, laboratory fatigue tests were to be performed as a part of this study. However, during the course of the work, the joint decision was made between The Georgia Department of Transportation and Georgia Tech that fatigue tests would not be performed. Instead, a theoretical model developed in the form of a computer program was used to estimate fatigue life. This modification in the program permitted concentrating more effort on studying the rutting behavior of [illegible].

Final Report

Georgia DOT Project 8812
GaTech Project E20-835

EVALUATION OF THE EFFECTS OF AGGREGATE ON RUTTING AND FATIGUE OF ASPHALT

Prepared for

Georgia Department of Transportation

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Chapter 1

INTRODUCTION

Asphalt concrete surface, binder and base courses are critical components of a flexible pavement. Therefore, rutting and cracking of these layers must be limited to a tolerable level. To meet varying needs, the Georgia Department of Transportation uses surface, binder, and base asphalt concrete mixes in flexible pavement construction. In recent years greater tire pressures and higher temperatures have, in some instances, resulted in rutting problems in these mixes.

Presently, mix designs are prepared considering primarily the influence of the asphalt content, percent voids, mineral filler, and the characteristics of bitumen binder. Laboratory tests and previous experience also show, however, aggregate characteristics also influence the behavior of the mix [1-5][1]. Aggregate variables of importance appear to include mineral composition, shape, surface area, surface texture, and angularity. Mica content, in the both free and bound states, and the presence of silica may have serious detrimental effects on the fatigue and/or rutting performance of an asphalt concrete mix.

Unfortunately, very little research involving the effect of quantifiable aggregate characteristics has been conducted on asphalt mixtures in general and in specific those used in Georgia. Furthermore, asphalt mixes are presently often designed using about the same gradation regardless of aggregate characteristics.

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[1] The numbers in brackets indicate references given at the end of this report.

OBJECTIVES OF PROPOSED STUDY

The overall purpose of this study is to determine the role that aggregate characteristics play in the rutting of asphalt concrete mixes and to develop more rut resistant asphalt concrete surface, binder, and base mixes for use in Georgia. The resulting mix design must be durable, have optimum resistance to rutting under high tire pressures and temperatures, and also show reasonably good fatigue behavior.

Specific objectives of this project are as follows:

1. Develop suitable test methods and measure pertinent characteristics of aggregate from 21 selected quarries. Aggregate properties studied include shape, surface area, surface texture, mineral composition, free mica content, and gradation-density characteristics.
2. Categorize the aggregates from the quarries tested for design purposes based on their physical characteristics.
3. Develop new gradations/asphalt mix designs as alternates to existing ones. Compare their rutting, fatigue, and resilient behavior with existing mix designs. Surface, binder, and base mixes are all studied using The Loaded Wheel Tester to evaluate rutting. Previously developed theoretical expressions are used to quantify probable fatigue behavior.
4. Develop asphalt mix designs for each aggregate and type mix. These designs are to optimize rutting and fatigue properties.

Quarries and Specific Aggregate Properties Included In Study

Aggregates obtained from the 21 quarries summarized in Table 1 were included in this study. More detailed testing was performed on aggregate from primary quarries, which are indicated in the table by an asterisk; the remaining ones are designated as secondary quarries. Granite gneiss aggregate comprised 76 percent of the different aggregate sources included in the study. A specific breakdown by geologic aggregate classification is as follows: granite gneiss (16 sources), limestone (3 sources), injected quartzite (1 source), alluvial sand and gravel (1 source). Detailed descriptions of the tests performed during this study are given in a series of Masters Special Research Problem reports [6-12].

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Table 1. List of Quarries and Aggregate Types Studied.

Quarry	Type of Aggregate	Quarry No. (Crs/Fine)
1. Athens, GA	Granite Gneiss	23/NA
2. Ball Ground, GA	Limestone	112/NA
3. Barin, GA	Granite Gneiss	44/NA
4. Buford, GA	Limestone	102/NA
5. Candler, GA	Granite Gneiss	24/40
6. Cummings, GA	Granite Gneiss	38/99
7. Dalton, GA	Limestone	13/88
8. Dan, GA	Injected Quartz	41/NA
9. Dixie (Chattanooga, TN)	Alluvial	NA/31
10. Griffin, GA	Granite Gneiss	77/NA
11. Kennesaw, GA	Granite Gneiss	46/NA
12. Lithia Springs, GA	Granite Gneiss	47/135
13. Lithonia, GA	Granite Gneiss	11/17
14. Mountain View, GA	Granite Gneiss	15/NA
15. Norcross, GA	Granite Gneiss	48/107
16. Palmer Station, GA	Granite Gneiss	17/29
17. Postell, GA	Granite Gneiss	28/NA
18. Ruby, GA	Granite Gneiss	54/NA
19. Stockbridge, GA	Granite Gneiss	50/106
20. Tyrone, GA	Granite Gneiss	14/30
21. White, GA	Limestone	67/NA

CHAPTER 2

FUNDAMENTAL AGGREGATE PROPERTIES AND COMPACTION CHARACTERISTICS

INTRODUCTION

Rutting in asphalt concrete is a function of many factors including the Marshall mix design characteristics, type and amount of mineral filler, aggregate gradation, and aggregate characteristics. This chapter summarizes the aggregate and mix design characteristics measured for the 21 quarries included in the investigation. The aggregate characterization tests used in this study are described more fully in Appendix A, B, and in a series of Masters Special Research Problem reports [6-12]. The results given in Chapter 4 establishes the importance of these factors on rutting for usually encountered variations in mix design parameters.

Overview of Results

Measured Characteristics. The summary aggregate characteristic tables and figures referred to in this section are presented in later sections of this chapter. Tables 2 through 8 summmarize the basic aggregate characteristics measured as a part of this study. Measured aggregate properties summarized include specific rugosity, surface area, shape classification, surface roughness, and free mica content. Modern digitizing techniques, described in Appendix A, were used to measure shape and surface roughness taking advantage of a micro-computer. Asphalt mix design characteristics are given in Tables 9 through 16.

Pouring Test. The pouring test, which is described in Appendix B, is a simple to perform test for measuring the macro- and micro surface characteristics of aggregates. The pouring test compares the packing characteristics of spherical beads with similar size aggregate particles. As shown in Chapter 4, aggregate surface characteristics determined from the pouring test are related to rutting and also mica content.

Index Density. The aggregate gradation which gives maximum density can, as an approximation, be defined by the exponent n in Talbot's equation $P = (d/D)^n$ which is discussed in the last section of this chapter.

A larger value of n indicates a coarser aggregate gradation. The typical n-value used in practice is 0.45 with this value seldom exceeding 0.5. Compacted unbound (dry) aggregate density, as a function of gradation, is determined for selected aggregate sources and a range of gradations that bound those that might be used by the Georgia Department of Transportation for E and base asphalt concrete mixes. Results for the E mixes are given in Table 17 and Figure 3; results for base mixes are given in Table 18 and Figure 4. These results indicate that maximum index density for an unbound aggregate mix is usually achieved for n-values less than 0.45. For a few aggregate sources, the index density was not significantly affected by a variation in n from 0.4 to 0.5. Index density was determined using a standard ASTM vibration test. The influence of n-value on density is very likely related to the specific test method used; the effect of test method was not investigated in this study.

AGGREGATE GRADATION

The specific aggregate gradations for E, F, B binder, and base mixes were used to weight several measured aggregate characteristics. Weighted aggregate characteristics calculated were specific rugosity, macro surface voids, micro surface voids, mica content, shape class, and surface area. In addition, the aggregate gradation's coefficient of uniformity, maximum size of aggregate, and percent fines were also tabulated and later used in the study of factors influencing rutting of asphalt concrete mixes.

The equation for the coefficient of uniformity, C_u is defined as:

$$C_u = D_{60}/D_{10} \qquad (1)$$

In equation (1) D_{60} is the grain size diameter corresponding to 60 percent of the material passing the U.S. No. 60 sieve size; D_{10} is the grain size diameter for which 10 percent of the material is finer.

AGGREGATE CHARACTERIZATION USING THE POURING TEST

Introduction

The pouring test, described sometime ago by Ishai and Gelber [13], offers a reasonably simple, easy to perform test for evaluating surface aggregate characteristics. The pouring test consists of comparing the packing characteristics of aggregate with similar size spherical beads. In the pouring test both the aggregate and similar size spherical beads are rained into a container. Both macro- and micro surface properties are evaluated from the results of the pouring test as well as their combined effects which is called specifc rugosity.

Basic Concepts

The specific rugosity represents the geometric irregularity of an aggregate including volume, shape, angularity, and surface texture or roughness. Specific rugosity is the volumetric portion of surface voids including the micro- and macro surface voids. For example, a specific rugosity of approximately zero indicates a very smooth, uniform particle such as a glass bead. Aggregates with specific rugosity greater than zero, therefore, have some surface voids or irregularities. Figure 1 illustrates the concept of micro surface voids (s_{mi}), macro surface voids (s_{ma}), and packing membrane volume (V_p).

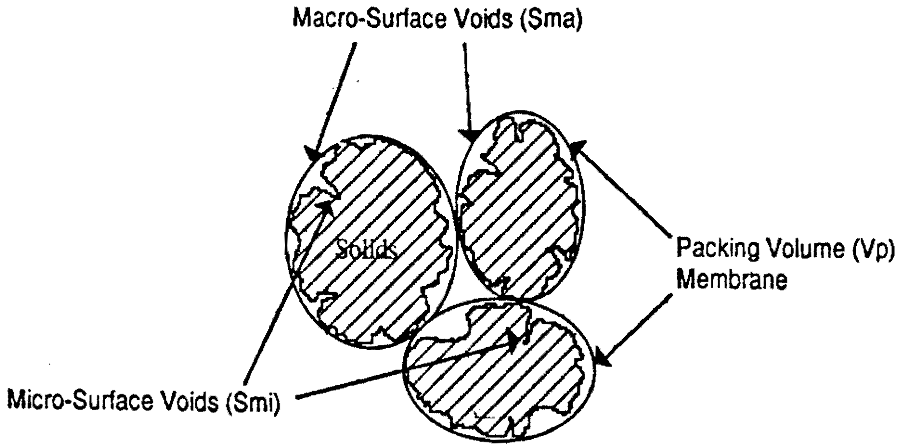
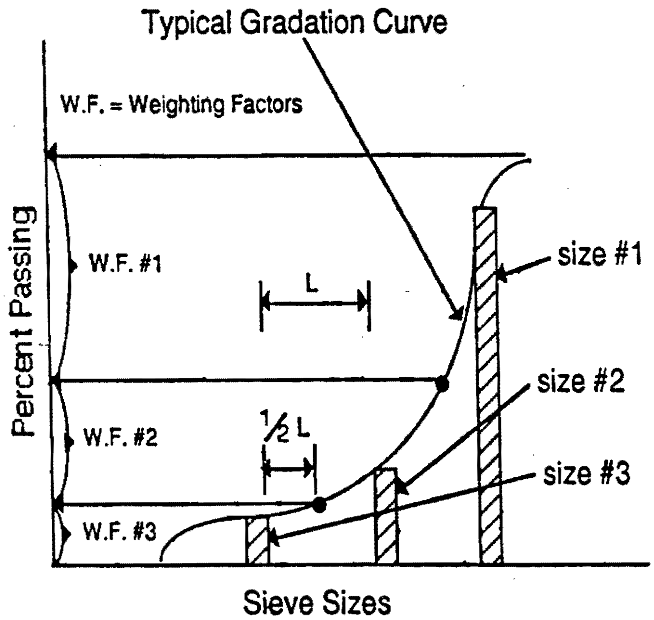


Figure 1. Packing Volume Membrane Concept.



Weighted Value =(Value for #1)*W.F.#1 +(Value for #2)*W.F.#2+(Value for #3)*W.F.#3

Figure 2. Example Determination of Weighting Factors.

The micro surface voids are the capillary voids on the surface of the aggregate that affect the absorbed moisture or asphalt in a mix. The macro surface voids are the peaks and dips on the surface of the aggregate. Specifically, the macro surface voids determine aggregate interlock. Aggregate interlock greatly influences the strength, workability, and stability, as well as the rutting resistance of asphalt concrete mixes.

Determination of Specific Rugosity

The specific rugosity was determined using the pouring test described in Appendix B. The pouring test was performed on six ranges of aggregate particle sizes. The six particle size ranges were 1 1/4 in. to 7/8 in., 5/8 in. to 7/16 in., 1/4 in No.4, No.12 to No.16, No.20 to No.30, No.30 to No.40, and No.45 to No.60. The details of the test such as pouring height, container, diameter, etc. are summarized in Appendix B.

The weighting factors used for each aggregate gradation were calculated based upon the relative amount of aggregate present in each size range for a specific mix. Figure 2 shows the relation between the gradation and the weighting factors applied to the values for specific rugosity, macro surface, and micro surface voids. Both the specific rugosity, macro surface voids, and micro surface void values for each aggregate size and the weighted values are given in Table 2, 3, and 4, respectively.

SURFACE AREA

Introduction

The surface area for four grain size ranges was calculated by Kemp [7] using the method of Aschenbrenner [19]. Following this approach a particle is modeled as a tetrakaidekahedron (TKH model) and the surface area (SA) calculated using the following formula:

Table 2. Aggregate Specific Rugosity - Pouring Test.

QUARRY	SIZE RET	Gb	Gap	Gag	Sma	Smi	Srv	Base (DOT) Weight Factor	Srv*W.F.	Coarse Base Weight Factor	Srv*W.F.	Fine Base Weight Factor	Srv*W.F.	Binder (DOT) Weight Factor	Srv*W.F.	F Mix (DOT) Weight Factor	Srv*W.F.	E Mix (DOT) Weight Factor	Srv*W.F.	Coarse E Mix Weight Factor	Srv*W.F.
Athens	#60	1.84	2.73	2.68	31.34	1.26	32.60	0.160	5.216	0.150	4.890	0.150	4.890	0.110	3.586	0.200	6.520	0.180	5.868	0.150	4.890
Athens	#40	1.87	2.73	2.68	30.22	1.28	31.50	0.040	1.260	0.040	1.260	0.030	0.945	0.040	1.260	0.060	1.890	0.060	1.890	0.060	1.890
Athens	#30	1.96	2.73	2.68	26.87	1.34	28.21	0.050	1.410	0.060	1.692	0.050	1.410	0.050	1.410	0.060	1.692	0.040	1.128	0.050	1.410
Athens	#16	2.06	2.73	2.68	23.13	1.41	24.54	0.100	2.454	0.070	1.718	0.120	2.945	0.100	2.454	0.180	4.418	0.200	4.908	0.140	3.436
Athens	#4	2.14	2.73	2.68	20.15	1.46	21.61	0.200	4.322	0.180	3.890	0.190	4.106	0.200	4.322	0.400	8.645	0.250	5.403	0.250	5.403
Athens	7/16"	2.26	2.73	2.68	15.67	1.54	17.22	0.350	6.026	0.400	6.886	0.210	3.615	0.450	7.747	0.100	1.722	0.250	4.304	0.350	6.026
Athens	7/8"	2.39	2.73	2.68	10.82	1.63	12.45	0.100	1.245	0.100	1.245	0.250	3.114	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
								Srv,weighted =	21.93	Srv,weighted =	21.58	Srv,weighted =	21.03	Srv,weighted =	20.78	Srv,weighted =	24.89	Srv,weighted =	23.50	Srv,weighted =	23.05
Ball Ground	#60	2.11	2.79	2.75	23.27	1.10	24.37	0.140	3.412	0.150	3.666	0.150	3.656	0.130	3.168	0.000	0.000	0.150	3.656	0.150	3.656
Ball Ground	#40	2.13	2.79	2.75	22.55	1.11	23.66	0.040	0.946	0.040	0.946	0.030	0.710	0.030	0.710	0.000	0.000	0.050	1.183	0.060	1.419
Ball Ground	#30	1.72	2.79	2.75	37.45	0.90	38.35	0.050	1.918	0.060	2.301	0.050	1.918	0.060	2.301	0.000	0.000	0.060	2.301	0.050	1.918
Ball Ground	#16	2.08	2.79	2.75	24.36	1.08	25.45	0.120	3.054	0.070	1.781	0.120	3.054	0.130	3.308	0.000	0.000	0.140	3.563	0.140	3.563
Ball Ground	#4	2.22	2.79	2.75	19.27	1.16	20.43	0.250	5.108	0.180	3.677	0.190	3.882	0.250	5.108	0.000	0.000	0.300	6.129	0.250	5.108
Ball Ground	7/16"	2.24	2.79	2.75	18.55	1.17	19.71	0.300	5.914	0.400	7.885	0.210	4.140	0.380	7.491	0.000	0.000	0.250	4.928	0.350	6.900
Ball Ground	7/8"	2.46	2.79	2.75	10.55	1.28	11.83	0.100	1.183	0.100	1.183	0.250	2.957	0.020	0.237	0.000	0.000	0.000	0.000	0.000	0.000
								Srv,weighted =	21.53	Srv,weighted =	21.43	Srv,weighted =	20.32	Srv,weighted =	22.32	Srv,weighted =	*	Srv,weighted =	21.76	Srv,weighted =	22.56
Barin	#60	1.96	2.72	2.67	26.59	1.35	27.94	0.190	5.309	0.150	4.191	0.150	4.191	0.170	4.750	0.220	6.147	0.220	6.147	0.150	4.191
Barin	#40	2.02	2.72	2.67	24.34	1.39	25.74	0.050	1.287	0.040	1.029	0.030	0.772	0.050	1.287	0.070	1.801	0.050	1.287	0.060	1.544
Barin	#30	2.05	2.72	2.67	23.22	1.41	24.63	0.040	0.985	0.060	1.478	0.050	1.232	0.050	1.232	0.040	0.985	0.060	1.478	0.050	1.232
Barin	#16	2.11	2.72	2.67	20.97	1.45	22.43	0.120	2.691	0.070	1.570	0.120	2.691	0.080	1.794	0.170	3.813	0.220	4.934	0.140	3.140
Barin	#4	2.05	2.72	2.67	23.22	1.41	24.63	0.150	3.695	0.180	4.434	0.190	4.680	0.250	6.158	0.300	7.390	0.380	9.360	0.250	6.158
Barin	7/16"	2.31	2.72	2.67	13.48	1.59	15.07	0.350	5.276	0.300	4.522	0.210	3.165	0.370	5.577	0.200	3.015	0.070	1.055	0.350	5.276
Barin	7/8"	2.40	2.72	2.67	10.11	1.65	11.76	0.100	1.176	0.100	1.176	0.250	2.941	0.030	0.353	0.000	0.000	0.000	0.000	0.000	0.000
								Srv,weighted =	20.42	Srv,weighted =	18.40	Srv,weighted =	19.67	Srv,weighted =	21.15	Srv,weighted =	23.15	Srv,weighted =	24.26	Srv,weighted =	21.54
Buford	#60	2.01	2.65	2.61	22.99	1.02	24.01	0.110	2.641	0.150	3.601	0.150	3.601	0.160	3.841	0.210	5.042	0.000	0.000	0.150	3.601
Buford	#40	1.96	2.65	2.61	24.90	0.99	25.90	0.090	2.331	0.040	1.036	0.030	0.777	0.040	1.036	0.030	0.777	0.000	0.000	0.060	1.554
Buford	#30	1.98	2.65	2.61	24.14	1.00	25.14	0.040	1.006	0.060	1.509	0.050	1.257	0.040	1.006	0.060	1.509	0.000	0.000	0.050	1.257
Buford	#16	2.03	2.65	2.61	22.22	1.03	23.25	0.110	2.558	0.070	1.628	0.120	2.790	0.110	2.558	0.200	4.650	0.000	0.000	0.140	3.255
Buford	#4	2.13	2.65	2.61	18.39	1.08	19.47	0.200	3.894	0.180	3.505	0.190	3.699	0.250	4.868	0.500	9.735	0.000	0.000	0.250	4.868
Buford	7/16"	2.18	2.65	2.61	16.48	1.11	17.58	0.350	6.153	0.400	7.032	0.210	3.692	0.350	6.153	0.000	0.000	0.000	0.000	0.350	6.153
Buford	7/8"	2.26	2.65	2.61	13.41	1.15	14.56	0.100	1.456	0.100	1.456	0.250	3.639	0.050	0.728	0.000	0.000	0.000	0.000	0.000	0.000
								Srv,weighted =	20.04	Srv,weighted =	19.77	Srv,weighted =	19.46	Srv,weighted =	20.19	Srv,weighted =	21.71	Srv,weighted =	*	Srv,weighted =	20.69
Candler	#60	2.05	2.64	2.61	21.46	0.89	22.35	0.200	4.470	0.150	3.352	0.150	3.352	0.170	3.799	0.150	3.352	0.230	5.140	0.150	3.352
Candler	#40	2.02	2.64	2.61	22.61	0.88	23.48	0.050	1.174	0.040	0.939	0.030	0.705	0.030	0.705	0.030	0.705	0.050	1.174	0.060	1.409
Candler	#30	1.99	2.64	2.61	23.75	0.87	24.62	0.030	0.739	0.060	1.477	0.050	1.231	0.030	0.739	0.060	1.477	0.050	1.231	0.050	1.231
Candler	#16	2.01	2.64	2.61	22.99	0.88	23.86	0.080	1.909	0.070	1.670	0.120	2.864	0.100	2.386	0.220	5.250	0.160	3.818	0.140	3.341
Candler	#4	2.08	2.64	2.61	20.31	0.91	21.21	0.190	4.030	0.180	3.818	0.190	4.030	0.270	5.727	0.440	9.333	0.270	5.727	0.250	5.303
Candler	7/16"	2.22	2.64	2.61	14.94	0.97	15.91	0.230	3.659	0.400	6.364	0.210	3.341	0.320	5.091	0.100	1.591	0.240	3.818	0.350	5.568
Candler	7/8"	2.39	2.64	2.61	8.43	1.04	9.47	0.220	2.083	0.100	0.947	0.250	2.367	0.080	0.758	0.000	0.000	0.000	0.000	0.000	0.000
								Srv,weighted =	18.06	Srv,weighted =	18.57	Srv,weighted =	17.69	Srv,weighted =	19.20	Srv,weighted =	21.71	Srv,weighted =	20.91	Srv,weighted =	20.20
Cummings	#60	1.94	2.66	2.58	24.81	2.26	27.07	0.150	4.060	0.150	4.060	0.150	4.060	0.160	4.331	0.000	0.000	0.000	0.000	0.150	4.060
Cummings	#40	1.93	2.66	2.58	25.19	2.25	27.44	0.050	1.372	0.040	1.098	0.030	0.823	0.060	1.647	0.000	0.000	0.000	0.000	0.060	1.647
Cummings	#30	1.97	2.66	2.58	23.64	2.30	25.94	0.040	1.038	0.060	1.556	0.050	1.297	0.060	1.556	0.000	0.000	0.000	0.000	0.050	1.297
Cummings	#16	2.08	2.66	2.58	19.38	2.42	21.80	0.110	2.398	0.070	1.526	0.120	2.617	0.120	2.617	0.000	0.000	0.000	0.000	0.140	3.053
Cummings	#4	2.22	2.76	2.71	18.08	1.48	19.57	0.160	3.130	0.180	3.522	0.190	3.717	0.200	3.913	0.000	0.000	0.000	0.000	0.250	4.891
Cummings	7/16"	2.00	2.76	2.71	26.20	1.34	27.54	0.290	7.986	0.400	11.014	0.210	5.783	0.350	9.638	0.000	0.000	0.000	0.000	0.350	9.638
Cummings	7/8"	2.12	2.76	2.71	21.77	1.42	23.19	0.150	3.478	0.100	2.319	0.250	5.797	0.050	1.159	0.000	0.000	0.000	0.000	0.000	0.000
								Srv,weighted =	23.46	Srv,weighted =	25.10	Srv,weighted =	24.09	Srv,weighted =	24.86	Srv,weighted =	*	Srv,weighted =	*	Srv,weighted =	24.59
Dalton	#60	2.14	2.75	2.68	20.15	2.03	22.18	0.130	2.884	0.150	3.327	0.150	3.327	0.110	2.440	0.000	0.000	0.000	0.000	0.150	3.327
Dalton	#40	2.11	2.75	2.68	21.27	2.00	23.27	0.040	0.931	0.040	0.931	0.030	0.698	0.030	0.698	0.000	0.000	0.000	0.000	0.060	1.396
Dalton	#30	2.14	2.75	2.68	20.15	2.03	22.18	0.060	1.331	0.060	1.331	0.050	1.109	0.040	0.887	0.000	0.000	0.000	0.000	0.050	1.109
Dalton	#16	2.09	2.75	2.68	22.01	1.99	24.00	0.140	3.360	0.070	1.680	0.120	2.880	0.210	5.040	0.000	0.000	0.000	0.000	0.140	3.360
Dalton	#4	2.11	2.74	2.71	22.14	0.85	22.99	0.180	4.139	0.180	4.139	0.190	4.369	0.260	5.978	0.000	0.000	0.000	0.000	0.250	5.749
Dalton	7/16"	2.22	2.74	2.71	18.08	0.90	18.98	0.370	7.022	0.400	7.591	0.210	3.985	0.300	5.693	0.000	0.000	0.000	0.000	0.350	6.642
Dalton	7/8"	2.34	2.74	2.71	13.65	0.95	14.60	0.180	2.628	0.100	1.460	0.250	3.650	0.05	0.730	0.000	0.000	0.000	0.000	0.000	0.000
								Srv,weighted =	22.29	Srv,weighted =	20.46	Srv,weighted =	20.02	Srv,weighted =	21.47	Srv,weighted =	*	Srv,weighted =	*	Srv,weighted =	21.58
Den	#60	1.94	2.69	2.64	26.52	1.37	27.88	0.140	3.903	0.150	4.182	0.150	4.182	0.130	3.625	0.000	0.000	0.000	0.000	0.150	4.182
Den	#40	1.93	2.69	2.64	26.89	1.36	28.25	0.050	1.413	0.040	1.130	0.030	0.848	0.040	1.130	0.000	0.000	0.000	0.000	0.060	1.695
Den	#30	2.00	2.69	2.64	24.24	1.41	25.65	0.090	2.309	0.060	1.539	0.050	1.283	0.050	1.283	0.000	0.000	0.000	0.000	0.050	1.283
Den	#16	2.04	2.69	2.64	22.73	1.44	24.16	0.120	2.900	0.070	1.691	0.120	2.900	0.130	3.141	0.000	0.000	0.000	0.000	0.140	3.383
Den	#4	2.09	2.69	2.64	20.83	1.47	22.30	0.200	4.461	0.180	4.015	0.190	4.238	0.250	5.576	0.000	0.000	0.000	0.000	0.250	5.576
Den	7/16"	2.18	2.69	2.64	17.42	1.53	18.96	0.250	4.740	0.400	7.584	0.210	3.981	0.350	6.636	0.000	0.000	0.000	0.000	0.350	6.636
Den	7/8"	2.34	2.69	2.64	11.36	1.65	13.01	0.150	1.952	0.100	1.301	0.250	3.253	0.050	0.651	0.000	0.000	0.000	0.000	0.000	0.000
								Srv,weighted =	21.68	Srv,weighted =	21.44	Srv,weighted =	20.68	Srv,weighted =	22.04	Srv,weighted =	*	Srv,weighted =	*	Srv,weighted =	22.75

Table 2. Aggregate Specific Rugosity - Pouring Test (continued).

QUARRY	SIZE RET	Gb	Gsb	Gsa	Sms	Smt	Srv	Base (DOT) Weight Factor	Srv*W.F.	Coarse Base Weight Factor	Srv*W.F.	Fine Base Weight Factor	Srv*W.F.	Binder (DOT) Weight Factor	Srv*W.F.	F Mix (DOT) Weight Factor	Srv*W.F.	E Mix (DOT) Weight Factor	Srv*W.F.	Coarse E Mix Weight Factor	Srv*W.F.
Dixie	#60		2.64	2.57																	
Dixie	#40	1.82	2.64	2.57	29.18	1.88	31.06	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.180	5.591	0.000	0.000	0.210	6.523
Dixie	#30	1.80	2.64	2.57	29.96	1.86	31.82	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.070	2.227	0.000	0.000	0.050	1.591
Dixie	#16	1.82	2.64	2.57	29.18	1.88	31.06	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.200	6.212	0.000	0.000	0.140	4.348
Dixie	#4	1.97	2.64	2.57	23.35	2.03	25.38	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.550	13.958	0.000	0.000	0.600	15.227
Dixie	7/16"		2.64	2.57																	
Dixie	7/8"		2.64	2.57																	
								Srv,weighted =	*	Srv,weighted =	*	Srv,weighted =	*	Srv,weighted =	*	Srv,weighted =	27.99	Srv,weighted =	*	Srv,weighted =	27.69
Griffin	#60	1.91	2.70	2.65	27.92	1.33	29.26	0.140	4.096	0.150	4.389	0.150	4.389	0.140	4.096	0.120	3.511	0.170	4.974	0.150	4.389
Griffin	#40	1.95	2.70	2.65	26.42	1.36	27.78	0.050	1.389	0.040	1.111	0.030	0.833	0.040	1.111	0.050	1.389	0.040	1.111	0.060	1.667
Griffin	#30	2.01	2.70	2.65	24.15	1.40	25.56	0.050	1.278	0.060	1.533	0.050	1.278	0.060	1.533	0.050	1.278	0.060	1.533	0.050	1.278
Griffin	#16	2.09	2.70	2.65	21.13	1.46	22.59	0.110	2.485	0.070	1.581	0.120	2.711	0.110	2.485	0.230	5.196	0.180	4.067	0.140	3.163
Griffin	#4	2.15	2.70	2.65	18.87	1.50	20.37	0.200	4.074	0.180	3.667	0.190	3.870	0.300	6.111	0.400	8.148	0.300	6.111	0.250	5.093
Griffin	7/16"	2.28	2.70	2.65	13.96	1.59	15.56	0.350	5.444	0.400	6.222	0.210	3.267	0.340	5.289	0.100	1.556	0.250	3.889	0.350	5.444
Griffin	7/8"	2.46	2.70	2.65	7.17	1.72	8.89	0.100	0.889	0.100	0.889	0.250	2.222	0.010	0.089	0.000	0.000	0.000	0.000	0.000	0.000
								Srv,weighted =	19.66	Srv,weighted =	19.39	Srv,weighted =	18.57	Srv,weighted =	20.71	Srv,weighted =	21.08	Srv,weighted =	21.69	Srv,weighted =	21.03
Kennesaw	#60	2.12	2.82	2.78	23.74	1.08	24.82	0.170	4.220	0.150	3.723	0.150	3.723	0.160	3.972	0.000	0.000	0.180	4.468	0.150	3.723
Kennesaw	#40	2.20	2.82	2.78	20.86	1.12	21.99	0.040	0.879	0.040	0.879	0.030	0.660	0.040	0.879	0.000	0.000	0.050	1.099	0.060	1.319
Kennesaw	#30	2.13	2.82	2.78	23.38	1.09	24.47	0.050	1.223	0.060	1.468	0.050	1.223	0.040	0.979	0.000	0.000	0.070	1.713	0.050	1.223
Kennesaw	#16	2.16	2.82	2.78	22.30	1.10	23.40	0.120	2.809	0.070	1.638	0.120	2.809	0.110	2.574	0.000	0.000	0.150	3.511	0.140	3.277
Kennesaw	#4	2.19	2.82	2.78	21.22	1.12	22.34	0.170	3.798	0.180	4.021	0.190	4.245	0.190	4.245	0.000	0.000	0.300	6.702	0.250	5.585
Kennesaw	7/16"	2.36	2.82	2.78	15.11	1.20	16.31	0.320	5.220	0.400	6.525	0.210	3.426	0.420	6.851	0.000	0.000	0.250	4.078	0.350	5.709
Kennesaw	7/8"	2.43	2.82	2.78	12.59	1.24	13.83	0.130	1.798	0.100	1.383	0.250	3.457	0.040	0.553	0.000	0.000	0.000	0.000	0.000	0.000
								Srv,weighted =	19.95	Srv,weighted =	19.64	Srv,weighted =	19.54	Srv,weighted =	20.05	Srv,weighted =	*	Srv,weighted =	21.57	Srv,weighted =	20.84
Lithia Springs	#60	1.99	2.64	2.61	23.75	0.87	24.62	0.130	3.201	0.150	3.693	0.150	3.693	0.150	3.693	0.000	0.000	0.000	0.000	0.150	3.693
Lithia Springs	#40	2.04	2.64	2.61	21.84	0.89	22.73	0.030	0.682	0.040	0.909	0.030	0.682	0.030	0.682	0.000	0.000	0.000	0.000	0.060	1.364
Lithia Springs	#30	2.07	2.64	2.61	20.69	0.90	21.59	0.060	1.295	0.060	1.295	0.050	1.080	0.050	1.080	0.000	0.000	0.000	0.000	0.050	1.080
Lithia Springs	#16	2.09	2.64	2.61	19.92	0.91	20.83	0.100	2.083	0.070	1.458	0.120	2.500	0.150	3.125	0.000	0.000	0.000	0.000	0.140	2.917
Lithia Springs	#4	2.19	2.64	2.61	16.09	0.95	17.05	0.280	4.773	0.180	3.068	0.190	3.239	0.220	3.750	0.000	0.000	0.000	0.000	0.250	4.261
Lithia Springs	7/16"	2.22	2.64	2.61	14.94	0.97	15.91	0.380	6.045	0.400	6.364	0.210	3.341	0.250	3.977	0.000	0.000	0.000	0.000	0.350	5.568
Lithia Springs	7/8"	2.31	2.64	2.61	11.49	1.01	12.50	0.020	0.250	0.100	1.250	0.250	3.125	0.150	1.875	0.000	0.000	0.000	0.000	0.000	0.000
								Srv,weighted =	18.33	Srv,weighted =	18.04	Srv,weighted =	17.66	Srv,weighted =	18.18	Srv,weighted =	*	Srv,weighted =	*	Srv,weighted =	18.88
Lithonia	#60	2.09	2.64	2.61	19.92	0.91	20.83	0.160	3.333	0.150	3.125	0.150	3.125	0.160	3.333	0.000	0.000	0.200	4.167	0.150	3.125
Lithonia	#40	2.09	2.64	2.61	19.92	0.91	20.83	0.040	0.833	0.040	0.833	0.030	0.625	0.040	0.833	0.000	0.000	0.070	1.458	0.060	1.250
Lithonia	#30	2.09	2.64	2.61	19.92	0.91	20.83	0.050	1.042	0.060	1.250	0.050	1.042	0.040	0.833	0.000	0.000	0.060	1.250	0.050	1.042
Lithonia	#16	2.06	2.64	2.61	21.07	0.90	21.97	0.120	2.636	0.070	1.538	0.120	2.636	0.110	2.417	0.000	0.000	0.150	3.295	0.140	3.076
Lithonia	#4	2.08	2.64	2.60	20.00	1.21	21.21	0.150	3.182	0.180	3.818	0.190	4.030	0.190	4.030	0.000	0.000	0.270	5.727	0.260	5.303
Lithonia	7/16"	2.28	2.64	2.60	12.31	1.33	13.64	0.480	6.545	0.400	5.455	0.210	2.864	0.460	6.273	0.000	0.000	0.250	3.409	0.350	4.773
Lithonia	7/8"	2.37	2.64	2.60	8.85	1.38	10.23	0.100	1.023	0.100	1.023	0.250	2.557	0.040	0.409	0.000	0.000	0.000	0.000	0.000	0.000
								Srv,weighted =	18.59	Srv,weighted =	17.04	Srv,weighted =	16.88	Srv,weighted =	18.13	Srv,weighted =	*	Srv,weighted =	19.31	Srv,weighted =	18.57
Mt View	#60	1.98	2.70	2.66	25.56	1.10	26.67	0.180	4.800	0.150	4.000	0.150	4.000	0.160	4.267	0.000	0.000	0.220	5.867	0.150	4.000
Mt View	#40	1.98	2.70	2.66	25.56	1.10	26.67	0.040	1.067	0.040	1.067	0.030	0.800	0.030	0.800	0.000	0.000	0.030	0.800	0.060	1.600
Mt View	#30	2.00	2.70	2.66	24.81	1.11	25.93	0.060	1.556	0.060	1.556	0.050	1.296	0.040	1.037	0.000	0.000	0.060	1.556	0.050	1.296
Mt View	#16	2.02	2.70	2.66	24.06	1.13	25.19	0.120	3.022	0.070	1.763	0.120	3.022	0.120	3.022	0.000	0.000	0.190	4.785	0.140	3.526
Mt View	#4	2.09	2.70	2.66	21.43	1.16	22.59	0.200	4.519	0.180	4.067	0.190	4.293	0.250	5.648	0.000	0.000	0.300	6.778	0.250	5.648
Mt View	7/16"	2.27	2.70	2.66	14.66	1.26	15.93	0.250	3.981	0.400	6.370	0.210	3.344	0.350	5.574	0.000	0.000	0.200	8.185	0.350	5.574
Mt View	7/8"	2.40	2.70	2.66	9.77	1.34	11.11	0.150	1.667	0.100	1.111	0.250	2.778	0.050	0.556	0.000	0.000	0.000	0.000	0.000	0.000
								Srv,weighted =	20.61	Srv,weighted =	19.93	Srv,weighted =	19.53	Srv,weighted =	20.90	Srv,weighted =	*	Srv,weighted =	22.97	Srv,weighted =	21.64
Norcross	#60	2.06	2.72	2.69	23.42	0.84	24.26	0.170	4.125	0.150	3.640	0.150	3.640	0.170	4.125	0.000	0.000	0.210	5.096	0.150	3.640
Norcross	#40	2.08	2.72	2.69	22.68	0.85	23.53	0.060	1.412	0.040	0.941	0.030	0.706	0.040	0.941	0.000	0.000	0.090	2.118	0.060	1.412
Norcross	#30	2.11	2.72	2.69	21.56	0.87	22.43	0.040	0.897	0.060	1.346	0.050	1.121	0.040	0.897	0.000	0.000	0.040	0.897	0.050	1.121
Norcross	#16	2.12	2.72	2.69	21.19	0.87	22.06	0.130	2.868	0.070	1.544	0.120	2.647	0.120	2.647	0.000	0.000	0.160	3.529	0.140	3.088
Norcross	#4	2.28	2.73	2.69	15.24	1.24	16.48	0.200	3.297	0.180	2.967	0.190	3.132	0.200	3.297	0.000	0.000	0.250	4.121	0.250	4.121
Norcross	7/16"	2.39	2.73	2.69	11.15	1.30	12.45	0.250	3.114	0.400	4.982	0.210	2.615	0.350	4.359	0.000	0.000	0.250	3.114	0.350	4.359
Norcross	7/8"	2.34	2.73	2.69	13.01	1.27	14.29	0.150	2.143	0.100	1.429	0.250	3.571	0.080	1.143	0.000	0.000	0.000	0.000	0.000	0.000
								Srv,weighted =	17.85	Srv,weighted =	16.85	Srv,weighted =	13.86	Srv,weighted =	17.41	Srv,weighted =	*	Srv,weighted =	18.87	Srv,weighted =	17.74
Palmer Sta	#60	2.04	2.69	2.65	23.02	1.14	24.16	0.170	4.108	0.150	3.625	0.150	3.625	0.180	4.349	0.000	0.000	0.230	5.558	0.150	3.625
Palmer Sta	#40	2.06	2.69	2.65	22.26	1.16	23.42	0.050	1.171	0.040	0.937	0.030	0.703	0.040	0.937	0.000	0.000	0.060	1.405	0.060	1.405
Palmer Sta	#30	2.07	2.69	2.65	21.89	1.16	23.05	0.050	1.152	0.060	1.383	0.050	1.152	0.040	0.922	0.000	0.000	0.080	1.844	0.050	1.152
Palmer Sta	#16	2.10	2.69	2.65	20.75	1.18	21.93	0.110	2.413	0.070	1.535	0.120	2.632	0.110	2.413	0.000	0.000	0.130	2.851	0.140	3.071
Palmer Sta	#4	2.22	2.69	2.65	16.23	1.25	17.47	0.220	3.844	0.180	3.145	0.190	3.320	0.230	4.019	0.000	0.000	0.250	4.368	0.250	4.368
Palmer Sta	7/16"	2.36	2.69	2.65	10.94	1.32	12.27	0.250	3.067	0.400	4.907	0.210	2.576	0.350	4.294	0.000	0.000	0.250	3.067	0.350	4.294
Palmer Sta	7/8"	2.47	2.69	2.65	6.79	1.39	8.18	0.150	1.227	0.100	0.818	0.250	2.045	0.05	0.409	0.000	0.000	0.000	0.000	0.000	0.000
								Srv,weighted =	16.98	Srv,weighted =	16.35	Srv,weighted =	16.05	Srv,weighted =	17.34	Srv,weighted =	*	Srv,weighted =	19.09	Srv,weighted =	17.91

Table 2. Aggregate Specific Rugosity - Pouring Test (continued).

QUARRY	SIZE RET.	Gb	Gap	Gag	Sms	Smi	Srv	Base (DOT) Weight Factor	Srv*W.F.	Coarse Base Weight Factor	Srv*W.F.	Fine Base Weight Factor	Srv*W.F.	Binder (DOT) Weight Factor	Srv*W.F.	F Mix (DOT) Weight Factor	Srv*W.F.	E Mix (DOT) Weight Factor	Srv*W.F.	Coarse E Mix Weight Factor	Srv*W.F.
Postell	#60	1.97	2.72	2.63	25.10	2.48	27.57	0.150	4.136	0.150	4.136	0.150	4.136	0.140	3.860	0.000	0.000	0.000	0.000	0.150	4.136
Postell	#40	1.98	2.72	2.63	24.71	2.49	27.21	0.040	1.088	0.040	1.088	0.030	0.816	0.030	0.816	0.000	0.000	0.000	0.000	0.060	1.632
Postell	#30	1.99	2.72	2.63	24.33	2.50	26.84	0.040	1.074	0.060	1.610	0.050	1.342	0.050	1.342	0.000	0.000	0.000	0.000	0.050	1.342
Postell	#16	2.02	2.72	2.63	23.19	2.54	25.74	0.120	3.088	0.070	1.801	0.120	3.088	0.180	4.632	0.000	0.000	0.000	0.000	0.140	3.603
Postell	#4	2.10	2.72	2.63	20.15	2.64	22.79	0.200	4.559	0.180	4.103	0.190	4.331	0.200	4.559	0.000	0.000	0.000	0.000	0.250	5.699
Postell	7/16"	2.19	2.72	2.63	16.73	2.76	19.49	0.250	4.871	0.400	7.794	0.210	4.092	0.300	5.846	0.000	0.000	0.000	0.000	0.350	6.820
Postell	7/8"	2.35	2.72	2.63	10.65	2.96	13.60	0.020	<u>0.272</u>	0.100	<u>1.360</u>	0.250	<u>3.401</u>	0.100	<u>1.360</u>	0.000	<u>0.000</u>	0.000	<u>0.000</u>	0.000	<u>0.000</u>
								Srv,weighted =	19.09	Srv,weighted =	21.89	Srv,weighted =	21.21	Srv,weighted =	22.42	Srv,weighted =	*	Srv,weighted =	*	Srv,weighted =	23.23
Ruby	#60	2.00	2.76	2.73	26.74	0.80	27.54	0.130	3.580	0.150	4.130	0.150	4.130	0.140	3.855	0.180	4.957	0.200	5.507	0.150	4.130
Ruby	#40	2.00	2.76	2.73	26.74	0.80	27.54	0.030	0.826	0.040	1.101	0.030	0.826	0.030	0.826	0.050	1.377	0.030	0.826	0.060	1.652
Ruby	#30	2.03	2.76	2.73	25.64	0.81	26.45	0.040	1.058	0.060	1.587	0.050	1.322	0.050	1.322	0.070	1.851	0.070	1.851	0.050	1.322
Ruby	#16	2.08	2.76	2.73	24.54	0.82	25.36	0.150	3.804	0.070	1.775	0.120	3.043	0.130	3.297	0.200	5.072	0.200	5.072	0.140	3.551
Ruby	#4	2.18	2.76	2.73	20.15	0.87	21.01	0.200	4.203	0.180	3.783	0.190	3.993	0.200	4.203	0.400	8.406	0.250	5.254	0.250	5.254
Ruby	7/16"	2.21	2.76	2.73	19.05	0.88	19.93	0.300	5.978	0.400	7.971	0.210	4.185	0.450	8.967	0.100	1.993	0.250	4.982	0.350	6.975
Ruby	7/8"	2.39	2.76	2.73	12.45	0.95	13.41	0.150	<u>2.011</u>	0.100	<u>1.341</u>	0.250	<u>3.351</u>	0.000	<u>0.000</u>	0.000	<u>0.000</u>	0.000	<u>0.000</u>	0.000	<u>0.000</u>
								Srv,weighted =	21.46	Srv,weighted =	21.69	Srv,weighted =	20.85	Srv,weighted =	22.47	Srv,weighted =	23.66	Srv,weighted =	23.49	Srv,weighted =	22.88
Stockbridge	#60	2.03	2.65	2.61	22.22	1.17	23.40	0.170	3.977	0.150	3.509	0.150	3.509	0.150	3.509	0.000	0.000	0.210	4.913	0.150	3.509
Stockbridge	#40	2.01	2.65	2.61	22.99	1.16	24.15	0.050	1.208	0.040	0.966	0.030	0.725	0.030	0.725	0.000	0.000	0.040	0.966	0.060	1.449
Stockbridge	#30	2.03	2.65	2.61	22.22	1.17	23.40	0.050	1.170	0.060	1.404	0.050	1.170	0.050	1.170	0.000	0.000	0.060	1.404	0.050	1.170
Stockbridge	#16	2.05	2.65	2.61	21.46	1.19	22.64	0.130	2.943	0.070	1.585	0.120	2.717	0.170	3.849	0.000	0.000	0.170	3.849	0.140	3.170
Stockbridge	#4	2.25	2.65	2.60	13.46	1.63	15.09	0.200	3.019	0.180	2.717	0.190	2.868	0.250	3.774	0.000	0.000	0.270	4.075	0.250	3.774
Stockbridge	7/16"	2.24	2.65	2.60	13.85	1.63	15.47	0.300	4.642	0.400	6.189	0.210	3.249	0.300	4.642	0.000	0.000	0.250	3.868	0.350	5.415
Stockbridge	7/8"	2.39	2.65	2.60	8.08	1.73	9.81	0.100	<u>0.981</u>	0.100	<u>0.981</u>	0.250	<u>2.453</u>	0.05	<u>0.491</u>	0.000	<u>0.000</u>	0.000	<u>0.000</u>	0.000	<u>0.000</u>
								Srv,weighted =	17.94	Srv,weighted =	17.35	Srv,weighted =	16.69	Srv,weighted =	18.16	Srv,weighted =	*	Srv,weighted =	19.08	Srv,weighted =	18.49
Tyrone	#60	1.98	2.68	2.64	25.00	1.12	26.12	0.130	3.396	0.150	3.918	0.150	3.918	0.130	3.396	0.220	5.746	0.220	5.746	0.150	3.918
Tyrone	#40	2.01	2.68	2.64	23.86	1.14	25.00	0.040	1.000	0.040	1.000	0.030	0.750	0.040	1.000	0.040	1.000	0.040	1.000	0.060	1.500
Tyrone	#30	2.07	2.68	2.64	21.59	1.17	22.76	0.060	1.366	0.060	1.366	0.050	1.138	0.060	1.366	0.070	1.593	0.070	1.593	0.050	1.138
Tyrone	#16	2.12	2.68	2.64	19.70	1.20	20.90	0.150	3.134	0.070	1.463	0.120	2.507	0.130	2.716	0.200	4.179	0.170	3.552	0.140	2.925
Tyrone	#4	2.18	2.69	2.65	17.74	1.22	18.96	0.200	3.792	0.180	3.413	0.190	3.602	0.200	3.792	0.420	7.963	0.250	4.740	0.250	4.740
Tyrone	7/16"	2.25	2.69	2.65	15.09	1.26	16.36	0.220	3.599	0.400	6.543	0.210	3.435	0.400	6.543	0.050	0.818	0.250	4.089	0.350	5.725
Tyrone	7/8"	2.37	2.69	2.65	10.57	1.33	11.90	0.200	<u>2.379</u>	0.100	<u>1.190</u>	0.250	<u>2.974</u>	0.040	<u>0.476</u>	0.000	<u>0.000</u>	0.000	<u>0.000</u>	0.000	<u>0.000</u>
								Srv,weighted =	18.67	Srv,weighted =	18.89	Srv,weighted =	18.32	Srv,weighted =	19.29	Srv,weighted =	21.30	Srv,weighted =	20.72	Srv,weighted =	19.95
White	#60	2.09	2.74	2.71	22.88	0.84	23.72	0.110	2.609	0.150	3.558	0.150	3.558	0.120	2.847	0.120	2.847	0.000	0.000	0.150	3.558
White	#40	2.11	2.74	2.71	22.14	0.85	22.99	0.040	0.920	0.040	0.920	0.030	0.690	0.020	0.460	0.050	1.150	0.000	0.000	0.060	1.380
White	#30	2.15	2.74	2.71	20.66	0.87	21.53	0.060	1.292	0.060	1.292	0.050	1.077	0.200	4.307	0.250	5.383	0.000	0.000	0.050	1.077
White	#16	2.19	2.74	2.71	19.19	0.88	20.07	0.190	3.814	0.070	1.405	0.120	2.409	0.160	3.212	0.250	5.018	0.000	0.000	0.140	2.810
White	#4	2.24	2.74	2.71	17.34	0.91	18.25	0.200	3.650	0.180	3.285	0.190	3.467	0.240	4.380	0.300	5.474	0.000	0.000	0.250	4.562
White	7/16"	2.33	2.74	2.71	14.02	0.94	14.96	0.300	4.489	0.400	5.985	0.210	3.142	0.320	4.788	0.200	2.993	0.000	0.000	0.350	5.237
White	7/8"	2.40	2.74	2.71	11.44	0.97	12.41	0.100	<u>1.241</u>	0.100	<u>1.241</u>	0.250	<u>3.102</u>	0.080	<u>0.993</u>	0.000	<u>0.000</u>	0.000	<u>0.000</u>	0.000	<u>0.000</u>
								Srv,weighted =	18.01	Srv,weighted =	17.69	Srv,weighted =	17.45	Srv,weighted =	20.99	Srv,weighted =	22.86	Srv,weighted =	*	Srv,weighted =	18.62

Table 3. Macro Surface Voids - Pouring Test.

QUARRY	SIZE RET	Gb	Gsa	Gsb	Sma	Base (DOT) Weight Factor	Sma*W.F.	Coarse Base Weight Factor	Sma*W.F.	Fine Base Weight Factor	Sma*W.F.	Binder (DOT) Weight Factor	Sma*W.F.	F Mix (DOT) Weight Factor	Sma*W.F.	E Mix (DOT) Weight Factor	Sma*W.F.	Coarse E Mix Weight Factor	Sma*W.F.
Athens	#60	1.84	2.73	2.68	31.34	0.160	5.015	0.150	4.701	0.150	4.701	0.110	3.448	0.200	6.269	0.180	5.642	0.150	4.701
Athens	#40	1.87	2.73	2.68	30.22	0.040	1.209	0.040	1.209	0.030	0.907	0.040	1.209	0.060	1.813	0.060	1.813	0.060	1.813
Athens	#30	1.96	2.73	2.68	26.87	0.050	1.343	0.060	1.612	0.050	1.343	0.050	1.343	0.060	1.612	0.040	1.075	0.050	1.343
Athens	#16	2.06	2.73	2.68	23.13	0.100	2.313	0.070	1.619	0.120	2.776	0.100	2.313	0.180	4.164	0.200	4.627	0.140	3.239
Athens	#4	2.14	2.73	2.68	20.15	0.200	4.030	0.180	3.627	0.190	3.828	0.200	4.030	0.400	8.060	0.250	5.037	0.250	5.037
Athens	7/16"	2.26	2.73	2.68	15.67	0.350	5.485	0.400	6.269	0.210	3.291	0.450	7.052	0.100	1.567	0.250	3.918	0.350	5.485
Athens	7/8"	2.39	2.73	2.68	10.82	0.100	1.082	0.100	1.082	0.250	2.705	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
						Sma,weighted =	20.48	Sma,weighted =	20.12	Sma,weighted =	19.55	Sma,weighted =	19.40	Sma,weighted =	23.49	Sma,weighted =	22.11	Sma,weighted	21.62
Ball Ground	#60	2.11	2.79	2.75	23.27	0.140	3.258	0.150	3.491	0.150	3.491	0.130	3.025	0.000	0.000	0.150	3.491	0.150	3.491
Ball Ground	#40	2.13	2.79	2.75	22.55	0.040	0.902	0.040	0.902	0.030	0.676	0.030	0.676	0.000	0.000	0.050	1.127	0.060	1.353
Ball Ground	#30	1.72	2.79	2.75	37.45	0.050	1.873	0.060	2.247	0.050	1.873	0.060	2.247	0.000	0.000	0.060	2.247	0.050	1.873
Ball Ground	#16	2.08	2.79	2.75	24.36	0.120	2.924	0.070	1.705	0.120	2.924	0.130	3.167	0.000	0.000	0.140	3.411	0.140	3.411
Ball Ground	#4	2.22	2.79	2.75	19.27	0.250	4.818	0.180	3.469	0.190	3.662	0.250	4.818	0.000	0.000	0.300	5.782	0.250	4.818
Ball Ground	7/16"	2.24	2.79	2.75	18.55	0.300	5.564	0.400	7.418	0.210	3.895	0.380	7.047	0.000	0.000	0.250	4.636	0.350	6.491
Ball Ground	7/8"	2.46	2.79	2.75	10.55	0.100	1.055	0.100	1.055	0.250	2.636	0.020	0.211	0.000	0.000	0.000	0.000	0.000	0.000
						Sma,weighted =	20.39	Sma,weighted =	20.29	Sma,weighted =	19.16	Sma,weighted =	21.19	Sma,weighted =	*	Sma,weighted =	20.69	Sma,weighted	21.44
Barin	#60	1.96	2.72	2.67	26.59	0.190	5.052	0.150	3.989	0.150	3.989	0.170	4.521	0.220	5.850	0.220	5.850	0.150	3.989
Barin	#40	2.02	2.72	2.67	24.34	0.050	1.217	0.040	0.974	0.030	0.730	0.050	1.217	0.070	1.704	0.050	1.217	0.060	1.461
Barin	#30	2.05	2.72	2.67	23.22	0.040	0.929	0.060	1.393	0.050	1.161	0.050	1.161	0.040	0.929	0.060	1.393	0.050	1.161
Barin	#16	2.11	2.72	2.67	20.97	0.120	2.517	0.070	1.468	0.120	2.517	0.080	1.678	0.170	3.566	0.220	4.614	0.140	2.936
Barin	#4	2.05	2.72	2.67	23.22	0.150	3.483	0.180	4.180	0.190	4.412	0.250	5.805	0.300	6.966	0.380	8.824	0.250	5.805
Barin	7/16"	2.31	2.72	2.67	13.48	0.350	4.719	0.300	4.045	0.210	2.831	0.370	4.989	0.200	2.697	0.070	0.944	0.350	4.719
Barin	7/8"	2.40	2.72	2.67	10.11	0.100	1.011	0.100	1.011	0.250	2.528	0.030	0.303	0.000	0.000	0.000	0.000	0.000	0.000
						Sma,weighted =	18.93	Sma,weighted =	17.06	Sma,weighted =	18.17	Sma,weighted =	19.67	Sma,weighted =	21.71	Sma,weighted =	22.84	Sma,weighted	20.07
Buford	#60	2.01	2.65	2.61	22.99	0.110	2.529	0.150	3.448	0.150	3.448	0.160	3.678	0.210	4.828	0.000	0.000	0.150	3.448
Buford	#40	1.96	2.65	2.61	24.90	0.090	2.241	0.040	0.996	0.030	0.747	0.040	0.996	0.030	0.747	0.000	0.000	0.060	1.494
Buford	#30	1.98	2.65	2.61	24.14	0.040	0.966	0.060	1.448	0.050	1.207	0.040	0.966	0.060	1.448	0.000	0.000	0.050	1.207
Buford	#16	2.03	2.65	2.61	22.22	0.110	2.444	0.070	1.556	0.120	2.667	0.110	2.444	0.200	4.444	0.000	0.000	0.140	3.111
Buford	#4	2.13	2.65	2.61	18.39	0.200	3.678	0.180	3.310	0.190	3.494	0.250	4.598	0.500	9.195	0.000	0.000	0.250	4.598
Buford	7/16"	2.18	2.65	2.61	16.48	0.350	5.766	0.400	6.590	0.210	3.460	0.350	5.766	0.000	0.000	0.000	0.000	0.350	5.766
Buford	7/8"	2.26	2.65	2.61	13.41	0.100	1.341	0.100	1.341	0.250	3.352	0.050	0.670	0.000	0.000	0.000	0.000	0.000	0.000
						Sma,weighted =	18.97	Sma,weighted =	18.69	Sma,weighted =	18.38	Sma,weighted =	19.12	Sma,weighted =	20.66	Sma,weighted =	*	Sma,weighted	19.62
Candler	#60	2.05	2.64	2.61	21.46	0.200	4.291	0.150	3.218	0.150	3.218	0.170	3.648	0.150	3.218	0.230	4.935	0.150	3.218
Candler	#40	2.02	2.64	2.61	22.61	0.050	1.130	0.040	0.904	0.030	0.678	0.030	0.678	0.030	0.678	0.050	1.130	0.060	1.356
Candler	#30	1.99	2.64	2.61	23.75	0.030	0.713	0.060	1.425	0.050	1.188	0.030	0.713	0.060	1.425	0.050	1.188	0.050	1.188
Candler	#16	2.01	2.64	2.61	22.99	0.080	1.839	0.070	1.609	0.120	2.759	0.100	2.299	0.220	5.057	0.160	3.678	0.140	3.218
Candler	#4	2.08	2.64	2.61	20.31	0.190	3.858	0.180	3.655	0.190	3.858	0.270	5.483	0.440	8.935	0.270	5.483	0.250	5.077
Candler	7/16"	2.22	2.64	2.61	14.94	0.230	3.437	0.400	5.977	0.210	3.138	0.320	4.782	0.100	1.494	0.240	3.586	0.350	5.230
Candler	7/8"	2.39	2.64	2.61	8.43	0.220	1.854	0.100	0.843	0.250	2.107	0.080	0.674	0.000	0.000	0.000	0.000	0.000	0.000
						Sma,weighted =	17.12	Sma,weighted =	17.63	Sma,weighted =	16.95	Sma,weighted =	18.28	Sma,weighted =	20.81	Sma,weighted =	20.00	Sma,weighted	19.29
Cummings	#60	1.94	2.66	2.58	24.81	0.150	3.721	0.150	3.721	0.150	3.721	0.160	3.969	0.000	0.000	0.000	0.000	0.150	3.721
Cummings	#40	1.93	2.66	2.58	25.19	0.050	1.260	0.040	1.008	0.030	0.756	0.060	1.512	0.000	0.000	0.000	0.000	0.060	1.512
Cummings	#30	1.97	2.66	2.58	23.64	0.040	0.946	0.060	1.419	0.050	1.182	0.060	1.419	0.000	0.000	0.000	0.000	0.050	1.182
Cummings	#16	2.08	2.66	2.58	19.38	0.110	2.132	0.070	1.357	0.120	2.326	0.120	2.326	0.000	0.000	0.000	0.000	0.140	2.713
Cummings	#4	2.22	2.76	2.71	18.08	0.160	2.893	0.180	3.255	0.190	3.435	0.200	3.616	0.000	0.000	0.000	0.000	0.250	4.520
Cummings	7/16"	2.00	2.76	2.71	26.20	0.290	7.598	0.400	10.480	0.210	5.502	0.350	9.170	0.000	0.000	0.000	0.000	0.350	9.170
Cummings	7/8"	2.12	2.76	2.71	21.77	0.150	3.266	0.100	2.177	0.250	5.443	0.050	1.089	0.000	0.000	0.000	0.000	0.000	0.000
						Sma,weighted =	21.81	Sma,weighted =	23.42	Sma,weighted =	22.36	Sma,weighted =	23.10	Sma,weighted =	*	Sma,weighted =	*	Sma,weighted	22.82
Dalton	#60	2.14	2.75	2.68	20.15	0.130	2.619	0.150	3.022	0.150	3.022	0.110	2.216	0.000	0.000	0.000	0.000	0.150	3.022
Dalton	#40	2.11	2.75	2.68	21.27	0.040	0.851	0.040	0.851	0.030	0.638	0.030	0.638	0.000	0.000	0.000	0.000	0.060	1.276
Dalton	#30	2.14	2.75	2.68	20.15	0.060	1.209	0.060	1.209	0.050	1.007	0.040	0.806	0.000	0.000	0.000	0.000	0.050	1.007
Dalton	#16	2.09	2.75	2.68	22.01	0.140	3.082	0.070	1.541	0.120	2.642	0.210	4.623	0.000	0.000	0.000	0.000	0.140	3.082
Dalton	#4	2.11	2.74	2.71	22.14	0.180	3.985	0.180	3.985	0.190	4.207	0.260	5.756	0.000	0.000	0.000	0.000	0.250	5.535
Dalton	7/16"	2.22	2.74	2.71	18.08	0.370	6.690	0.400	7.232	0.210	3.797	0.300	5.424	0.000	0.000	0.000	0.000	0.350	6.328
Dalton	7/8"	2.34	2.74	2.71	13.65	0.180	2.458	0.100	1.365	0.250	3.413	0.05	0.683	0.000	0.000	0.000	0.000	0.000	0.000
						Sma,weighted =	20.89	Sma,weighted =	19.21	Sma,weighted =	18.73	Sma,weighted =	20.15	Sma,weighted =	*	Sma,weighted =	*	Sma,weighted	20.25
Dan	#60	1.94	2.69	2.64	26.52	0.140	3.712	0.150	3.977	0.150	3.977	0.130	3.447	0.000	0.000	0.000	0.000	0.150	3.977
Dan	#40	1.93	2.69	2.64	26.89	0.050	1.345	0.040	1.076	0.030	0.807	0.040	1.076	0.000	0.000	0.000	0.000	0.060	1.614
Dan	#30	2.00	2.69	2.64	24.24	0.090	2.182	0.060	1.455	0.050	1.212	0.050	1.212	0.000	0.000	0.000	0.000	0.050	1.212
Dan	#16	2.04	2.69	2.64	22.73	0.120	2.727	0.070	1.591	0.120	2.727	0.130	2.955	0.000	0.000	0.000	0.000	0.140	3.182
Dan	#4	2.09	2.69	2.64	20.83	0.200	4.167	0.180	3.750	0.190	3.958	0.250	5.208	0.000	0.000	0.000	0.000	0.250	5.208
Dan	7/16"	2.18	2.69	2.64	17.42	0.250	4.356	0.400	6.970	0.210	3.659	0.350	6.098	0.000	0.000	0.000	0.000	0.350	6.098
Dan	7/8"	2.34	2.69	2.64	11.36	0.150	1.705	0.100	1.136	0.250	2.841	0.050	0.568	0.000	0.000	0.000	0.000	0.000	0.000
						Sma,weighted =	20.19	Sma,weighted =	19.95	Sma,weighted =	19.18	Sma,weighted =	20.56	Sma,weighted =	*	Sma,weighted =	*	Sma,weighted	21.29

Table 3. Macro Surface Voids - Pouring Test (continued).

QUARRY	SIZE RET	Gb	Gsp	Gsg	Sma	Base (DOT) Weight Factor	Sma*W.F.	Coarse Base Weight Factor	Sma*W.F.	Fine Base Weight Factor	Sma*W.F.	Binder (DOT) Weight Factor	Sma*W.F.	F Mix (DOT) Weight Factor	Sma*W.F.	E Mix (DOT) Weight Factor	Sma*W.F.	Coarse E Mix Weight Factor	Sma*W.F.
Dixie	#60		2.64	2.57															
Dixie	#40	1.82	2.64	2.57	29.18	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.180	5.253	0.000	0.000	0.210	6.128
Dixie	#30	1.80	2.64	2.57	29.95	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.070	2.097	0.000	0.000	0.050	1.498
Dixie	#16	1.82	2.64	2.57	29.18	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.200	5.837	0.000	0.000	0.140	4.086
Dixie	#4	1.97	2.64	2.57	23.35	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.550	12.840	0.000	0.000	0.600	14.008
Dixie	7/16"		2.64	2.57															
Dixie	7/8"		2.64	2.57															
						Sma,weighted =	*	Sma,weighted =	*	Sma,weighted =	*	Sma,weighted =	*	Sma,weighted =	26.03	Sma,weighted =	*	Ima,weighted ·	25.72
Griffin	#60	1.91	2.70	2.65	27.92	0.140	3.909	0.150	4.189	0.150	4.189	0.140	3.909	0.120	3.351	0.170	4.747	0.150	4.189
Griffin	#40	1.95	2.70	2.65	26.42	0.050	1.321	0.040	1.057	0.030	0.792	0.040	1.057	0.050	1.321	0.040	1.057	0.060	1.585
Griffin	#30	2.01	2.70	2.65	24.15	0.050	1.208	0.060	1.449	0.050	1.208	0.060	1.449	0.050	1.208	0.060	1.449	0.050	1.208
Griffin	#16	2.09	2.70	2.65	21.13	0.110	2.325	0.070	1.479	0.120	2.536	0.110	2.325	0.230	4.860	0.180	3.804	0.140	2.958
Griffin	#4	2.15	2.70	2.65	18.87	0.200	3.774	0.180	3.396	0.190	3.585	0.300	5.660	0.400	7.547	0.300	5.660	0.250	4.717
Griffin	7/16"	2.28	2.70	2.65	13.96	0.350	4.887	0.400	5.585	0.210	2.932	0.340	4.747	0.100	1.396	0.250	3.491	0.350	4.887
Griffin	7/8"	2.48	2.70	2.65	7.17	0.100	0.717	0.100	0.717	0.250	1.792	0.010	0.072	0.000	0.000	0.000	0.000	0.000	0.000
						Sma,weighted =	18.14	Sma,weighted =	17.87	Sma,weighted =	17.03	Sma,weighted =	19.22	Sma,weighted =	19.68	Sma,weighted =	20.21	Ima,weighted ·	19.54
Kennesaw	#60	2.12	2.82	2.78	23.74	0.170	4.036	0.150	3.561	0.150	3.561	0.160	3.799	0.000	0.000	0.180	4.273	0.150	3.561
Kennesaw	#40	2.20	2.82	2.78	20.86	0.040	0.835	0.040	0.835	0.030	0.626	0.040	0.835	0.000	0.000	0.050	1.043	0.060	1.252
Kennesaw	#30	2.13	2.82	2.78	23.38	0.050	1.169	0.060	1.403	0.050	1.169	0.040	0.935	0.000	0.000	0.070	1.637	0.050	1.169
Kennesaw	#16	2.16	2.82	2.78	22.30	0.120	2.676	0.070	1.561	0.120	2.676	0.110	2.453	0.000	0.000	0.150	3.345	0.140	3.122
Kennesaw	#4	2.19	2.82	2.78	21.22	0.170	3.608	0.180	3.820	0.190	4.032	0.190	4.032	0.000	0.000	0.300	6.367	0.250	5.306
Kennesaw	7/16"	2.36	2.82	2.78	15.11	0.320	4.835	0.400	6.043	0.210	3.173	0.420	6.345	0.000	0.000	0.250	3.777	0.350	5.288
Kennesaw	7/8"	2.43	2.82	2.78	12.59	0.130	1.637	0.100	1.259	0.250	3.147	0.040	0.504	0.000	0.000	0.000	0.000	0.000	0.000
						Sma,weighted =	18.79	Sma,weighted =	18.48	Sma,weighted =	18.38	Sma,weighted =	18.90	Sma,weighted =	*	Sma,weighted =	20.44	Ima,weighted ·	19.70
Lithia Springs	#60	1.99	2.64	2.61	23.75	0.130	3.088	0.150	3.563	0.150	3.563	0.150	3.563	0.000	0.000	0.000	0.000	0.150	3.563
Lithia Springs	#40	2.04	2.64	2.61	21.84	0.030	0.655	0.040	0.874	0.030	0.655	0.030	0.655	0.000	0.000	0.000	0.000	0.060	1.310
Lithia Springs	#30	2.07	2.64	2.61	20.69	0.060	1.241	0.060	1.241	0.050	1.034	0.050	1.034	0.000	0.000	0.000	0.000	0.050	1.034
Lithia Springs	#16	2.09	2.64	2.61	19.92	0.100	1.992	0.070	1.395	0.120	2.391	0.150	2.989	0.000	0.900	0.000	0.000	0.140	2.789
Lithia Springs	#4	2.19	2.64	2.61	16.09	0.280	4.506	0.180	2.897	0.190	3.057	0.220	3.540	0.000	0.000	0.000	0.000	0.250	4.023
Lithia Springs	7/16"	2.22	2.64	2.61	14.94	0.380	5.678	0.400	5.977	0.210	3.138	0.250	3.736	0.000	0.000	0.000	0.000	0.350	5.230
Lithia Springs	7/8"	2.31	2.64	2.61	11.49	0.020	0.230	0.100	1.149	0.250	2.874	0.150	1.724	0.000	0.000	0.000	0.000	0.000	0.000
						Sma,weighted =	17.39	Sma,weighted =	17.10	Sma,weighted =	16.71	Sma,weighted =	17.24	Sma,weighted =	*	Sma,weighted =	*	Ima,weighted ·	17.95
Lithonia	#60	2.09	2.64	2.61	19.92	0.160	3.188	0.150	2.989	0.150	2.989	0.160	3.188	0.000	0.000	0.200	3.985	0.150	2.989
Lithonia	#40	2.09	2.64	2.61	19.92	0.040	0.797	0.040	0.797	0.030	0.598	0.040	0.797	0.000	0.000	0.070	1.395	0.060	1.195
Lithonia	#30	2.09	2.64	2.61	19.92	0.050	0.996	0.060	1.195	0.050	0.996	0.040	0.797	0.000	0.000	0.060	1.195	0.050	0.996
Lithonia	#16	2.06	2.64	2.61	21.07	0.120	2.529	0.070	1.475	0.120	2.629	0.110	2.318	0.000	0.000	0.150	3.161	0.140	2.950
Lithonia	#4	2.08	2.64	2.60	20.00	0.150	3.000	0.180	3.600	0.190	3.800	0.190	3.800	0.000	0.000	0.270	5.400	0.250	5.000
Lithonia	7/16"	2.28	2.64	2.60	12.31	0.480	5.908	0.400	4.923	0.210	2.585	0.460	5.662	0.000	0.000	0.250	3.077	0.350	4.308
Lithonia	7/8"	2.37	2.64	2.60	8.85	0.100	0.885	0.100	0.885	0.250	2.212	0.040	0.354	0.000	0.000	0.000	0.000	0.000	0.000
						Sma,weighted =	17.30	Sma,weighted =	15.86	Sma,weighted =	15.71	Sma,weighted =	16.92	Sma,weighted =	*	Sma,weighted =	18.21	Ima,weighted ·	17.44
Mt View	#60	1.98	2.70	2.66	25.56	0.180	4.602	0.150	3.835	0.150	3.835	0.160	4.090	0.000	0.000	0.220	5.624	0.150	3.835
Mt View	#40	1.98	2.70	2.66	25.56	0.040	1.023	0.040	1.023	0.030	0.767	0.030	0.767	0.000	0.000	0.030	0.767	0.060	1.534
Mt View	#30	2.00	2.70	2.66	24.81	0.060	1.489	0.060	1.489	0.050	1.241	0.040	0.992	0.000	0.000	0.060	1.489	0.050	1.241
Mt View	#16	2.02	2.70	2.66	24.06	0.120	2.887	0.070	1.684	0.120	2.887	0.120	2.887	0.000	0.000	0.190	4.571	0.140	3.368
Mt View	#4	2.09	2.70	2.66	21.43	0.200	4.286	0.180	3.857	0.190	4.071	0.250	5.357	0.000	0.000	0.300	6.429	0.250	5.357
Mt View	7/16"	2.27	2.70	2.66	14.66	0.250	3.665	0.400	5.865	0.210	3.079	0.350	5.132	0.000	0.000	0.200	2.932	0.350	5.132
Mt View	7/8"	2.40	2.70	2.66	9.77	0.150	1.466	0.100	0.977	0.250	2.444	0.050	0.489	0.000	0.000	0.000	0.000	0.000	0.000
						Sma,weighted =	19.42	Sma,weighted =	18.73	Sma,weighted =	18.32	Sma,weighted =	19.71	Sma,weighted =	*	Sma,weighted =	21.81	Ima,weighted ·	20.47
Norcross	#60	2.06	2.72	2.69	23.42	0.170	3.981	0.150	3.513	0.150	3.513	0.170	3.981	0.000	0.000	0.210	4.918	0.150	3.513
Norcross	#40	2.08	2.72	2.69	22.68	0.060	1.361	0.040	0.907	0.030	0.680	0.040	0.907	0.000	0.000	0.090	2.041	0.060	1.361
Norcross	#30	2.11	2.72	2.69	21.56	0.040	0.862	0.060	1.294	0.050	1.078	0.040	0.862	0.000	0.000	0.040	0.862	0.050	1.078
Norcross	#16	2.12	2.72	2.69	21.19	0.130	2.755	0.070	1.483	0.120	2.543	0.120	2.543	0.000	0.000	0.160	3.390	0.140	2.967
Norcross	#4	2.28	2.73	2.69	15.24	0.200	3.048	0.180	2.743	0.190	2.896	0.200	3.048	0.000	0.000	0.250	3.810	0.250	3.810
Norcross	7/16"	2.39	2.73	2.69	11.15	0.250	2.788	0.400	4.461	0.210	2.342	0.350	3.903	0.000	0.000	0.250	2.788	0.350	3.903
Norcross	7/8"	2.34	2.73	2.69	13.01	0.150	1.952	0.100	1.301	0.250	3.253	0.080	1.041	0.000	0.000	0.000	0.000	0.000	0.000
						Sma,weighted =	16.75	Sma,weighted =	15.70	Sma,weighted =	13.05	Sma,weighted =	16.29	Sma,weighted =	*	Sma,weighted =	17.81	Ima,weighted ·	16.63
Palmer Sta	#60	2.04	2.69	2.65	23.02	0.170	3.913	0.150	3.453	0.150	3.453	0.180	4.143	0.000	0.000	0.230	5.294	0.150	3.453
Palmer Sta	#40	2.06	2.69	2.65	22.26	0.050	1.113	0.040	0.891	0.030	0.668	0.040	0.891	0.000	0.000	0.060	1.336	0.060	1.336
Palmer Sta	#30	2.07	2.69	2.65	21.89	0.050	1.094	0.060	1.313	0.050	1.094	0.040	0.875	0.000	0.000	0.080	1.751	0.050	1.094
Palmer Sta	#16	2.10	2.69	2.65	20.75	0.110	2.283	0.070	1.453	0.120	2.491	0.110	2.283	0.000	0.000	0.130	2.698	0.140	2.906
Palmer Sta	#4	2.22	2.69	2.65	16.23	0.220	3.570	0.180	2.921	0.190	3.083	0.230	3.732	0.000	0.000	0.250	4.057	0.250	4.057
Palmer Sta	7/16"	2.36	2.69	2.65	10.94	0.250	2.736	0.400	4.377	0.210	2.298	0.350	3.830	0.000	0.000	0.250	2.736	0.350	3.830
Palmer Sta	7/8"	2.47	2.69	2.65	6.79	0.150	1.019	0.100	0.679	0.250	1.698	0.05	0.340	0.000	0.000	0.000	0.000	0.000	0.000
						Sma,weighted =	15.73	Sma,weighted =	15.09	Sma,weighted =	14.78	Sma,weighted =	16.09	Sma,weighted =	*	Sma,weighted =	17.87	Ima,weighted ·	16.68

Table 3. Macro Surface Voids - Pouring Test (continued).

QUARRY	SIZE RET	Gb	Gap	Gag	Sma	Base (DOT) Weight Factor	Sma*W.F.	Coarse Base Weight Factor	Sma*W.F.	Fine Base Weight Factor	Sma*W.F.	Binder (DOT) Weight Factor	Sma*W.F.	F Mix (DOT) Weight Factor	Sma*W.F.	E Mix (DOT) Weight Factor	Sma*W.F.	Coarse E Mix Weight Factor	Sma*W.F.
Postell	#60	1.97	2.72	2.63	25.10	0.150	3.764	0.150	3.764	0.150	3.764	0.140	3.513	0.000	0.000	0.000	0.000	0.150	3.764
Postell	#40	1.98	2.72	2.63	24.71	0.040	0.989	0.040	0.989	0.030	0.741	0.030	0.741	0.000	0.000	0.000	0.000	0.060	1.483
Postell	#30	1.99	2.72	2.63	24.33	0.040	0.973	0.060	1.460	0.050	1.217	0.050	1.217	0.000	0.000	0.000	0.000	0.050	1.217
Postell	#16	2.02	2.72	2.63	23.19	0.120	2.783	0.070	1.624	0.120	2.783	0.180	4.175	0.000	0.000	0.000	0.000	0.140	3.247
Postell	#4	2.10	2.72	2.63	20.15	0.200	4.030	0.180	3.627	0.190	3.829	0.200	4.030	0.000	0.000	0.000	0.000	0.250	5.038
Postell	7/16"	2.19	2.72	2.63	16.73	0.250	4.183	0.400	6.692	0.210	3.513	0.300	5.019	0.000	0.000	0.000	0.000	0.350	5.856
Postell	7/8"	2.35	2.72	2.63	10.65	0.020	0.213	0.100	1.065	0.250	2.662	0.100	1.065	0.000	0.000	0.000	0.000	0.000	0.000
						Sma,weighted =	16.94	Sma,weighted =	19.22	Sma,weighted =	18.51	Sma,weighted =	19.76	Sma,weighted =	*	Sma,weighted =	*	Sma,weighted =	20.60
Ruby	#60	2.00	2.76	2.73	26.74	0.130	3.476	0.150	4.011	0.150	4.011	0.140	3.744	0.180	4.813	0.200	5.348	0.150	4.011
Ruby	#40	2.00	2.76	2.73	26.74	0.030	0.802	0.040	1.070	0.030	0.802	0.030	0.802	0.050	1.337	0.030	0.802	0.060	1.604
Ruby	#30	2.03	2.76	2.73	25.64	0.040	1.026	0.060	1.538	0.050	1.282	0.050	1.282	0.070	1.795	0.070	1.795	0.050	1.282
Ruby	#16	2.06	2.76	2.73	24.54	0.150	3.681	0.070	1.718	0.120	2.945	0.130	3.190	0.200	4.908	0.200	4.908	0.140	3.436
Ruby	#4	2.18	2.76	2.73	20.15	0.200	4.029	0.180	3.626	0.190	3.828	0.200	4.029	0.400	8.059	0.250	5.037	0.250	5.037
Ruby	7/16"	2.21	2.76	2.73	19.05	0.300	5.714	0.400	7.619	0.210	4.000	0.450	8.571	0.100	1.905	0.250	4.762	0.350	6.667
Ruby	7/8"	2.39	2.76	2.73	12.45	0.150	1.868	0.100	1.245	0.250	3.114	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
						Sma,weighted =	20.60	Sma,weighted =	20.83	Sma,weighted =	19.98	Sma,weighted =	21.62	Sma,weighted =	22.82	Sma,weighted =	22.65	Sma,weighted =	22.04
Stockbridge	#60	2.03	2.65	2.61	22.22	0.170	3.778	0.150	3.333	0.150	3.333	0.150	3.333	0.000	0.000	0.210	4.667	0.150	3.333
Stockbridge	#40	2.01	2.65	2.61	22.99	0.050	1.149	0.240	0.920	0.030	0.690	0.030	0.690	0.000	0.000	0.040	0.920	0.060	1.379
Stockbridge	#30	2.03	2.65	2.61	22.22	0.050	1.111	0.060	1.333	0.050	1.111	0.050	1.111	0.000	0.000	0.060	1.333	0.050	1.111
Stockbridge	#16	2.05	2.65	2.61	21.46	0.130	2.789	0.070	1.502	0.120	2.575	0.170	3.648	0.000	0.000	0.170	3.648	0.140	3.004
Stockbridge	#4	2.25	2.65	2.60	13.46	0.200	2.692	0.180	2.423	0.190	2.558	0.250	3.365	0.000	0.000	0.270	3.635	0.250	3.365
Stockbridge	7/16"	2.24	2.65	2.60	13.85	0.300	4.154	0.400	5.538	0.210	2.908	0.300	4.154	0.000	0.000	0.250	3.462	0.350	4.846
Stockbridge	7/8"	2.39	2.65	2.60	8.08	0.100	0.808	0.100	0.808	0.250	2.019	0.05	0.404	0.000	0.000	0.000	0.000	0.000	0.000
						Sma,weighted =	16.48	Sma,weighted =	15.86	Sma,weighted =	15.19	Sma,weighted =	16.70	Sma,weighted =	*	Sma,weighted =	17.66	Sma,weighted =	17.04
Tyrone	#60	1.98	2.68	2.64	25.00	0.130	3.250	0.150	3.750	0.150	3.750	0.130	3.250	0.220	5.500	0.220	5.500	0.150	3.750
Tyrone	#40	2.01	2.68	2.64	23.86	0.040	0.955	0.040	0.955	0.030	0.716	0.040	0.955	0.040	0.955	0.040	0.955	0.060	1.432
Tyrone	#30	2.07	2.68	2.64	21.59	0.060	1.295	0.060	1.295	0.050	1.080	0.060	1.295	0.070	1.511	0.070	1.511	0.050	1.080
Tyrone	#16	2.12	2.68	2.64	19.70	0.150	2.955	0.070	1.379	0.120	2.364	0.130	2.561	0.200	3.939	0.170	3.348	0.140	2.758
Tyrone	#4	2.18	2.69	2.65	17.74	0.200	3.547	0.180	3.192	0.190	3.370	0.200	3.547	0.420	7.449	0.250	4.434	0.250	4.434
Tyrone	7/16"	2.25	2.69	2.65	15.09	0.220	3.321	0.400	6.038	0.210	3.170	0.400	6.038	0.050	0.755	0.250	3.774	0.350	5.283
Tyrone	7/8"	2.37	2.69	2.65	10.57	0.200	2.113	0.100	1.057	0.250	2.642	0.040	0.423	0.000	0.000	0.000	0.000	0.000	0.000
						Sma,weighted =	17.44	Sma,weighted =	17.67	Sma,weighted =	17.09	Sma,weighted =	18.07	Sma,weighted =	20.11	Sma,weighted =	19.52	Sma,weighted =	18.74
White	#60	2.09	2.74	2.71	22.88	0.110	2.517	0.150	3.432	0.150	3.432	0.120	2.745	0.120	2.745	0.000	0.000	0.150	3.432
White	#40	2.11	2.74	2.71	22.14	0.040	0.886	0.040	0.886	0.030	0.664	0.020	0.443	0.050	1.107	0.000	0.000	0.060	1.328
White	#30	2.15	2.74	2.71	20.66	0.060	1.240	0.060	1.240	0.050	1.033	0.200	4.133	0.250	5.166	0.000	0.000	0.050	1.033
White	#16	2.19	2.74	2.71	19.19	0.190	3.646	0.070	1.343	0.120	2.303	0.160	3.070	0.250	4.797	0.000	0.000	0.140	2.686
White	#4	2.24	2.74	2.71	17.34	0.200	3.469	0.180	3.122	0.190	3.295	0.240	4.162	0.300	5.203	0.000	0.000	0.250	4.336
White	7/16"	2.33	2.74	2.71	14.02	0.300	4.207	0.400	5.609	0.210	2.945	0.320	4.487	0.200	2.804	0.000	0.000	0.350	4.908
White	7/8"	2.40	2.74	2.71	11.44	0.100	1.144	0.100	1.144	0.250	2.860	0.080	0.915	0.000	0.000	0.000	0.000	0.000	0.000
						Sma,weighted =	17.11	Sma,weighted =	16.77	Sma,weighted =	16.53	Sma,weighted =	19.96	Sma,weighted =	21.82	Sma,weighted =	*	Sma,weighted =	17.72

Table 4. Micro Surface Voids - Pouring Test.

QUARRY	SIZE RET	Gb	Gsb	Gsa	Smi	Base (DOT) Weight Factor	Smi*W.F.	Coarse Base Weight Factor	Smi*W.F.	Fine Base Weight Factor	Smi*W.F.	Binder (DOT) Weight Factor	Smi*W.F.	F Mix (DOT) Weight Factor	Smi*W.F.	E Mix (DOT) Weight Factor	Smi*W.F.	Coarse E Mix Weight Factor	Smi*W.F.
Athens	#60	1.84	2.73	2.68	1.26	0.160	0.201	0.150	0.189	0.150	0.189	0.110	0.138	0.200	0.251	0.180	0.226	0.150	0.189
Athens	#40	1.87	2.73	2.68	1.28	0.040	0.051	0.040	0.051	0.030	0.038	0.040	0.051	0.060	0.077	0.060	0.077	0.060	0.077
Athens	#30	1.96	2.73	2.68	1.34	0.050	0.067	0.060	0.080	0.050	0.067	0.050	0.067	0.060	0.080	0.040	0.054	0.050	0.067
Athens	#16	2.06	2.73	2.68	1.41	0.100	0.141	0.070	0.099	0.120	0.169	0.100	0.141	0.180	0.253	0.200	0.282	0.140	0.197
Athens	#4	2.14	2.73	2.68	1.46	0.200	0.292	0.180	0.263	0.190	0.278	0.200	0.292	0.400	0.585	0.250	0.366	0.250	0.366
Athens	7/16"	2.26	2.73	2.68	1.54	0.350	0.541	0.400	0.618	0.210	0.324	0.450	0.695	0.100	0.154	0.250	0.386	0.350	0.541
Athens	7/8"	2.39	2.73	2.68	1.63	0.100	0.163	0.100	0.163	0.250	0.408	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
						Smi,weighted =	1.46	Smi,weighted =	1.46	Smi,weighted =	1.47	Smi,weighted =	1.38	Smi,weighted =	1.40	Smi,weighted =	1.39	Smi,weighted =	1.44
Ball Ground	#60	2.11	2.79	2.75	1.10	0.140	0.154	0.150	0.165	0.150	0.165	0.130	0.143	0.000	0.000	0.150	0.165	0.150	0.165
Ball Ground	#40	2.13	2.79	2.75	1.11	0.040	0.044	0.040	0.044	0.030	0.033	0.030	0.033	0.000	0.000	0.050	0.056	0.060	0.067
Ball Ground	#30	1.72	2.79	2.75	0.90	0.050	0.045	0.060	0.054	0.050	0.045	0.060	0.054	0.000	0.000	0.060	0.054	0.050	0.045
Ball Ground	#16	2.08	2.79	2.75	1.08	0.120	0.130	0.070	0.076	0.120	0.130	0.130	0.141	0.000	0.000	0.140	0.152	0.140	0.152
Ball Ground	#4	2.22	2.79	2.75	1.16	0.250	0.289	0.180	0.208	0.190	0.220	0.250	0.289	0.000	0.000	0.300	0.347	0.250	0.289
Ball Ground	7/16"	2.24	2.79	2.75	1.17	0.300	0.350	0.400	0.467	0.210	0.245	0.380	0.444	0.000	0.000	0.250	0.292	0.350	0.409
Ball Ground	7/8"	2.46	2.79	2.75	1.28	0.100	0.128	0.100	0.128	0.250	0.321	0.020	0.026	0.000	0.000	0.000	0.000	0.000	0.000
						Smi,weighted =	1.14	Smi,weighted =	1.14	Smi,weighted =	1.16	Smi,weighted =	1.13	Smi,weighted =	*	Smi,weighted =	1.07	Smi,weighted =	1.13
Barin	#60	1.96	2.72	2.67	1.35	0.190	0.256	0.150	0.202	0.150	0.202	0.170	0.229	0.220	0.297	0.220	0.297	0.150	0.202
Barin	#40	2.02	2.72	2.67	1.39	0.050	0.070	0.040	0.056	0.030	0.042	0.050	0.070	0.070	0.097	0.050	0.070	0.060	0.083
Barin	#30	2.05	2.72	2.67	1.41	0.040	0.056	0.060	0.085	0.050	0.071	0.050	0.071	0.040	0.056	0.060	0.085	0.050	0.071
Barin	#16	2.11	2.72	2.67	1.45	0.120	0.174	0.070	0.102	0.120	0.174	0.080	0.116	0.170	0.247	0.220	0.320	0.140	0.203
Barin	#4	2.05	2.72	2.67	1.41	0.150	0.212	0.180	0.254	0.190	0.268	0.250	0.353	0.300	0.423	0.380	0.536	0.250	0.353
Barin	7/16"	2.31	2.72	2.67	1.59	0.350	0.557	0.300	0.477	0.210	0.334	0.370	0.588	0.200	0.318	0.070	0.111	0.350	0.557
Barin	7/8"	2.40	2.72	2.67	1.65	0.100	0.165	0.100	0.165	0.250	0.413	0.030	0.050	0.000	0.000	0.000	0.000	0.000	0.000
						Smi,weighted =	1.49	Smi,weighted =	1 34	Smi,weighted =	1.50	Smi,weighted =	1.48	Smi,weighted =	1.44	Smi,weighted =	1.42	Smi,weighted =	1.47
Buford	#60	2.01	2.65	2.61	1.02	0.110	0.112	0.150	0.153	0.150	0.153	0.160	0.163	0.210	0.214	0.000	0.000	0.150	0.153
Buford	#40	1.96	2.65	2.61	0.99	0.090	0.089	0.040	0.040	0.030	0.030	0.040	0.040	0.030	0.030	0.000	0.000	0.060	0.060
Buford	#30	1.98	2.65	2.61	1.00	0.040	0.040	0.060	0.060	0.050	0.050	0.040	0.040	0.060	0.060	0.000	0.000	0.050	0.050
Buford	#15	2.03	2.65	2.61	1.03	0.110	0.113	0.070	0.072	0.120	0.124	0.110	0.113	0.200	0.206	0.000	0.000	0.140	0.144
Buford	#4	2.13	2.65	2.61	1.08	0.200	0.216	0.180	0.194	0.190	0.205	0.250	0.270	0.500	0.540	0.000	0.000	0.250	0.270
Buford	7/16"	2.18	2.65	2.61	1.11	0.350	0.387	0.400	0.442	0.210	0.232	0.350	0.387	0.000	0.000	0.000	0.000	0.350	0.387
Buford	7/8"	2.26	2.65	2.81	1.15	0.100	0.115	0.100	0.115	0.250	0.286	0.050	0.057	0.000	0.000	0.000	0.000	0.000	0.000
						Smi,weighted =	1.07	Smi,weighted =	1.08	Smi,weighted =	1.08	Smi,weighted =	1.07	Smi,weighted =	1.05	Smi,weighted =	*	Smi,weighted =	1.06
Candler	#60	2.05	2.64	2.61	0.89	0.200	0.179	0.150	0.134	0.150	0.134	0.170	0.152	0.150	0.134	0.230	0.205	0.150	0.134
Candler	#40	2.02	2.64	2.61	0.88	0.050	0.044	0.040	0.035	0.030	0.026	0.030	0.026	0.030	0.026	0.050	0.044	0.060	0.053
Candler	#30	1.99	2.64	2.61	0.87	0.030	0.026	0.060	0.052	0.050	0.043	0.030	0.026	0.060	0.052	0.050	0.043	0.050	0.043
Candler	#16	2.01	2.64	2.61	0.88	0.080	0.070	0.070	0.061	0.120	0.105	0.100	0.088	0.220	0.193	0.160	0.140	0.140	0.123
Candler	#4	2.08	2.64	2.61	0.91	0.190	0.172	0.180	0.163	0.190	0.172	0.270	0.245	0.440	0.398	0.270	0.245	0.250	0.226
Candler	7/16"	2.22	2.64	2.61	0.97	0.230	0.222	0.400	0.387	0.210	0.203	0.320	0.309	0.100	0.097	0.240	0.232	0.350	0.338
Candler	7/8"	2.39	2.64	2.61	1.04	0.220	0.229	0.100	0.104	0.250	0.260	0.080	0.083	0.000	0.000	0.000	0.000	0.000	0.000
						Smi,weighted =	0.94	Smi,weighted =	0.94	Smi,weighted =	0.94	Smi,weighted =	0.93	Smi,weighted =	0.90	Smi,weighted =	0.91	Smi,weighted =	0.92
Cummings	#60	1.94	2.66	2.58	2.26	0.150	0.339	0.150	0.339	0.150	0.339	0.160	0.362	0.000	0.000	0.000	0.000	0.150	0.339
Cummings	#40	1.93	2.66	2.58	2.25	0.050	0.112	0.040	0.090	0.030	0.067	0.060	0.135	0.000	0.000	0.000	0.000	0.060	0.135
Cummings	#30	1.97	2.66	2.58	2.30	0.040	0.092	0.060	0.138	0.050	0.115	0.060	0.138	0.000	0.000	0.000	0.000	0.050	0.115
Cummings	#16	2.08	2.66	2.58	2.42	0.110	0.267	0.070	0.170	0.120	0.291	0.120	0.291	0.000	0.000	0.000	0.000	0.140	0.339
Cummings	#4	2.22	2.76	2.71	1.48	0.160	0.237	0.180	0.267	0.190	0.282	0.200	0.297	0.000	0.000	0.000	0.000	0.250	0.371
Cummings	7/16"	2.00	2.76	2.71	1.34	0.290	0.388	0.400	0.535	0.210	0.281	0.350	0.468	0.000	0.000	0.000	0.000	0.350	0.468
Cummings	7/8"	2.12	2.76	2.71	1.42	0.150	0.213	0.100	0.142	0.250	0.354	0.050	0.071	0.000	0.000	0.000	0.000	0.000	0.000
						Smi,weighted =	1.65	Smi,weighted =	1.68	Smi,weighted =	1.73	Smi,weighted =	1.76	Smi,weighted =	*	Smi,weighted =	*	Smi,weighted =	1.77
Dalton	#60	2.14	2.75	2.68	2.03	0.130	0.264	0.150	0.305	0.150	0.305	0.110	0.224	0.000	0.000	0.000	0.000	0.150	0.305
Dalton	#40	2.11	2.75	2.68	2.00	0.040	0.080	0.040	0.080	0.030	0.060	0.030	0.060	0.000	0.000	0.000	0.000	0.060	0.120
Dalton	#30	2.14	2.75	2.68	2.03	0.060	0.122	0.060	0.122	0.050	0.102	0.040	0.081	0.000	0.000	0.000	0.000	0.050	0.102
Dalton	#16	2.09	2.75	2.68	1.99	0.140	0.278	0.070	0.139	0.120	0.238	0.210	0.417	0.000	0.000	0.000	0.000	0.140	0.278
Dalton	#4	2.11	2.74	2.71	0.85	0.180	0.153	0.180	0.153	0.190	0.162	0.260	0.222	0.000	0.000	0.000	0.000	0.250	0.213
Dalton	7/16"	2.22	2.74	2.71	0.90	0.370	0.332	0.400	0.359	0.210	0.188	0.300	0.269	0.000	0.000	0.000	0.000	0.350	0.314
Dalton	7/8"	2.34	2.74	2.71	0.95	0.180	0.170	0.100	0.095	0.250	0.236	0.05	0.047	0.000	0.000	0.000	0.000	0.000	0.000
						Smi,weighted =	1.40	Smi,weighted =	1.25	Smi,weighted =	1.29	Smi,weighted =	1.32	Smi,weighted =	*	Smi,weighted =	*	Smi,weighted =	1.33
Dan	#60	1.94	2.69	2.64	1.37	0.140	0.191	0.150	0.205	0.150	0.205	0.130	0.178	0.000	0.000	0.000	0.000	0.150	0.205
Dan	#40	1.93	2.69	2.64	1.36	0.050	0.068	0.040	0.054	0.030	0.041	0.040	0.054	0.000	0.000	0.000	0.000	0.060	0.082
Dan	#30	2.00	2.69	2.64	1.41	0.090	0.127	0.060	0.084	0.050	0.070	0.050	0.070	0.000	0.000	0.000	0.000	0.050	0.070
Dan	#16	2.04	2.69	2.64	1.44	0.120	0.172	0.070	0.101	0.120	0.172	0.130	0.187	0.000	0.000	0.000	0.000	0.140	0.201
Dan	#4	2.09	2.69	2.64	1.47	0.200	0.294	0.180	0.265	0.190	0.280	0.250	0.368	0.000	0.000	0.000	0.000	0.250	0.368
Dan	7/16"	2.18	2.69	2.64	1.53	0.250	0.384	0.400	0.614	0.210	0.322	0.350	0.537	0.000	0.000	0.000	0.000	0.350	0.537
Dan	7/8"	2.34	2.69	2.64	1.65	0.150	0.247	0.100	0.165	0.250	0.412	0.050	0.082	0.000	0.000	0.000	0.000	0.000	0.000
						Smi,weighted =	1.48	Smi,weighted =	1.49	Smi,weighted =	1.50	Smi,weighted =	1.48	Smi,weighted =	*	Smi,weighted =	*	Smi,weighted =	1.46

Table 4. Micro Surface Voids - Pouring Test (continued).

QUARRY	SIZE RET	Gb	Gap	Gag	Smi	Base (DOT) Weight Factor	Smi*W.F.	Coarse Base Weight Factor	Smi*W.F.	Fine Base Weight Factor	Smi*W.F.	Binder (DOT) Weight Factor	Smi*W.F.	F Mix (DOT) Weight Factor	Smi*W.F.	E Mix (DOT) Weight Factor	Smi*W.F.	Coarse E Mix Weight Factor	Smi*W.F.
Dixie	#60		2.64	2.57															
Dixie	#40	1.82	2.64	2.57	1.88	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.180	0.338	0.000	0.000	0.210	0.394
Dixie	#30	1.80	2.64	2.57	1.86	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.070	0.130	0.000	0.000	0.050	0.093
Dixie	#16	1.82	2.64	2.57	1.88	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.200	0.376	0.000	0.000	0.140	0.263
Dixie	#4	1.97	2.64	2.57	2.03	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.550	1.118	0.000	0.000	0.600	1.219
Dixie	7/16"		2.64	2.57															
Dixie	7/8"		2.64	2.57															
						Smi,weighted =	*	Smi,weighted =	*	Smi,weighted =	*	Smi,weighted =	*	Smi,weighted =	1.96	Smi,weighted =	*	Smi,weighted =	1.97
Griffin	#60	1.91	2.70	2.65	1.33	0.140	0.187	0.150	0.200	0.150	0.200	0.140	0.187	0.120	0.160	0.170	0.227	0.150	0.200
Griffin	#40	1.95	2.70	2.65	1.36	0.050	0.068	0.040	0.055	0.030	0.041	0.040	0.055	0.050	0.068	0.040	0.055	0.060	0.082
Griffin	#30	2.01	2.70	2.65	1.40	0.050	0.070	0.060	0.084	0.050	0.070	0.060	0.084	0.050	0.070	0.060	0.084	0.050	0.070
Griffin	#16	2.09	2.70	2.65	1.46	0.110	0.161	0.070	0.102	0.120	0.175	0.110	0.161	0.230	0.336	0.180	0.263	0.140	0.204
Griffin	#4	2.15	2.70	2.65	1.50	0.200	0.300	0.180	0.270	0.190	0.285	0.300	0.451	0.400	0.601	0.300	0.451	0.250	0.376
Griffin	7/16"	2.28	2.70	2.65	1.59	0.350	0.558	0.400	0.637	0.210	0.335	0.340	0.542	0.100	0.159	0.250	0.398	0.350	0.558
Griffin	7/8"	2.46	2.70	2.65	1.72	0.100	0.172	0.100	0.172	0.250	0.430	0.010	0.017	0.000	0.000	0.000	0.000	0.000	0.000
						Smi,weighted =	1.52	Smi,weighted =	1.52	Smi,weighted =	1.54	Smi,weighted =	1.50	Smi,weighted =	1.39	Smi,weighted =	1.48	Smi,weighted =	1.49
Kennesaw	#60	2.12	2.82	2.78	1.08	0.170	0.184	0.150	0.162	0.150	0.162	0.160	0.173	0.000	0.000	0.180	0.195	0.150	0.162
Kennesaw	#40	2.20	2.82	2.78	1.12	0.040	0.045	0.040	0.045	0.030	0.034	0.040	0.045	0.000	0.000	0.050	0.056	0.060	0.067
Kennesaw	#30	2.13	2.82	2.78	1.09	0.060	0.054	0.060	0.065	0.050	0.054	0.040	0.043	0.000	0.000	0.070	0.076	0.050	0.054
Kennesaw	#16	2.16	2.82	2.78	1.10	0.120	0.132	0.070	0.077	0.120	0.132	0.110	0.121	0.000	0.000	0.150	0.165	0.140	0.154
Kennesaw	#4	2.19	2.82	2.78	1.12	0.170	0.190	0.180	0.201	0.190	0.212	0.190	0.212	0.000	0.000	0.300	0.335	0.250	0.279
Kennesaw	7/16"	2.36	2.82	2.79	1.20	0.320	0.385	0.400	0.482	0.210	0.253	0.420	0.506	0.000	0.000	0.250	0.301	0.350	0.421
Kennesaw	7/8"	2.43	2.82	2.78	1.24	0.130	0.161	0.100	0.124	0.250	0.310	0.040	0.050	0.000	0.000	0.000	0.000	0.000	0.000
						Smi,weighted =	1.15	Smi,weighted =	1.16	Smi,weighted =	1.16	Smi,weighted =	1.15	Smi,weighted =	*	Smi,weighted =	1.13	Smi,weighted =	1.14
Lithia Springs	#60	1.99	2.64	2.61	0.87	0.130	0.113	0.150	0.130	0.150	0.130	0.150	0.130	0.000	0.000	0.000	0.000	0.150	0.130
Lithia Springs	#40	2.04	2.64	2.61	0.89	0.030	0.027	0.040	0.036	0.030	0.027	0.030	0.027	0.000	0.000	0.000	0.000	0.060	0.053
Lithia Springs	#30	2.07	2.64	2.61	0.90	0.060	0.054	0.060	0.054	0.050	0.045	0.050	0.045	0.000	0.000	0.000	0.000	0.050	0.045
Lithia Springs	#16	2.09	2.64	2.61	0.91	0.100	0.091	0.070	0.064	0.120	0.109	0.150	0.136	0.000	0.000	0.000	0.000	0.140	0.127
Lithia Springs	#4	2.19	2.64	2.61	0.95	0.280	0.267	0.180	0.172	0.190	0.181	0.220	0.210	0.000	0.000	0.000	0.000	0.250	0.238
Lithia Springs	7/16"	2.22	2.64	2.61	0.97	0.380	0.367	0.400	0.387	0.210	0.203	0.250	0.242	0.000	0.000	0.000	0.000	0.350	0.338
Lithia Springs	7/8"	2.31	2.64	2.61	1.01	0.020	0.020	0.100	0.101	0.250	0.251	0.150	0.151	0.000	0.000	0.000	0.000	0.000	0.000
						Smi,weighted =	0.94	Smi,weighted =	0.94	Smi,weighted =	0.95	Smi,weighted =	0.94	Smi,weighted =	*	Smi,weighted =	*	Smi,weighted =	0.93
Lithonia	#60	2.09	2.64	2.61	0.91	0.160	0.146	0.150	0.136	0.150	0.136	0.160	0.146	0.000	0.000	0.200	0.182	0.150	0.136
Lithonia	#40	2.09	2.64	2.61	0.91	0.040	0.036	0.040	0.036	0.030	0.027	0.040	0.036	0.000	0.000	0.070	0.064	0.060	0.055
Lithonia	#30	2.09	2.64	2.61	0.91	0.050	0.045	0.060	0.055	0.050	0.045	0.040	0.036	0.000	0.000	0.060	0.055	0.050	0.045
Lithonia	#16	2.06	2.64	2.61	0.90	0.120	0.108	0.070	0.063	0.120	0.108	0.110	0.099	0.000	0.000	0.150	0.135	0.140	0.126
Lithonia	#4	2.08	2.64	2.60	1.21	0.150	0.182	0.180	0.218	0.190	0.230	0.190	0.230	0.000	0.000	0.270	0.327	0.250	0.303
Lithonia	7/16"	2.28	2.64	2.60	1.33	0.480	0.638	0.400	0.531	0.210	0.279	0.460	0.611	0.000	0.000	0.250	0.332	0.350	0.465
Lithonia	7/8"	2.37	2.64	2.60	1.38	0.100	0.138	0.100	0.138	0.250	0.345	0.040	0.055	0.000	0.000	0.000	0.000	0.000	0.000
						Smi,weighted =	1.29	Smi,weighted =	1.18	Smi,weighted =	1.17	Smi,weighted =	1.21	Smi,weighted =	*	Smi,weighted =	1.09	Smi,weighted =	1.13
Mt View	#60	1.98	2.70	2.66	1.10	0.180	0.198	0.150	0.165	0.150	0.165	0.160	0.176	0.000	0.000	0.220	0.243	0.150	0.165
Mt View	#40	1.98	2.70	2.66	1.10	0.040	0.044	0.040	0.044	0.030	0.033	0.030	0.033	0.000	0.000	0.030	0.033	0.060	0.066
Mt View	#30	2.00	2.70	2.66	1.11	0.060	0.067	0.060	0.067	0.050	0.056	0.040	0.045	0.000	0.000	0.060	0.067	0.050	0.056
Mt View	#16	2.02	2.70	2.66	1.13	0.120	0.136	0.070	0.079	0.120	0.135	0.120	0.135	0.000	0.000	0.190	0.214	0.140	0.158
Mt View	#4	2.09	2.70	2.66	1.16	0.200	0.233	0.180	0.210	0.190	0.221	0.250	0.291	0.000	0.000	0.300	0.349	0.250	0.291
Mt View	7/16"	2.27	2.70	2.66	1.26	0.250	0.316	0.400	0.506	0.210	0.265	0.350	0.442	0.000	0.000	0.200	0.253	0.350	0.442
Mt View	7/8"	2.40	2.70	2.66	1.34	0.150	0.201	0.100	0.134	0.250	0.334	0.050	0.067	0.000	0.000	0.000	0.000	0.000	0.000
						Smi,weighted =	1.19	Smi,weighted =	1.20	Smi,weighted =	1.21	Smi,weighted =	1.19	Smi,weighted =	*	Smi,weighted =	1.16	Smi,weighted =	1.18
Norcross	#60	2.06	2.72	2.69	0.84	0.170	0.144	0.150	0.127	0.150	0.127	0.170	0.144	0.000	0.000	0.210	0.177	0.150	0.127
Norcross	#40	2.09	2.72	2.69	0.85	0.060	0.051	0.040	0.034	0.030	0.026	0.040	0.034	0.000	0.000	0.090	0.077	0.060	0.051
Norcross	#30	2.11	2.72	2.69	0.87	0.040	0.035	0.060	0.052	0.050	0.043	0.040	0.035	0.000	0.000	0.040	0.035	0.050	0.043
Norcross	#16	2.12	2.72	2.69	0.87	0.130	0.113	0.070	0.061	0.120	0.104	0.120	0.104	0.000	0.000	0.160	0.139	0.140	0.122
Norcross	#4	2.28	2.73	2.69	1.24	0.200	0.248	0.180	0.224	0.190	0.236	0.200	0.248	0.000	0.000	0.250	0.310	0.250	0.310
Norcross	7/16"	2.39	2.73	2.69	1.30	0.250	0.325	0.400	0.521	0.210	0.273	0.350	0.456	0.000	0.000	0.250	0.325	0.350	0.456
Norcross	7/8"	2.34	2.73	2.69	1.27	0.150	0.191	0.100	0.127	0.250	0.319	0.080	0.102	0.000	0.000	0.000	0.000	0.000	0.000
						Smi,weighted =	1.11	Smi,weighted =	1.15	Smi,weighted =	0.81	Smi,weighted =	1.12	Smi,weighted =	*	Smi,weighted =	1.06	Smi,weighted =	1.11
Palmer Sta	#60	2.04	2.69	2.65	1.14	0.170	0.195	0.150	0.172	0.150	0.172	0.180	0.206	0.000	0.000	0.230	0.263	0.150	0.172
Palmer Sta	#40	2.06	2.69	2.65	1.16	0.050	0.058	0.040	0.046	0.030	0.035	0.040	0.046	0.000	0.000	0.060	0.069	0.060	0.069
Palmer Sta	#30	2.07	2.69	2.65	1.16	0.050	0.058	0.060	0.070	0.050	0.058	0.040	0.046	0.000	0.000	0.080	0.093	0.050	0.058
Palmer Sta	#16	2.10	2.69	2.65	1.18	0.110	0.130	0.070	0.082	0.120	0.141	0.110	0.130	0.000	0.000	0.130	0.153	0.140	0.165
Palmer Sta	#4	2.22	2.69	2.65	1.25	0.220	0.274	0.180	0.224	0.190	0.237	0.230	0.287	0.000	0.000	0.250	0.311	0.250	0.311
Palmer Sta	7/16"	2.36	2.69	2.65	1.32	0.250	0.331	0.400	0.530	0.210	0.278	0.350	0.463	0.000	0.000	0.250	0.331	0.350	0.463
Palmer Sta	7/8"	2.47	2.69	2.65	1.39	0.150	0.208	0.100	0.139	0.250	0.348	0.05	0.069	0.000	0.000	0.000	0.000	0.000	0.000
						Smi,weighted =	1.25	Smi,weighted =	1.26	Smi,weighted =	1.27	Smi,weighted =	1.25	Smi,weighted =	*	Smi,weighted =	1.22	Smi,weighted =	1.24

Table 4. Micro Surface Voids - Pouring Test (continued).

QUARRY	SIZE RET	Gb	Gsp	Gsa	Smi	Base (DOT) Weight Factct	Sm*W.F.	Course Base Weight Factor	Sm*W.F.	Fine Base Weight Factor	Sm*W.F.	Binder (DOT) Weight Factor	Smi*W.F.	F Mix (DOT) Weight Factor	Smi*W.F.	E Mix (DOT) Weight Factor	Smi*W.F.	Coarse E Mix Weight Factor	Sm*W.F.
Postell	#60	1.97	2.72	2.63	2.48	0.150	0.372	0.150	0.372	0.150	0.372	0.140	0.347	0.000	0.000	0.000	0.000	0.150	0.372
Postell	#40	1.98	2.72	2.63	2.49	0.040	0.100	0.040	0.100	0.030	0.075	0.030	0.075	0.000	0.000	0.000	0.000	0.060	0.149
Postell	#30	1.99	2.72	2.63	2.50	0.040	0.100	0.060	0.150	0.050	0.125	0.050	0.125	0.000	0.000	0.000	0.000	0.050	0.125
Postell	#16	2.02	2.72	2.63	2.54	0.120	0.305	0.070	0.178	0.120	0.305	0.180	0.457	0.000	0.000	0.000	0.000	0.140	0.356
Postell	#4	2.10	2.72	2.63	2.64	0.200	0.528	0.180	0.476	0.190	0.502	0.200	0.528	0.000	0.000	0.000	0.000	0.250	0.661
Postell	7/16"	2.19	2.72	2.63	2.76	0.250	0.689	0.400	1.102	0.210	0.579	0.300	0.827	0.000	0.000	0.000	0.000	0.350	0.964
Postell	7/8"	2.35	2.72	2.63	2.96	0.020	0.059	0.100	0.296	0.250	0.739	0.100	0.298	0.000	0.000	0.000	0.000	0.000	0.000
						Smi,weighted =	2.15	Smi,weighted =	2.67	Smi,weighted =	2.70	Smi,weighted =	2.65	Smi,weighted =	*	Smi,weighted =	*	Smi,weighted =	2.63
Ruby	#60	2.00	2.76	2.73	0.80	0.130	0.104	0.150	0.119	0.150	0.119	0.140	0.111	0.180	0.143	0.200	0.159	0.150	0.119
Ruby	#40	2.00	2.76	2.73	0.80	0.030	0.024	0.040	0.032	0.030	0.024	0.030	0.024	0.050	0.040	0.030	0.024	0.060	0.048
Ruby	#30	2.03	2.76	2.73	0.81	0.040	0.032	0.060	0.048	0.050	0.040	0.050	0.040	0.070	0.057	0.070	0.057	0.050	0.040
Ruby	#16	2.06	2.76	2.73	0.82	0.150	0.123	0.070	0.057	0.120	0.098	0.130	0.107	0.200	0.164	0.200	0.164	0.140	0.115
Ruby	#4	2.18	2.76	2.73	0.87	0.200	0.174	0.180	0.156	0.190	0.165	0.200	0.174	0.400	0.347	0.250	0.217	0.250	0.217
Ruby	7/16"	2.21	2.76	2.73	0.88	0.300	0.264	0.400	0.352	0.210	0.185	0.450	0.396	0.100	0.088	0.250	0.220	0.350	0.308
Ruby	7/8"	2.39	2.76	2.73	0.95	0.150	0.143	0.100	0.095	0.250	0.238	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
						Smi,weighted =	0.86	Smi,weighted =	0.86	Smi,weighted =	0.87	Smi,weighted =	0.85	Smi,weighted =	0.84	Smi,weighted =	0.84	Smi,weighted =	0.85
Stockbridge	#60	2.03	2.65	2.61	1.17	0.170	0.200	0.150	0.176	0.150	0.176	0.150	0.176	0.000	0.000	0.210	0.247	0.150	0.176
Stockbridge	#40	2.01	2.65	2.61	1.16	0.050	0.058	0.040	0.046	0.030	0.035	0.030	0.035	0.000	0.000	0.040	0.046	0.060	0.070
Stockbridge	#30	2.03	2.65	2.61	1.17	0.050	0.059	0.060	0.070	0.050	0.059	0.050	0.059	0.000	0.000	0.060	0.070	0.050	0.059
Stockbridge	#16	2.05	2.65	2.61	1.19	0.130	0.154	0.070	0.083	0.120	0.142	0.170	0.202	0.000	0.000	0.170	0.202	0.140	0.166
Stockbridge	#4	2.25	2.65	2.60	1.63	0.200	0.327	0.180	0.294	0.190	0.310	0.250	0.408	0.000	0.000	0.270	0.441	0.250	0.408
Stockbridge	7/16"	2.24	2.65	2.60	1.63	0.300	0.488	0.400	0.650	0.210	0.341	0.300	0.488	0.000	0.000	0.250	0.406	0.350	0.569
Stockbridge	7/8"	2.39	2.65	2.60	1.73	0.100	0.173	0.100	0.173	0.250	0.434	0.05	0.087	0.000	0.000	0.000	0.000	0.000	0.000
						Smi,weighted =	1.46	Smi,weighted =	1.49	Smi,weighted =	1.50	Smi,weighted =	1.45	Smi,weighted =	*	Smi,weighted =	1.41	Smi,weighted =	1.45
Tyrone	#60	1.98	2.68	2.64	1.12	0.130	0.145	0.150	0.168	0.150	0.168	0.130	0.146	0.220	0.246	0.220	0.246	0.150	0.168
Tyrone	#40	2.01	2.68	2.64	1.14	0.040	0.045	0.040	0.045	0.030	0.034	0.040	0.045	0.040	0.045	0.040	0.045	0.060	0.068
Tyrone	#30	2.07	2.68	2.64	1.17	0.060	0.070	0.060	0.070	0.050	0.059	0.060	0.070	0.070	0.082	0.070	0.082	0.050	0.059
Tyrone	#16	2.12	2.68	2.64	1.20	0.150	0.180	0.070	0.084	0.120	0.144	0.130	0.156	0.200	0.240	0.170	0.204	0.140	0.168
Tyrone	#4	2.18	2.69	2.65	1.22	0.200	0.245	0.180	0.220	0.190	0.232	0.200	0.245	0.420	0.514	0.250	0.306	0.250	0.306
Tyrone	7/16"	2.25	2.69	2.65	1.26	0.220	0.278	0.400	0.505	0.210	0.265	0.400	0.505	0.050	0.063	0.250	0.316	0.350	0.442
Tyrone	7/8"	2.37	2.69	2.65	1.33	0.200	0.266	0.100	0.133	0.250	0.332	0.040	0.053	0.000	0.000	0.000	0.000	0.000	0.000
						Smi,weighted =	1.23	Smi,weighted =	1.23	Smi,weighted =	1.23	Smi,weighted =	1.22	Smi,weighted =	1.19	Smi,weighted =	1.20	Smi,weighted =	1.21
White	#60	2.09	2.74	2.71	0.84	0.110	0.093	0.150	0.127	0.150	0.127	0.120	0.101	0.120	0.101	0.000	0.000	0.150	0.127
White	#40	2.11	2.74	2.71	0.85	0.040	0.034	0.040	0.034	0.030	0.026	0.020	0.017	0.050	0.043	0.000	0.000	0.060	0.051
White	#30	2.15	2.74	2.71	0.87	0.060	0.052	0.060	0.052	0.050	0.043	0.200	0.174	0.250	0.217	0.000	0.000	0.050	0.043
White	#16	2.19	2.74	2.71	0.88	0.190	0.168	0.070	0.062	0.120	0.106	0.160	0.142	0.250	0.221	0.000	0.000	0.140	0.124
White	#4	2.24	2.74	2.71	0.91	0.200	0.181	0.180	0.163	0.190	0.172	0.240	0.217	0.300	0.272	0.000	0.000	0.250	0.226
White	7/16"	2.33	2.74	2.71	0.94	0.300	0.282	0.400	0.377	0.210	0.198	0.320	0.301	0.200	0.188	0.000	0.000	0.350	0.329
White	7/8"	2.40	2.74	2.71	0.97	0.100	0.097	0.100	0.097	0.250	0.242	0.080	0.078	0.000	0.000	0.000	0.000	0.000	0.000
						Smi,weighted =	0.91	Smi,weighted =	0.91	Smi,weighted =	0.91	Smi,weighted =	1.03	Smi,weighted =	1.04	Smi,weighted =	*	Smi,weighted =	0.90

$$SA = 1/4\ [ab+bc+ca+6\sqrt{a^2b^2+b^2c^2+c^2a^2}] \qquad (2)$$

where

a = longest dimension of aggregate

b = average intermediate dimension of aggregate

c = average smallest dimension of aggregate

The TKH model has been found to give reasonably good results compared to the quantative stereology method described in Appendix A.

Results

The surface area for the following four particle size ranges was determined for aggregate from each of the 21 quarries included in this study: 1/2 in. to 3/8 in., No. 4 to No. 8 sieve, No. 8 to No. 120 sieve, and passing the No. 120 sieve.

For each asphalt concrete mix studied, the four surface area values were weighted according to the aggregate gradations used in each mix for each quarry. Specifically, the percentage of aggregate within each size range was multiplied by its respective surface area. Then the sum of these products was divided by the total percentage of aggregate within the four size ranges. For example, if the mix gradation had 10 percent of the total aggregate weight in each of the four measured size ranges, then the weighted surface area (S.A.,w) would be the sum of one-tenth the surface area of each size ranged divided by 0.40. Both the surface areas for each size range and the weighted surface areas are given in Table 5.

SHAPE CLASSIFICATION

The shape classification values used in this study were reported by Kemp [7]. The shape of aggregate particles was determined using the general method proposed by Lees [1]. The digitizing techniques described

Table 5. Aggregate Surface Area.

QUARRY	SIZE PASS	SIZE RET	Surface Area (in2/lb)	Base (DOT) Weight Factor	S.A.*W.F.	Coarse Base Weight Factor	S.A.*W.F.	Fine Base Weight Factor	S.A.*W.F.	Binder (DOT) Weight Factor	S.A.*W.F.	F Mix (DOT) Weight Factor	S.A.*W.F.	E Mix (DOT) Weight Factor	S.A.*W.F.	Coarse E Mix Weight Factor	S.A.*W.F.
Athens	#120	-	1049687.00	0.070	73478.090	0.080	83974.960	0.070	73478.090	0.080	83974.960	0.090	94471.830	0.090	94471.830	0.090	94471.830
Athens	#8	#120	12156.30	0.270	3282.201	0.220	2674.386	0.240	2917.512	0.250	3039.075	0.360	4376.268	0.360	4376.268	0.290	3525.327
Athens	#4	#8	557.26	0.080	44.581	0.090	50.153	0.100	55.726	0.090	50.153	0.180	100.307	0.140	78.016	0.130	72.444
Athens	1/2"	3/8"	151.17	0.110	16.629	0.060	9.070	0.070	10.582	0.100	15.117	0.040	6.047	0.130	19.652	0.130	19.652
				S.A.,weighted =	144946.23	S.A.,weighted =	192685.71	S.A.,weighted =	159295.65	S.A.,weighted =	167460.20	S.A.,weighted =	147693.21	S.A.,weighted =	137424.68	S.A.,weighted =	153264.46
Ball Ground	#120	-	1225590.00	0.080	98047.200	0.080	98047.200	0.070	85791.300	0.080	98047.200	0.000	0.000	0.100	122559.000	0.090	110303.100
Ball Ground	#8	#120	11115.00	0.270	3001.320	0.220	2445.520	0.240	2667.840	0.250	2779.000	0.000	0.000	0.350	3890.600	0.290	3223.640
Ball Ground	#4	#8	572.49	0.100	57.249	0.090	51.524	0.100	57.249	0.130	74.424	0.000	0.000	0.150	85.874	0.130	74.424
Ball Ground	1/2"	3/8"	169.17	0.070	11.842	0.060	10.150	0.070	11.842	0.150	25.376	0.000	0.000	0.140	23.684	0.130	21.992
				S.A.,weighted =	194456.94	S.A.,weighted =	223454.21	S.A.,weighted =	184433.81	S.A.,weighted =	165452.46	S.A.,weighted =	*	S.A.,weighted =	171025.89	S.A.,weighted =	177536.18
Barin	#120	-	827577.00	0.100	82757.700	0.080	66206.160	0.070	57930.390	0.090	74481.930	0.110	91033.470	0.110	91033.470	0.090	74481.930
Barin	#8	#120	8300.00	0.250	2075.000	0.220	1826.000	0.240	1992.000	0.240	1992.000	0.340	2822.000	0.340	2822.000	0.290	2407.000
Barin	#4	#8	564.79	0.100	56.479	0.090	50.831	0.100	56.479	0.100	56.479	0.230	129.902	0.140	79.071	0.130	73.423
Barin	1/2"	3/8"	161.30	0.120	19.356	0.060	9.678	0.070	11.291	0.160	25.808	0.000	0.000	0.140	22.582	0.130	20.969
				S.A.,weighted =	148962.34	S.A.,weighted =	151317.04	S.A.,weighted =	124979.50	S.A.,weighted =	129756.30	S.A.,weighted =	138213.78	S.A.,weighted =	128708.39	S.A.,weighted =	120286.44
Buford	#120	-	960009.00	0.090	86400.810	0.080	76800.720	0.070	67200.630	0.090	86400.810	0.100	96000.900	0.000	0.000	0.090	86400.810
Buford	#8	#120	9170.60	0.250	2292.650	0.220	2017.532	0.240	2200.944	0.240	2200.944	0.350	3209.710	0.000	0.000	0.290	2659.474
Buford	#4	#8	570.68	0.110	62.775	0.090	51.361	0.100	57.068	0.100	57.068	0.230	131.256	0.000	0.000	0.130	74.188
Buford	1/2"	3/8"	168.85	0.120	20.262	0.060	10.131	0.070	11.820	0.180	30.393	0.000	0.000	0.000	0.000	0.130	21.951
				S.A.,weighted =	155748.24	S.A.,weighted =	175288.32	S.A.,weighted =	144730.13	S.A.,weighted =	145392.16	S.A.,weighted =	146090.98	S.A.,weighted =	*	S.A.,weighted =	139306.91
Candler	#120	-	958371.00	0.110	105420.810	0.080	76669.680	0.070	67085.970	0.100	95837.100	0.120	115004.520	0.100	95837.100	0.090	86253.390
Candler	#8	#120	10806.00	0.230	2485.380	0.220	2377.320	0.240	2593.440	0.230	2485.380	0.330	3565.980	0.350	3782.100	0.290	3133.740
Candler	#4	#8	580.10	0.110	63.811	0.090	52.209	0.100	58.010	0.120	69.612	0.090	52.209	0.140	81.214	0.130	75.413
Candler	1/2"	3/8"	186.61	0.100	18.661	0.060	11.197	0.070	13.063	0.070	13.063	0.000	0.000	0.160	29.858	0.130	24.259
				S.A.,weighted =	196343.02	S.A.,weighted =	175800.90	S.A.,weighted =	145313.51	S.A.,weighted =	189240.68	S.A.,weighted =	219571.68	S.A.,weighted =	132973.70	S.A.,weighted =	139823.13
Cummings	#120	-	1059591.00	0.090	95363.190	0.080	84767.280	0.070	74171.370	0.090	95363.190	0.000	0.000	0.000	0.000	0.090	95363.190
Cummings	#8	#120	9129.10	0.260	2373.566	0.220	2008.402	0.240	2190.984	0.290	2647.439	0.000	0.000	0.000	0.000	0.290	2647.439
Cummings	#4	#8	426.47	0.130	55.441	0.090	38.382	0.100	42.647	0.080	34.118	0.000	0.000	0.000	0.000	0.130	55.441
Cummings	1/2"	3/8"	181.45	0.110	19.960	0.060	10.887	0.070	12.702	0.120	21.774	0.000	0.000	0.000	0.000	0.130	23.589
				S.A.,weighted =	165783.32	S.A.,weighted =	192944.34	S.A.,weighted =	169203.55	S.A.,weighted =	169080.21	S.A.,weighted =	*	S.A.,weighted =	*	S.A.,weighted =	153265.09
Dalton	#120	-	953017.00	0.080	76241.360	0.080	76241.360	0.070	66711.190	0.070	66711.190	0.000	0.000	0.000	0.000	0.090	85771.530
Dalton	#8	#120	11090.30	0.260	2883.478	0.220	2439.866	0.240	2661.672	0.260	2883.478	0.000	0.000	0.000	0.000	0.290	3216.187
Dalton	#4	#8	587.69	0.080	47.015	0.090	52.892	0.100	58.769	0.130	76.400	0.000	0.000	0.000	0.000	0.130	76.400
Dalton	1/2"	3/8"	191.69	0.120	23.003	0.060	11.501	0.070	13.418	0.08	15.335	0.000	0.000	0.000	0.000	0.130	24.920
				S.A.,weighted =	146657.14	S.A.,weighted =	174990.27	S.A.,weighted =	144677.19	S.A.,weighted =	129048.89	S.A.,weighted =	*	S.A.,weighted =	*	S.A.,weighted =	139201.62
Dan	#120	-	1510845.00	0.080	120867.600	0.080	120867.600	0.070	105759.150	0.070	105759.150	0.000	0.000	0.000	0.000	0.090	135976.050
Dan	#8	#120	7060.00	0.270	1906.200	0.220	1553.200	0.240	1694.400	0.260	1835.600	0.000	0.000	0.000	0.000	0.290	2047.400
Dan	#4	#8	587.39	0.130	76.361	0.090	52.865	0.100	58.739	0.140	82.235	0.000	0.000	0.000	0.000	0.130	76.361
Dan	1/2"	3/8"	180.44	0.060	10.826	0.060	10.826	0.070	12.631	0.120	21.653	0.000	0.000	0.000	0.000	0.130	23.457
				S.A.,weighted =	227520.35	S.A.,weighted =	272187.76	S.A.,weighted =	224010.25	S.A.,weighted =	182540.06	S.A.,weighted =	*	S.A.,weighted =	*	S.A.,weighted =	215817.61
Dixie	#120	-	1882183.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.100	188218.300	0.000	0.000	0.090	169396.470
Dixie	#8	#120	8248.50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.350	2886.975	0.000	0.000	0.290	2392.065
Dixie	#4	#8	585.37	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.130	76.098	0.000	0.000	0.130	76.098
Dixie	1/2"	3/8"	185.40	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.100	18.540	0.000	0.000	0.130	24.102
				S.A.,weighted =	*	S.A.,weighted =	*	S.A.,weighted =	*	S.A.,weighted =	*	S.A.,weighted =	281176.34	S.A.,weighted =	*	S.A.,weighted =	268576.15
Griffin	#120	-	1134179.00	0.080	90734.320	0.080	90734.320	0.070	79392.530	0.080	90734.320	0.100	113417.900	0.100	113417.900	0.090	102076.110
Griffin	#8	#120	9850.50	0.260	2561.130	0.220	2167.110	0.240	2364.120	0.250	2462.625	0.350	3447.675	0.350	3447.675	0.290	2856.645
Griffin	#4	#8	455.64	0.100	45.564	0.090	41.008	0.100	45.564	0.120	54.677	0.190	86.572	0.130	59.233	0.130	59.233
Griffin	1/2"	3/8"	169.39	0.100	16.939	0.060	10.163	0.070	11.857	0.140	23.715	0.010	1.694	0.150	25.409	0.130	22.021
				S.A.,weighted =	172885.10	S.A.,weighted =	205561.34	S.A.,weighted =	170445.98	S.A.,weighted =	158093.79	S.A.,weighted =	179928.99	S.A.,weighted =	160205.78	S.A.,weighted =	164084.39
Kennesaw	#120	-	1449316.00	0.100	144931.600	0.080	115945.280	0.070	101452.120	0.080	115945.280	0.000	0.000	0.100	144931.600	0.090	130438.440
Kennesaw	#8	#120	9069.60	0.250	2267.400	0.220	1995.312	0.240	2176.704	0.250	2267.400	0.000	0.000	0.350	3174.360	0.290	2630.184
Kennesaw	#4	#8	432.34	0.090	38.911	0.090	38.911	0.100	43.234	0.120	51.881	0.000	0.000	0.150	64.851	0.130	56.204
Kennesaw	1/2"	3/8"	157.77	0.110	17.355	0.060	9.466	0.070	11.044	0.140	22.088	0.000	0.000	0.160	25.243	0.130	20.510
				S.A.,weighted =	267736.85	S.A.,weighted =	262197.71	S.A.,weighted =	216006.46	S.A.,weighted =	*	S.A.,weighted =	*	S.A.,weighted =	194994.81	S.A.,weighted =	208039.59
Lithia Springs	#120	-	963884.00	0.080	77110.720	0.080	77110.720	0.070	67471.880	0.080	77110.720	0.000	0.000	0.000	0.000	0.090	86749.560
Lithia Springs	#8	#120	12245.20	0.270	3306.204	0.220	2693.944	0.240	2938.848	0.250	3061.300	0.000	0.000	0.000	0.000	0.290	3551.108
Lithia Springs	#4	#8	681.88	0.130	88.644	0.090	61.369	0.100	68.188	0.120	81.826	0.000	0.000	0.000	0.000	0.130	88.644
Lithia Springs	1/2"	3/8"	177.38	0.090	15.964	0.060	10.643	0.070	12.417	0.150	26.607	0.000	0.000	0.000	0.000	0.130	23.059
				S.A.,weighted =	141265.85	S.A.,weighted =	177503.72	S.A.,weighted =	146856.94	S.A.,weighted =	133800.75	S.A.,weighted =	*	S.A.,weighted =	*	S.A.,weighted =	141269.33

Table 5. Aggregate Surface Area (continued).

QUARRY	SIZE PASS	SIZE RET	Surface Area (in2/lb)	Base (DOT) Weight Factor	S.A.*W.F.	Coarse Base Weight Factor	S.A.*W.F.	Fine Base Weight Factor	S.A.*W.F.	Binder (DOT) Weight Factor	S.A.*W.F.	F Mix (DOT) Weight Factor	S.A.*W.F.	E Mix (DOT) Weight Factor	S.A.*W.F.	Coarse E Mix Weight Factor	S.A.*W.F.
Lithonia	#120	-	1454224.00	0.080	116337.920	0.080	116337.920	0.070	101795.680	0.080	116337.920	0.000	0.000	0.110	159964.640	0.090	130880.160
Lithonia	#8	#120	8838.30	0.270	2386.341	0.220	1944.426	0.240	2121.192	0.250	2209.575	0.000	0.000	0.340	3005.022	0.290	2563.107
Lithonia	#4	#8	427.79	0.080	34.223	0.090	38.501	0.100	42.779	0.080	34.223	0.000	0.000	0.120	51.335	0.130	55.613
Lithonia	1/2"	3/8"	155.50	0.130	20.228	0.060	9.336	0.070	10.892	0.190	29.584	0.000	0.000	0.150	23.340	0.130	20.228
				S.A.,weighted =	212104.84	S.A.,weighted =	262955.96	S.A.,weighted =	216605.30	S.A.,weighted =	197685.47	S.A.,weighted =	*	S.A.,weighted =	226450.47	S.A.,weighted =	208623.61
Mt View	#120	-	1348489.00	0.090	121364.010	0.080	107879.120	0.070	94394.230	0.080	107879.120	0.000	0.000	0.110	148333.790	0.090	121364.010
Mt View	#8	#120	10204.30	0.260	2653.118	0.220	2244.946	0.240	2449.032	0.250	2551.075	0.000	0.000	0.340	3469.462	0.290	2959.247
Mt View	#4	#8	446.40	0.110	49.104	0.090	40.176	0.100	44.640	0.140	62.496	0.000	0.000	0.150	66.960	0.130	58.032
Mt View	1/2"	3/8"	172.90	0.090	15.561	0.060	10.374	0.070	12.103	0.090	15.561	0.000	0.000	0.150	25.935	0.130	22.477
				S.A.,weighted =	225603.26	S.A.,weighted =	244832.48	S.A.,weighted =	201875.01	S.A.,weighted =	197336.16	S.A.,weighted =	*	S.A.,weighted =	202528.20	S.A.,weighted =	194380.68
Norcross	#120	-	1074588.00	0.080	85967.040	0.080	85967.040	0.070	75221.160	0.090	96712.920	0.000	0.000	0.120	128950.560	0.090	96712.920
Norcross	#8	#120	11362.90	0.220	2499.838	0.220	2499.838	0.240	2727.096	0.260	2954.354	0.000	0.000	0.330	3749.757	0.290	3295.241
Norcross	#4	#8	595.85	0.090	53.627	0.090	53.627	0.100	59.585	0.080	47.668	0.000	0.000	0.130	77.461	0.130	77.461
Norcross	1/2"	3/8"	174.97	0.160	27.995	0.060	10.498	0.070	12.248	0.150	26.246	0.000	0.000	0.150	26.246	0.130	22.746
				S.A.,weighted =	160997.27	S.A.,weighted =	196735.56	S.A.,weighted =	162541.85	S.A.,weighted =	171967.56	S.A.,weighted =	*	S.A.,weighted =	181923.32	S.A.,weighted =	156419.32
Palmer Sta	#120	-	763091.00	0.070	53416.370	0.080	61047.280	0.070	53416.370	0.100	76309.100	0.000	0.000	0.100	76309.100	0.090	68678.190
Palmer Sta	#8	#120	10417.10	0.280	2916.788	0.220	2291.762	0.240	2500.104	0.230	2395.933	0.000	0.000	0.350	3645.985	0.290	3020.959
Palmer Sta	#4	#8	651.87	0.100	65.187	0.090	58.668	0.100	65.187	0.110	71.706	0.000	0.000	0.130	84.743	0.130	84.743
Palmer Sta	1/2"	3/8"	176.86	0.080	14.149	0.060	10.612	0.070	12.380	0.07	12.380	0.000	0.000	0.150	26.529	0.130	22.992
				S.A.,weighted =	106438.67	S.A.,weighted =	140907.38	S.A.,weighted =	116654.25	S.A.,weighted =	154466.47	S.A.,weighted =	*	S.A.,weighted =	109679.94	S.A.,weighted =	112198.26
Postell	#120	-	1124548.00	0.090	101209.320	0.080	89963.840	0.070	78718.360	0.080	89963.840	0.000	0.000	0.000	0.000	0.090	101209.320
Postell	#8	#120	9424.70	0.260	2450.422	0.220	2073.434	0.240	2261.928	0.250	2356.175	0.000	0.000	0.000	0.000	0.290	2733.163
Postell	#4	#8	639.19	0.140	89.487	0.090	57.527	0.100	63.919	0.150	95.879	0.000	0.000	0.000	0.000	0.130	83.095
Postell	1/2"	3/8"	189.89	0.110	20.888	0.060	11.393	0.070	13.292	0.12	22.787	0.000	0.000	0.000	0.000	0.130	24.686
				S.A.,weighted =	172950.19	S.A.,weighted =	204680.43	S.A.,weighted =	168869.79	S.A.,weighted =	154064.47	S.A.,weighted =	*	S.A.,weighted =	*	S.A.,weighted =	162578.54
Ruby	#120	-	1020362.00	0.080	81628.960	0.080	81628.960	0.070	71425.340	0.080	81628.960	0.100	102036.200	0.110	112239.820	0.090	91832.580
Ruby	#8	#120	9656.60	0.250	2414.150	0.220	2124.452	0.240	2317.584	0.250	2414.150	0.350	3379.810	0.340	3283.244	0.290	2800.414
Ruby	#4	#8	591.18	0.100	59.118	0.090	53.206	0.100	59.118	0.100	59.118	0.180	106.412	0.150	88.677	0.130	76.853
Ruby	1/2"	3/8"	167.71	0.050	8.386	0.060	10.063	0.070	11.740	0.160	26.834	0.010	1.677	0.160	26.834	0.130	21.802
				S.A.,weighted =	175230.44	S.A.,weighted =	186259.29	S.A.,weighted =	153778.71	S.A.,weighted =	142591.63	S.A.,weighted =	164801.41	S.A.,weighted =	152156.02	S.A.,weighted =	148018.20
Stockbridge	#120	-	972610.00	0.100	97261.000	0.080	77808.800	0.070	68082.700	0.090	87534.900	0.000	0.000	0.110	106987.100	0.090	87534.900
Stockbridge	#8	#120	9762.40	0.240	2342.976	0.220	2147.728	0.240	2342.976	0.260	2538.224	0.000	0.000	0.340	3319.216	0.290	2831.096
Stockbridge	#4	#8	590.17	0.110	64.919	0.090	53.115	0.100	59.017	0.140	82.624	0.000	0.000	0.140	82.624	0.130	76.722
Stockbridge	1/2"	3/8"	186.51	0.100	18.651	0.060	11.191	0.070	13.056	0.08	14.921	0.000	0.000	0.140	26.111	0.130	24.246
				S.A.,weighted =	181250.08	S.A.,weighted =	177824.08	S.A.,weighted =	146870.31	S.A.,weighted =	158194.16	S.A.,weighted =	*	S.A.,weighted =	151253.49	S.A.,weighted =	141354.63
Tyrone	#120	-	1774556.00	0.070	124218.920	0.080	141964.480	0.070	124218.920	0.070	124218.920	0.110	195201.160	0.110	195201.160	0.090	159710.040
Tyrone	#8	#120	7724.70	0.270	2085.669	0.220	1699.434	0.240	1853.928	0.260	2008.422	0.340	2626.398	0.340	2626.398	0.290	2240.163
Tyrone	#4	#8	629.11	0.120	75.493	0.090	56.620	0.100	62.911	0.110	69.202	0.200	125.822	0.130	81.784	0.130	81.784
Tyrone	1/2"	3/8"	156.61	0.090	14.095	0.060	9.397	0.070	10.963	0.170	26.624	0.000	0.000	0.150	23.492	0.130	20.359
				S.A.,weighted =	229807.59	S.A.,weighted =	319399.85	S.A.,weighted =	262805.67	S.A.,weighted =	207087.16	S.A.,weighted =	304543.66	S.A.,weighted =	271140.87	S.A.,weighted =	253206.79
White	#120	-	1290546.00	0.080	103243.680	0.080	103243.680	0.070	90338.220	0.070	90338.220	0.100	129054.600	0.000	0.000	0.090	116149.140
White	#8	#120	13459.70	0.270	3634.119	0.220	2961.134	0.240	3230.328	0.240	3230.328	0.350	4710.895	0.000	0.000	0.290	3903.313
White	#4	#8	564.07	0.130	73.329	0.090	50.766	0.100	56.407	0.120	67.688	0.170	95.892	0.000	0.000	0.130	73.329
White	1/2"	3/8"	165.69	0.090	14.912	0.060	9.941	0.070	11.598	0.110	18.226	0.000	0.000	0.000	0.000	0.130	21.540
				S.A.,weighted =	187659.72	S.A.,weighted =	236145.60	S.A.,weighted =	195076.15	S.A.,weighted =	173434.19	S.A.,weighted =	215905.46	S.A.,weighted =	*	S.A.,weighted =	187730.19

in Appendix A were used to measure the length, width, and thickness of aggregate particles from each quarry. Then each particle in a representative sample was categorized as either a rod, blade, disc, or equidiemnsional. A shape classification varying from 1 to 9 was then calculated for each particle using equation (3) which was developed by Kemp [7]:

$$\text{Shape Class} = 10 \times [(\text{No. of Rods} \times 4) + (\text{No. of Blades} \times 9) + (\text{No. of Discs} \times 9) + (\text{No. of Equid} \times 1)]/\text{Sum of Particles.} \quad (3)$$

Similar to surface area, shape classes were assigned to aggregate size ranges of 1/2 in. to 3/8 in., No. 4 to No. 8, No. 8 to No. 120, and passing the No. 120. To determine a composite shape classification to represent a mix, the four shape class values were weighted according to the aggregate gradations following a similar procedure to that used for surface area and mica content. Shape classification results are given in Table 6.

Surface Roughness

Surface roughness values are given in Table 7. The techniques used to measure surface roughness are summarized in Appendix A and described more fully by Sheffield [6]. As used in this study, surface roughness is defined as the true length of a very small segment of the surface profile divided by the length of the best fit line using linear regression analysis. Surface roughness varies from 1.13 for the Dixie quarry to 1.26 for the Kennesaw Quarry. The validity of the use of surface roughness is open to criticism because of the large variation of surface roughness along the surface of a single particle and also within a group of particles from the same quarry. However, the values of surface roughness tabulated in Table 7 should show general trends.

Table 6. Aggregate Shape Classifications.

QUARRY	SIZE PASS	SIZE RET	Shape Classification	Base (DOT) Weight Factor	S.C.*W.F.	Imp. Coarse Base Weight Factor	S.C.*W.F.	Imp. Fine Base Weight Factor	S.C.*W.F.	Binder (DOT) Weight Factor	S.C.*W.F.	F Mix (DOT) Weight Factor	S.C.*W.F.	E Mix (DOT) Weight Factor	S.C.*W.F.	Imp. Coarse E Mix Weight Factor	S.C.*W.F.
Athens	#120		7.1	0.070	0.497	0.080	0.568	0.070	0.497	0.080	0.568	0.090	0.639	0.090	0.639	0.090	0.639
Athens	#8	#120	7.4	0.270	1.998	0.220	1.628	0.240	1.776	0.250	1.850	0.360	2.664	0.360	2.664	0.290	2.146
Athens	#4	#8	7.5	0.080	0.600	0.090	0.675	0.100	0.750	0.090	0.675	0.180	1.350	0.140	1.050	0.130	0.975
Athens	1/2"	3/8"	6.0	0.110	0.660	0.060	0.360	0.070	0.420	0.100	0.600	0.040	0.240	0.130	0.780	0.130	0.780
				S.C.,weighted =	7.1	S.C.,weighted =	7.2	S.C.,weighted =	7.2	S.C.,weighted =	7.1	S.C.,weighted =	7.3	S.C.,weighted =	7.1	S.C.,weighted =	7.1
Ball Ground	#120		7.3	0.080	0.584	0.080	0.584	0.070	0.511	0.080	0.584	0.000	0.000	0.100	0.730	0.090	0.657
Ball Ground	#8	#120	4.6	0.270	1.242	0.220	1.012	0.240	1.104	0.250	1.150	0.000	0.000	0.350	1.610	0.290	1.334
Ball Ground	#4	#8	7.7	0.100	0.770	0.090	0.693	0.100	0.770	0.130	1.001	0.000	0.000	0.150	1.155	0.130	1.001
Ball Ground	1/2"	3/8"	8.6	0.070	0.602	0.060	0.516	0.070	0.602	0.150	1.290	0.000	0.000	0.140	1.204	0.130	1.118
				S.C.,weighted =	6.2	S.C.,weighted =	6.2	S.C.,weighted =	6.2	S.C.,weighted =	6.6	S.C.,weighted =	*	S.C.,weighted =	6.4	S.C.,weighted =	6.4
Barin	#120		6.5	0.100	0.650	0.080	0.520	0.070	0.455	0.090	0.585	0.110	0.715	0.110	0.715	0.090	0.585
Barin	#8	#120	4.4	0.250	1.100	0.220	0.968	0.240	1.056	0.240	1.056	0.340	1.496	0.340	1.496	0.290	1.276
Barin	#4	#8	7.1	0.100	0.710	0.090	0.639	0.100	0.710	0.100	0.710	0.230	1.633	0.140	0.994	0.130	0.923
Barin	1/2"	3/8"	7.1	0.120	0.852	0.060	0.426	0.070	0.497	0.160	1.136	0.000	0.000	0.140	0.994	0.130	0.923
				S.C.,weighted =	5.8	S.C.,weighted =	5.7	S.C.,weighted =	5.7	S.C.,weighted =	5.9	S.C.,weighted =	5.7	S.C.,weighted =	5.8	S.C.,weighted =	5.8
Buford	#120		5.3	0.090	0.477	0.080	0.424	0.070	0.371	0.090	0.477	0.100	0.530	0.000	0.000	0.090	0.477
Buford	#8	#120	3.5	0.250	0.875	0.220	0.770	0.240	0.840	0.240	0.840	0.350	1.225	0.000	0.000	0.290	1.015
Buford	#4	#8	7.4	0.110	0.814	0.090	0.666	0.100	0.740	0.100	0.740	0.230	1.702	0.000	0.000	0.130	0.962
Buford	1/2"	3/8"	6.4	0.120	0.768	0.060	0.384	0.070	0.448	0.180	1.152	0.000	0.000	0.300	0.000	0.130	0.832
				S.C.,weighted =	5.1	S.C.,weighted =	5.0	S.C.,weighted =	5.0	S.C.,weighted =	5.3	S.C.,weighted =	5.1	S.C.,weighted =	*	S.C.,weighted =	5.1
Candler	#120		7.7	0.110	0.847	0.080	0.616	0.070	0.539	0.100	0.770	0.120	0.924	0.100	0.770	0.090	0.693
Candler	#8	#120	3.6	0.230	0.828	0.220	0.792	0.240	0.864	0.230	0.828	0.330	1.188	0.350	1.260	0.290	1.044
Candler	#4	#8	9.0	0.110	0.990	0.090	0.810	0.100	0.900	0.120	1.080	0.090	0.810	0.140	1.260	0.130	1.170
Candler	1/2"	3/8"	7.6	0.100	0.760	0.060	0.456	0.070	0.532	0.070	0.532	0.000	0.000	0.160	1.216	0.130	0.988
				S.C.,weighted =	6.2	S.C.,weighted =	5.9	S.C.,weighted =	5.9	S.C.,weighted =	6.2	S.C.,weighted =	5.4	S.C.,weighted =	6.0	S.C.,weighted =	6.1
Cummings	#120		6.4	0.090	0.576	0.080	0.512	0.070	0.448	0.090	0.576	0.000	0.000	0.000	0.000	0.090	0.576
Cummings	#8	#120	5.7	0.260	1.482	0.220	1.254	0.240	1.368	0.290	1.653	0.000	0.000	0.000	0.000	0.290	1.653
Cummings	#4	#8	7.8	0.130	1.014	0.090	0.702	0.100	0.780	0.080	0.624	0.000	0.000	0.000	0.000	0.130	1.014
Cummings	1/2"	3/8"	7.7	0.110	0.847	0.060	0.462	0.070	0.539	0.120	0.924	0.000	0.000	0.000	0.000	0.130	1.001
				S.C.,weighted =	6.6	S.C.,weighted =	6.5	S.C.,weighted =	6.5	S.C.,weighted =	6.5	S.C.,weighted =	*	S.C.,weighted =	*	S.C.,weighted =	6.6
Dalton	#120		5.3	0.080	0.424	0.080	0.424	0.070	0.371	0.070	0.371	0.000	0.000	0.000	0.000	0.090	0.477
Dalton	#8	#120	5.6	0.260	1.456	0.220	1.232	0.240	1.344	0.260	1.456	0.000	0.000	0.000	0.000	0.290	1.624
Dalton	#4	#8	8.6	0.080	0.688	0.090	0.774	0.100	0.860	0.130	1.118	0.000	0.000	0.000	0.000	0.130	1.118
Dalton	1/2"	3/8"	7.5	0.120	0.900	0.060	0.450	0.070	0.525	0.08	0.600	0.000	0.000	0.000	0.000	0.130	0.975
				S.C.,weighted =	6.4	S.C.,weighted =	6.4	S.C.,weighted =	6.5	S.C.,weighted =	6.6	S.C.,weighted =	*	S.C.,weighted =	*	S.C.,weighted =	6.6
Dan	#120		6.7	0.080	0.536	0.080	0.536	0.070	0.469	0.070	0.469	0.000	0.000	0.000	0.000	0.090	0.603
Dan	#8	#120	4.0	0.270	1.080	0.220	0.880	0.240	0.960	0.260	1.040	0.000	0.000	0.000	0.000	0.290	1.160
Dan	#4	#8	8.1	0.130	1.053	0.090	0.729	0.100	0.810	0.140	1.134	0.000	0.000	0.000	0.000	0.130	1.053
Dan	1/2"	3/8"	8.2	0.060	0.492	0.060	0.492	0.070	0.574	0.120	0.984	0.000	0.000	0.000	0.000	0.130	1.066
				S.C.,weighted =	5.9	S.C.,weighted =	5.9	S.C.,weighted =	5.9	S.C.,weighted =	6.1	S.C.,weighted =	*	S.C.,weighted =	*	S.C.,weighted =	6.1
Dixie	#120		7.7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.100	0.770	0.000	0.000	0.090	0.693
Dixie	#8	#120	4.2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.350	1.470	0.000	0.000	0.290	1.218
Dixie	#4	#8	7.3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.130	0.949	0.000	0.000	0.130	0.949
Dixie	1/2"	3/8"	4.9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.100	0.490	0.000	0.000	0.130	0.637
				S.C.,weighted =	*	S.C.,weighted =	*	S.C.,weighted =	*	S.C.,weighted =	*	S.C.,weighted =	5.4	S.C.,weighted =	*	S.C.,weighted =	5.5
Griffin	#120		6.8	0.080	0.544	0.080	0.544	0.070	0.476	0.080	0.544	0.100	0.680	0.100	0.680	0.090	0.612
Griffin	#8	#120	4.4	0.260	1.144	0.220	0.968	0.240	1.056	0.250	1.100	0.350	1.540	0.350	1.540	0.290	1.276
Griffin	#4	#8	8.9	0.100	0.890	0.090	0.801	0.100	0.890	0.120	1.068	0.190	1.691	0.130	1.157	0.130	1.157
Griffin	1/2"	3/8"	5.5	0.100	0.550	0.060	0.330	0.070	0.385	0.140	0.770	0.010	0.055	0.150	0.825	0.130	0.715
				S.C.,weighted =	5.8	S.C.,weighted =	5.9	S.C.,weighted =	5.8	S.C.,weighted =	5.9	S.C.,weighted =	6.1	S.C.,weighted =	5.8	S.C.,weighted =	5.9
Kennesaw	#120		5.8	0.100	0.580	0.080	0.464	0.070	0.406	0.080	0.464	0.000	0.000	0.100	0.580	0.090	0.522
Kennesaw	#8	#120	5.3	0.250	1.325	0.220	1.166	0.240	1.272	0.250	1.325	0.000	0.000	0.350	1.855	0.290	1.537
Kennesaw	#4	#8	7.4	0.090	0.666	0.090	0.666	0.100	0.740	0.120	0.888	0.000	0.000	0.150	1.110	0.130	0.962
Kennesaw	1/2"	3/8"	6.0	0.110	0.660	0.060	0.360	0.070	0.420	0.140	0.840	0.000	0.000	0.160	0.960	0.130	0.780
				S.C.,weighted =	5.9	S.C.,weighted =	5.9	S.C.,weighted =	5.9	S.C.,weighted =	6.0	S.C.,weighted =	*	S.C.,weighted =	5.9	S.C.,weighted =	5.9
Lithia Springs	#120		5.9	0.080	0.472	0.080	0.472	0.070	0.413	0.080	0.472	0.000	0.000	0.000	0.000	0.090	0.531
Lithia Springs	#8	#120	5.4	0.270	1.458	0.220	1.188	0.240	1.296	0.250	1.350	0.000	0.000	0.000	0.000	0.290	1.566
Lithia Springs	#4	#8	7.0	0.130	0.910	0.090	0.630	0.100	0.700	0.120	0.840	0.000	0.000	0.000	0.000	0.130	0.910
Lithia Springs	1/2"	3/8"	7.6	0.090	0.684	0.060	0.456	0.070	0.532	0.150	1.140	0.000	0.000	0.000	0.000	0.130	0.988
				S.C.,weighted =	6.2	S.C.,weighted =	6.1	S.C.,weighted =	6.1	S.C.,weighted =	6.3	S.C.,weighted =	*	S.C.,weighted =	*	S.C.,weighted =	6.2

Table 6. Aggregate Shape Classifications (continued).

QUARRY	SIZE PASS	SIZE RET	Shape Classification	Base (DOT) Weight Factor	S.C.*W.F.	Imp. Coarse Base Weight Factor	S.C.*W.F.	Imp. Fine Base Weight Factor	S.C.*W.F.	Binder (DOT) Weight Factor	S.C.*W.F.	F Mix (DOT) Weight Factor	S.C.*W.F.	E Mix (DOT) Weight Factor	S.C.*W.F.	Imp. Coarse E Mix Weight Factor	S.C.*W.F.
Lithonia	#120		7.0	0.080	0.560	0.080	0.560	0.070	0.490	0.080	0.560	0.000	0.000	0.110	0.770	0.090	0.630
Lithonia	#8	#120	4.4	0.270	1.188	0.220	0.968	0.240	1.056	0.250	1.100	0.000	0.000	0.340	1.496	0.290	1.276
Lithonia	#4	#8	7.7	0.080	0.616	0.090	0.693	0.100	0.770	0.080	0.616	0.000	0.000	0.120	0.924	0.130	1.001
Lithonia	1/2"	3/8"	5.6	0.130	0.728	0.060	0.336	0.070	0.392	0.190	1.064	0.000	0.000	0.150	0.840	0.130	0.728
				S.C.,weighted =	5.5	S.C.,weighted =	5.7	S.C.,weighted =	5.6	S.C.,weighted =	5.6	S.C.,weighted =	*	S.C.,weighted =	5.8	S.C.,weighted =	5.7
Mt View	#120	-	6.7	0.090	0.603	0.080	0.536	0.070	0.469	0.080	0.536	0.000	0.000	0.110	0.737	0.090	0.603
Mt View	#8	#120	5.7	0.260	1.482	0.220	1.254	0.240	1.368	0.250	1.425	0.000	0.000	0.340	1.938	0.290	1.653
Mt View	#4	#8	7.9	0.110	0.869	0.090	0.711	0.100	0.790	0.140	1.106	0.000	0.000	0.150	1.185	0.130	1.027
Mt View	1/2"	3/8"	6.5	0.090	0.585	0.060	0.390	0.070	0.455	0.090	0.585	0.000	0.000	0.150	0.975	0.130	0.845
				S.C.,weighted =	6.4	S.C.,weighted =	6.4	S.C.,weighted =	6.4	S.C.,weighted =	6.5	S.C.,weighted =	*	S.C.,weighted =	6.4	S.C.,weighted =	6.5
Norcross	#120		6.2	0.080	0.496	0.080	0.496	0.070	0.434	0.090	0.558	0.000	0.000	0.120	0.744	0.090	0.558
Norcross	#8	#120	6.2	0.220	1.364	0.220	1.364	0.240	1.488	0.260	1.612	0.000	0.000	0.330	2.046	0.290	1.798
Norcross	#4	#8	7.2	0.090	0.648	0.090	0.648	0.100	0.720	0.080	0.576	0.000	0.000	0.130	0.936	0.130	0.936
Norcross	1/2"	3/8"	7.9	0.160	1.264	0.060	0.474	0.070	0.553	0.150	1.185	0.000	0.000	0.150	1.185	0.130	1.027
				S.C.,weighted =	6.9	S.C.,weighted =	6.6	S.C.,weighted =	6.7	S.C.,weighted =	6.8	S.C.,weighted =	*	S.C.,weighted =	6.7	S.C.,weighted =	6.7
Palmer Sta	#120	-	4.5	0.070	0.315	0.080	0.360	0.070	0.315	0.100	0.450	0.000	0.000	0.100	0.450	0.090	0.405
Palmer Sta	#8	#120	5.0	0.280	1.400	0.220	1.100	0.240	1.200	0.230	1.150	0.000	0.000	0.350	1.750	0.290	1.450
Palmer Sta	#4	#8	7.7	0.100	0.770	0.090	0.693	0.100	0.770	0.110	0.847	0.000	0.000	0.130	1.001	0.130	1.001
Palmer Sta	1/2"	3/8"	7.5	0.080	0.600	0.060	0.450	0.070	0.525	0.07	0.525	0.000	0.000	0.150	1.125	0.130	0.975
				S.C.,weighted =	5.8	S.C.,weighted =	5.8	S.C.,weighted =	5.9	S.C.,weighted =	5.8	S.C.,weighted =	*	S.C.,weighted =	5.9	S.C.,weighted	6.0
Postell	#120	-	6.9	0.090	0.621	0.080	0.552	0.070	0.483	0.080	0.552	0.000	0.000	0.000	0.000	0.090	0.621
Postell	#8	#120	4.5	0.260	1.170	0.220	0.990	0.240	1.080	0.250	1.125	0.000	0.000	0.000	0.000	0.290	1.305
Postell	#4	#8	8.5	0.140	1.190	0.090	0.765	0.100	0.850	0.150	1.275	0.000	0.000	0.000	0.000	0.130	1.105
Postell	1/2"	3/8"	7.4	0.110	0.814	0.060	0.444	0.070	0.518	0.12	0.888	0.000	0.000	0.000	0.000	0.130	0.962
				S.C.,weighted =	6.3	S.C.,weighted =	6.1	S.C.,weighted =	6.1	S.C.,weighted =	6.4	S.C.,weighted =	*	S.C.,weighted =	*	S.C.,weighted =	6.2
Ruby	#120		6.6	0.080	0.528	0.080	0.528	0.070	0.462	0.080	0.528	0.100	0.660	0.110	0.726	0.090	0.594
Ruby	#8	#120	4.9	0.250	1.225	0.220	1.078	0.240	1.176	0.250	1.225	0.350	1.715	0.340	1.666	0.290	1.421
Ruby	#4	#8	7.6	0.100	0.760	0.090	0.684	0.100	0.760	0.100	0.760	0.180	1.368	0.150	1.140	0.130	0.988
Ruby	1/2"	3/8"	7.4	0.050	0.370	0.060	0.444	0.070	0.518	0.160	1.184	0.010	0.074	0.160	1.184	0.130	0.962
				S.C.,weighted =	6.0	S.C.,weighted =	6.1	S.C.,weighted =	6.1	S.C.,weighted =	6.3	S.C.,weighted =	6.0	S.C.,weighted =	6.2	S.C.,weighted	6.2
Stockbridge	#120		6.5	0.100	0.650	0.080	0.520	0.070	0.455	0.090	0.585	0.000	0.000	0.110	0.715	0.090	0.585
Stockbridge	#8	#120	5.1	0.240	1.224	0.220	1.122	0.240	1.224	0.260	1.326	0.000	0.000	0.340	1.734	0.290	1.479
Stockbridge	#4	#8	7.8	0.110	0.858	0.090	0.702	0.100	0.780	0.140	1.092	0.000	0.000	0.140	1.092	0.130	1.014
Stockbridge	1/2"	3/8"	7.9	0.100	0.790	0.060	0.474	0.070	0.553	0.08	0.632	0.000	0.000	0.140	1.106	0.130	1.027
				S.C.,weighted =	6.4	S.C.,weighted =	6.3	S.C.,weighted =	6.3	S.C.,weighted =	6.4	S.C.,weighted =	*	S.C.,weighted =	6.4	S.C.,weighted =	6.4
Tyrone	#120	-	7.3	0.070	0.511	0.080	0.584	0.070	0.511	0.070	0.511	0.110	0.803	0.110	0.803	0.090	0.657
Tyrone	#8	#120	5.2	0.270	1.404	0.220	1.144	0.240	1.248	0.260	1.352	0.340	1.768	0.340	1.768	0.290	1.508
Tyrone	#4	#8	6.4	0.120	0.768	0.090	0.576	0.100	0.640	0.110	0.704	0.200	1.280	0.130	0.832	0.130	0.832
Tyrone	1/2"	3/8"	6.1	0.090	0.549	0.060	0.366	0.070	0.427	0.170	1.037	0.000	0.000	0.150	0.915	0.130	0.793
				S.C.,weighted =	5.9	S.C.,weighted =	5.9	S.C.,weighted =	5.9	S.C.,weighted =	5.9	S.C.,weighted =	5.9	S.C.,weighted =	5.9	S.C.,weighted =	5.9
White	#120	-	7.3	0.080	0.584	0.080	0.584	0.070	0.511	0.070	0.511	0.100	0.730	0.000	0.000	0.090	0.657
White	#8	#120	5.2	0.270	1.404	0.220	1.144	0.240	1.248	0.240	1.248	0.350	1.820	0.000	0.000	0.290	1.508
White	#4	#8	6.4	0.130	0.832	0.090	0.576	0.100	0.640	0.120	0.768	0.170	1.088	0.000	0.000	0.130	0.832
White	1/2"	3/8"	7.9	0.090	0.711	0.060	0.474	0.070	0.553	0.110	0.869	0.000	0.000	0.000	0.000	0.130	1.027
				S.C.,weighted =	6.2	S.C.,weighted =	6.2	S.C.,weighted =	6.2	S.C.,weighted =	6.3	S.C.,weighted =	5.9	S.C.,weighted =	*	S.C.,weighted =	6.3

Table 7. Aggregate Surface Roughness.

Quarry Name	Surface Rough.
Athens	1.18
Ball Gr.	1.15
Barin	1.18
Buford	1.16
Candler	1.22
Cumm.	1.18
Dalton	1.13
Dan	1.16
Dixie	1.13
Griffin	1.18
Kenn.	1.26
Lith. Sp.	1.20
Lithonia	1.17
Mt. View	1.17
Norcros.	1.21
Palm. St.	1.16
Postell	1.17
Ruby	1.21
Stockbrg	1.24
Tyrone	1.18
White	1.14

FREE MICA CONTENT

Free mica content values for each quarry were obtained for four size ranges using the techniques described in Chapter 3. The following U. S. standard sieve size ranges were used: No.16 to No.30, No.30 to No.50, No.50 to No.100 and No.100 to No.200. Weighted mica content values were then calculated for the fine aggregate portion of asphalt mix gradations. The fine aggregate size is defined as all particles passing the No.8 sieve.

To develop weighted free mica contents for the entire fine aggregate size, the mica content for aggregate passing the No.8 sieve and retained on the No.16 sieve was estimated by projecting forward the linear trend existing from the aggregate sizes passing the No.16 and retained on the No.30 sieve. For all quarries, a zero free mica content was estimated for the aggregate size range from the No.8 to the No.16 sieve. The free mica content for the fines (particles passing the No.200 sieve) was arbitrarily assumed to be equal to the mica content for particle sizes passing the No.100 and retained on the No.200 sieve.

Weighted free mica content values were calculated for specific aggregate gradations of the asphalt concrete mixes used in this study. Specifically, the percent of aggregate within each sieve size range is multiplied by the respective mica content. The weighted mica content for each grading is the sum of these products divided by the sum of the percents retained in each size range included. The free mica contents (M_i) for each size range and the weighted mica contents (Mi,w) for each mix are given in Table 8.

MARSHALL MIX DESIGN VARIABLES

The Marshall mix design variables considered in this study as potential indicators of rutting are as follows:

Table 8. Aggregate Free Mica Contents.

QUARRY	SIZE PASS	SIZE RET	Mica Content (%)	Base (DOT) Weight Factor	M.*W.F.	Coarse Base Weight Factor	M.*W.F.	Fine Base Weight Factor	M.*W.F.	B Binder (DOT) Weight Factor	M.*W.F.	F Mix (DOT) Weight Factor	M.*W.F.	E Mix (DOT) Weight Factor	M.*W.F.	Coarse E Mix Weight Factor	M.*W.F.
Athens	#100	#200	41.2	0.070	2.884	0.080	3.296	0.070	2.884	0.080	3.296	0.090	3.708	0.090	3.708	0.090	3.708
Athens	#50	#100	37.3	0.070	2.611	0.030	1.119	0.060	2.238	0.060	2.238	0.070	2.611	0.070	2.611	0.050	1.865
Athens	#30	#50	40.1	0.060	2.406	0.040	1.604	0.070	2.807	0.060	2.406	0.100	4.010	0.080	3.208	0.070	2.807
Athens	#16	#30	18.0	0.060	1.080	0.060	1.080	0.050	0.900	0.070	1.260	0.080	1.440	0.090	1.620	0.080	1.440
Athens	#8	#16	0.0	0.080	0.000	0.090	0.000	0.080	0.000	0.060	0.000	0.110	0.000	0.120	0.000	0.090	0.000
				M.,weighted =	26.4	M.,weighted =	23.7	M.,weighted =	26.8	M.,weighted =	27.9	M.,weighted =	26.2	M.,weighted =	24.8	M.,weighted =	25.8
Ball Ground	#100	#200	39.2	0.080	3.136	0.080	3.136	0.070	2.744	0.080	3.136	0.000	0.000	0.100	3.920	0.090	3.528
Ball Ground	#50	#100	26.6	0.040	1.064	0.030	0.798	0.060	1.596	0.040	1.064	0.000	0.000	0.040	1.064	0.050	1.330
Ball Ground	#30	#50	5.7	0.060	0.342	0.040	0.228	0.070	0.399	0.050	0.285	0.000	0.000	0.060	0.342	0.070	0.399
Ball Ground	#16	#30	1.0	0.080	0.080	0.060	0.060	0.050	0.050	0.070	0.070	0.000	0.000	0.100	0.100	0.080	0.080
Ball Ground	#8	#16	0.0	0.090	0.000	0.090	0.000	0.080	0.000	0.090	0.000	0.000	0.000	0.150	0.000	0.090	0.000
				M.,weighted =	13.2	M.,weighted =	14.1	M.,weighted =	14.5	M.,weighted =	13.8	M.,weighted =	*	M.,weighted =	12.1	M.,weighted =	14.0
Barin	#100	#200	26.4	0.100	2.640	0.080	2.112	0.070	1.848	0.090	2.376	0.110	2.904	0.110	2.904	0.090	2.376
Barin	#50	#100	37.3	0.060	2.238	0.030	1.119	0.060	2.238	0.060	2.238	0.080	2.984	0.080	2.984	0.050	1.865
Barin	#30	#50	35.3	0.080	2.824	0.040	1.412	0.070	2.471	0.070	2.471	0.080	2.824	0.090	3.177	0.070	2.471
Barin	#16	#30	10.0	0.050	0.500	0.060	0.600	0.050	0.500	0.050	0.500	0.070	0.700	0.070	0.700	0.080	0.800
Barin	#8	#16	0.0	0.060	0.000	0.090	0.000	0.080	0.000	0.060	0.000	0.110	0.000	0.100	0.000	0.090	0.000
				M.,weighted =	23.4	M.,weighted =	17.5	M.,weighted =	21.4	M.,weighted =	23.0	M.,weighted =	20.9	M.,weighted =	21.7	M.,weighted =	19.8
Buford	#100	#200	32.9	0.090	2.961	0.080	2.632	0.070	2.303	0.090	2.961	0.100	3.290	0.100	3.290	0.090	2.961
Buford	#50	#100	16.9	0.060	1.014	0.030	0.507	0.060	1.014	0.070	1.183	0.100	1.690	0.080	1.352	0.050	0.845
Buford	#30	#50	1.4	0.060	0.084	0.040	0.056	0.070	0.098	0.040	0.056	0.040	0.056	0.080	0.112	0.070	0.098
Buford	#16	#30	3.3	0.050	0.165	0.060	0.198	0.050	0.165	0.040	0.132	0.090	0.297	0.050	0.165	0.080	0.264
Buford	#8	#16	0.0	0.080	0.000	0.090	0.000	0.080	0.000	0.090	0.000	0.120	0.000	0.140	0.000	0.090	0.000
				M.,weighted =	12.4	M.,weighted =	11.3	M.,weighted =	10.8	M.,weighted =	13.1	M.,weighted =	11.9	M.,weighted =	10.9	M.,weighted =	11.0
Candler	#100	#200	12.3	0.110	1.353	0.080	0.984	0.070	0.861	0.100	1.230	0.120	1.476	0.100	1.230	0.090	1.107
Candler	#50	#100	9.2	0.070	0.644	0.030	0.276	0.060	0.552	0.060	0.552	0.080	0.736	0.090	0.829	0.050	0.460
Candler	#30	#50	6.3	0.070	0.441	0.040	0.252	0.070	0.441	0.040	0.252	0.050	0.315	0.090	0.567	0.070	0.441
Candler	#16	#30	1.0	0.040	0.040	0.060	0.060	0.050	0.050	0.040	0.040	0.090	0.090	0.060	0.060	0.080	0.090
Candler	#8	#16	0.0	0.050	0.000	0.090	0.000	0.080	0.000	0.090	0.000	0.110	0.000	0.110	0.000	0.090	0.000
				M.,weighted =	7.3	M.,weighted =	5.2	M.,weighted =	5.8	M.,weighted =	6.3	M.,weighted =	5.8	M.,weighted =	6.0	M.C.,weighted =	5.5
Cummings	#100	#200	30.0	0.090	2.700	0.080	2.400	0.070	2.100	0.090	2.700	0.000	0.000	0.100	3.000	0.090	2.700
Cummings	#50	#100	34.4	0.040	1.376	0.030	1.032	0.060	2.064	0.050	1.720	0.000	0.000	0.060	2.064	0.050	1.720
Cummings	#30	#50	17.0	0.070	1.190	0.040	0.680	0.070	1.190	0.090	1.530	0.000	0.000	0.090	1.530	0.070	1.190
Cummings	#16	#30	5.0	0.050	0.250	0.060	0.300	0.050	0.250	0.070	0.350	0.000	0.000	0.090	0.450	0.080	0.400
Cummings	#8	#16	0.0	0.100	0.000	0.090	0.000	0.080	0.000	0.080	0.000	0.000	0.000	0.110	0.000	0.090	0.000
				M.,weighted =	15.8	M.,weighted =	14.7	M.,weighted =	17.0	M.,weighted =	16.6	M.,weighted =	*	M.,weighted =	15.7	M.C.,weighted =	15.8
Dalton	#100	#200	19.0	0.080	1.520	0.080	1.520	0.070	1.330	0.070	1.330	0.000	0.000	0.080	1.520	0.090	1.710
Dalton	#50	#100	15.4	0.040	0.616	0.030	0.462	0.060	0.924	0.020	0.308	0.000	0.000	0.030	0.462	0.050	0.770
Dalton	#30	#50	0.7	0.050	0.034	0.040	0.027	0.070	0.047	0.040	0.027	0.000	0.000	0.060	0.040	0.070	0.047
Dalton	#16	#30	0.0	0.070	0.000	0.060	0.000	0.050	0.000	0.070	0.000	0.000	0.000	0.100	0.000	0.080	0.000
Dalton	#8	#16	0.0	0.100	0.000	0.090	0.000	0.080	0.000	0.070	0.000	0.300	0.000	0.180	0.000	0.090	0.000
				M.,weighted =	6.4	M.,weighted =	6.7	M.,weighted =	7.0	M.,weighted =	6.2	M.,weighted =	*	M.,weighted =	4.5	M.C.,weighted =	6.6
Dan	#100	#200	23.8	0.080	1.904	0.080	1.904	0.070	1.666	0.070	1.666	0.000	0.000	0.110	2.618	0.090	2.142
Dan	#50	#100	20.8	0.040	0.832	0.030	0.624	0.060	1.248	0.040	0.832	0.000	0.000	0.060	1.248	0.050	1.040
Dan	#30	#50	23.0	0.060	1.380	0.040	0.920	0.070	1.610	0.060	1.380	0.000	0.000	0.090	2.070	0.070	1.610
Dan	#16	#30	6.7	0.070	0.469	0.060	0.402	0.050	0.335	0.070	0.469	0.000	0.000	0.090	0.603	0.080	0.536
Dan	#8	#16	0.0	0.100	0.000	0.090	0.000	0.080	0.000	0.090	0.000	0.000	0.000	0.100	0.000	0.090	0.000
				M.,weighted =	13.1	M.,weighted =	12.8	M.,weighted =	14.7	M.,weighted =	13.2	M.,weighted =	*	M.,weighted =	14.5	M.,weighted =	14.0
Dixie	#100	#200	2.4	0.000	0.000	0.080	0.192	0.070	0.168	0.000	0.000	0.100	0.240	0.090	0.216	0.090	0.216
Dixie	#50	#100	2.8	0.000	0.000	0.030	0.084	0.060	0.168	0.000	0.000	0.020	0.056	0.050	0.140	0.050	0.140
Dixie	#30	#50	0.5	0.000	0.000	0.040	0.020	0.070	0.035	0.000	0.000	0.070	0.035	0.090	0.045	0.070	0.035
Dixie	#16	#30	0.1	0.000	0.000	0.060	0.006	0.050	0.005	0.000	0.000	0.090	0.009	0.070	0.007	0.080	0.008
Dixie	#8	#16	0.0	0.000	0.000	0.090	0.000	0.080	0.000	0.000	0.000	0.170	0.000	0.150	0.000	0.090	0.000
				M.,weighted =	*	M.,weighted =	1.0	M.,weighted =	1.1	M.,weighted =	*	M.,weighted =	0.8	M.,weighted =	0.9	M.,weighted =	1.1
Griffin	#100	#200	43.3	0.080	3.464	0.080	3.464	0.070	3.031	0.080	3.464	0.100	4.330	0.100	4.330	0.090	3.897
Griffin	#50	#100	31.8	0.040	1.272	0.030	0.954	0.060	1.908	0.050	1.590	0.050	1.590	0.050	1.590	0.050	1.590
Griffin	#30	#50	19.7	0.060	1.182	0.040	0.788	0.070	1.379	0.040	0.788	0.070	1.379	0.070	1.379	0.070	1.379
Griffin	#16	#30	8.3	0.070	0.581	0.060	0.498	0.050	0.415	0.080	0.664	0.100	0.830	0.100	0.830	0.080	0.664
Griffin	#8	#16	0.0	0.090	0.000	0.090	0.000	0.080	0.000	0.080	0.000	0.130	0.000	0.130	0.000	0.090	0.000
				M.,weighted =	19.1	M.,weighted =	19.0	M.,weighted =	20.4	M.,weighted =	19.7	M.,weighted =	18.1	M.,weighted =	18.1	M.,weighted =	19.8

Table 8. Aggregate Free Mica Contents (continued).

QUARRY	SIZE PASS	SIZE RET	Mica Content (%)	Base (DOT) Weight Factor	M.*W.F.	Coarse Base Weight Factor	M.*W.F.	Fine Base Weight Factor	M.*W.F.	B Binder (DOT) Weight Factor	M.*W.F.	F Mix (DOT) Weight Factor	M.*W.F.	E Mix (DOT) Weight Factor	M.*W.F.	Coarse E Mix Weight Factor	M.*W.F.
Kennesaw	#100	#200	25.9	0.100	2.590	0.080	2.072	0.070	1.813	0.090	2.331	0.000	0.000	0.100	2.590	0.090	2.331
Kennesaw	#50	#100	38.9	0.050	1.945	0.030	1.167	0.060	2.334	0.050	1.945	0.000	0.000	0.070	2.723	0.050	1.945
Kennesaw	#30	#50	13.7	0.060	0.822	0.040	0.548	0.070	0.959	0.060	0.822	0.000	0.000	0.080	1.096	0.070	0.959
Kennesaw	#16	#30	2.3	0.050	0.115	0.060	0.138	0.050	0.115	0.060	0.138	0.000	0.000	0.080	0.184	0.080	0.184
Kennesaw	#8	#16	0.0	0.090	0.000	0.090	0.000	0.080	0.000	0.070	0.000	0.000	0.000	0.120	0.000	0.090	0.000
				M.,weighted =	15.6	M.,weighted =	13.1	M.,weighted =	15.8	M.,weighted =	15.9	M.,weighted =	*	M.C.,weighted =	14.7	M.,weighted =	14.3
Lithia Springs	#100	#200	23.7	0.080	1.896	0.080	1.896	0.070	1.659	0.080	1.896	0.000	0.000	0.120	2.844	0.090	2.133
Lithia Springs	#50	#100	27.7	0.050	1.385	0.030	0.831	0.060	1.662	0.040	1.108	0.000	0.000	0.070	1.939	0.050	1.385
Lithia Springs	#30	#50	13.1	0.060	0.786	0.040	0.524	0.070	0.917	0.060	0.786	0.000	0.000	0.080	1.048	0.070	0.917
Lithia Springs	#16	#30	2.3	0.070	0.161	0.060	0.138	0.050	0.115	0.060	0.138	0.000	0.000	0.070	0.161	0.080	0.184
Lithia Springs	#8	#16	0.0	0.090	0.000	0.090	0.000	0.080	0.000	0.090	0.000	0.000	0.000	0.110	0.000	0.090	0.000
				M.,weighted =	12.1	M.,weighted =	11.3	M.,weighted =	13.2	M.,weighted =	11.9	M.,weighted =	*	M.C.,weighted =	13.3	M.,weighted =	12.2
Lithonia	#100	#200	20.6	0.080	1.648	0.080	1.648	0.070	1.442	0.080	1.648	0.000	0.000	0.110	2.266	0.090	1.854
Lithonia	#50	#100	20.1	0.070	1.407	0.030	0.603	0.060	1.206	0.060	1.206	0.000	0.000	0.090	1.809	0.050	1.005
Lithonia	#30	#50	8.7	0.050	0.435	0.040	0.348	0.070	0.609	0.050	0.435	0.000	0.000	0.070	0.609	0.070	0.609
Lithonia	#16	#30	1.7	0.060	0.102	0.060	0.102	0.050	0.085	0.060	0.102	0.000	0.000	0.070	0.119	0.080	0.136
Lithonia	#8	#16	0.0	0.090	0.000	0.090	0.000	0.080	0.000	0.080	0.000	0.000	0.000	0.110	0.000	0.090	0.000
				M.,weighted =	10.3	M.,weighted =	9.0	M.,weighted =	10.1	M.,weighted =	10.3	M.,weighted =	*	M.,weighted =	10.7	M.,weighted =	9.5
Mt View	#100	#200	28.0	0.090	2.520	0.080	2.240	0.070	1.960	0.080	2.240	0.000	0.000	0.110	3.080	0.090	2.520
Mt View	#50	#100	33.0	0.070	2.310	0.030	0.990	0.060	1.980	0.070	2.310	0.000	0.000	0.100	3.300	0.050	1.650
Mt View	#30	#50	15.7	0.060	0.942	0.040	0.628	0.070	1.099	0.030	0.471	0.000	0.000	0.040	0.628	0.070	1.099
Mt View	#16	#30	2.3	0.040	0.092	0.060	0.138	0.050	0.115	0.070	0.161	0.000	0.000	0.090	0.207	0.080	0.184
Mt View	#8	#16	0.0	0.090	0.000	0.090	0.000	0.080	0.000	0.080	0.000	0.000	0.000	0.110	0.000	0.090	0.000
				M.,weighted =	16.8	M.,weighted =	13.3	M.,weighted =	15.6	M.,weighted =	15.7	M.,weighted =	*		16.0	M.,weighted =	14.4
Norcross	#100	#200	27.0	0.100	2.700	0.080	2.160	0.070	1.890	0.090	2.430	0.000	0.000	0.120	3.240	0.090	2.430
Norcross	#50	#100	30.5	0.060	1.830	0.030	0.915	0.060	1.830	0.060	1.830	0.000	0.000	0.080	2.440	0.050	1.525
Norcross	#30	#50	13.0	0.070	0.910	0.040	0.520	0.070	0.910	0.070	0.910	0.000	0.000	0.090	1.170	0.070	0.910
Norcross	#16	#30	3.0	0.050	0.150	0.060	0.180	0.050	0.150	0.040	0.120	0.000	0.000	0.060	0.180	0.080	0.240
Norcross	#8	#16	0.0	0.070	0.000	0.090	0.000	0.080	0.000	0.090	0.000	0.000	0.000	0.100	0.000	0.090	0.000
				M.,weighted =	16.0	M.,weighted =	12.6	M.,weighted =	14.5	M.,weighted =	15.1	M.,weighted =	*	M.,weighted =	15.6	M.,weighted =	13.4
Palmer Sta	#100	#200	25.2	0.070	1.764	0.080	2.016	0.070	1.764	0.100	2.520	0.000	0.000	0.100	2.520	0.090	2.268
Palmer Sta	#50	#100	26.9	0.080	2.152	0.030	0.807	0.060	1.614	0.070	1.883	0.000	0.000	0.100	2.690	0.050	1.345
Palmer Sta	#30	#50	13.7	0.070	0.959	0.040	0.548	0.070	0.959	0.050	0.685	0.000	0.000	0.090	1.233	0.070	0.959
Palmer Sta	#16	#30	3.7	0.060	0.222	0.060	0.222	0.050	0.185	0.050	0.185	0.000	0.000	0.080	0.295	0.080	0.296
Palmer Sta	#8	#16	0.0	0.070	0.000	0.090	0.000	0.080	0.000	0.060	0.000	0.000	0.000	0.080	0.000	0.090	0.000
				M.,weighted =	14.6	M.,weighted =	12.0	M.,weighted =	13.7	M.,weighted =	16.0	M.,weighted =	*	M.,weighted =	15.0	M.,weighted =	12.8
Postell	#100	#200	36.7	0.090	3.303	0.080	2.936	0.070	2.569	0.080	2.936	0.000	0.000	0.110	4.037	0.090	3.303
Postell	#50	#100	39.0	0.040	1.560	0.030	1.170	0.060	2.340	0.050	1.950	0.000	0.000	0.060	2.340	0.050	1.950
Postell	#30	#50	2.7	0.050	0.135	0.040	0.108	0.070	0.189	0.040	0.108	0.000	0.000	0.070	0.189	0.070	0.189
Postell	#16	#30	0.7	0.070	0.047	0.060	0.040	0.050	0.034	0.060	0.040	0.000	0.000	0.080	0.054	0.080	0.054
Postell	#8	#16	0.0	0.100	0.000	0.090	0.000	0.080	0.000	0.100	0.000	0.000	0.000	0.130	0.000	0.090	0.000
				M.,weighted =	14.4	M.,weighted =	14.2	M.,weighted =	15.6	M.,weighted =	15.3	M.,weighted =	*	M.,weighted =	14.7	M.,weighted =	14.5
Ruby	#100	#200	51.0	0.080	4.080	0.080	4.080	0.070	3.570	0.080	4.080	0.100	5.100	0.110	5.610	0.090	4.590
Ruby	#50	#100	36.0	0.040	1.440	0.030	1.080	0.060	2.160	0.040	1.440	0.070	2.520	0.060	2.160	0.050	1.800
Ruby	#30	#50	6.3	0.050	0.315	0.040	0.252	0.070	0.441	0.050	0.315	0.060	0.378	0.050	0.315	0.070	0.441
Ruby	#16	#30	0.3	0.060	0.018	0.060	0.018	0.050	0.015	0.070	0.021	0.100	0.030	0.100	0.030	0.080	0.024
Ruby	#8	#16	0.0	0.100	0.000	0.090	0.000	0.080	0.000	0.090	0.000	0.120	0.000	0.130	0.000	0.090	0.000
				M.,weighted =	17.7	M.,weighted =	18.1	M.,weighted =	18.7	M.,weighted =	17.7	M.,weighted =	17.8	M.,weighted =	18.0	M.,weighted =	18.0
Stockbridge	#100	#200	16.0	0.100	1.600	0.080	1.280	0.070	1.120	0.090	1.440	0.000	0.000	0.110	1.760	0.090	1.440
Stockbridge	#50	#100	12.9	0.060	0.774	0.030	0.387	0.060	0.774	0.040	0.516	0.000	0.000	0.070	0.903	0.050	0.645
Stockbridge	#30	#50	2.3	0.060	0.138	0.040	0.092	0.070	0.161	0.060	0.138	0.000	0.000	0.080	0.184	0.070	0.161
Stockbridge	#16	#30	1.0	0.070	0.070	0.060	0.060	0.050	0.050	0.050	0.050	0.000	0.000	0.080	0.080	0.080	0.080
Stockbridge	#8	#16	0.0	0.050	0.000	0.090	0.000	0.080	0.000	0.090	0.000	0.000	0.000	0.090	0.000	0.090	0.000
				M.,weighted =	7.6	M.,weighted =	6.1	M.,weighted =	6.4	M.,weighted =	6.5	M.,weighted =	*	M.,weighted =	6.8	M.,weighted =	6.1
Tyrone	#100	#200	30.0	0.070	2.100	0.080	2.400	0.070	2.100	0.070	2.100	0.110	3.300	0.110	3.300	0.090	2.700
Tyrone	#50	#100	26.0	0.050	1.300	0.030	0.780	0.060	1.560	0.050	1.300	0.180	4.680	0.090	2.080	0.050	1.300
Tyrone	#30	#50	9.0	0.050	0.450	0.040	0.360	0.070	0.630	0.050	0.450	0.070	0.630	0.070	0.630	0.070	0.630
Tyrone	#16	#30	4.0	0.080	0.320	0.060	0.240	0.050	0.200	0.080	0.320	0.080	0.320	0.080	0.320	0.080	0.320
Tyrone	#8	#16	0.0	0.090	0.000	0.090	0.000	0.080	0.000	0.080	0.000	0.090	0.000	0.110	0.000	0.090	0.000
				M.,weighted =	12.3	M.,weighted =	12.6	M.,weighted =	13.6	M.,weighted =	12.6	M.,weighted =	16.8	M.,weighted =	14.1	M.,weighted =	13.0

Table 8. Aggregate Free Mica Contents (continued).

QUARRY	SIZE PASS	SIZE RET	Mica Content (%)	Base (DOT) Weight Factor	M.*W.F.	Coarse Base Weight Factor	M.*W.F.	Fine Base Weight Factor	M.*W.F.	B Binder (DOT) Weight Factor	M.*W.F.	F Mix (DOT) Weight Factor	M.*W.F.	E Mix (DOT) Weight Factor	M.*W.F.	Coarse E Mix Weight Factor	M.*W.F.
White	#100	#200	4.8	0.080	0.384	0.080	0.384	0.070	0.336	0.070	0.336	0.100	0.480	0.120	0.576	0.090	0.432
White	#50	#100	3.5	0.030	0.105	0.030	0.105	0.060	0.210	0.030	0.105	0.030	0.105	0.070	0.245	0.050	0.175
White	#30	#50	0.0	0.040	0.000	0.040	0.000	0.070	0.000	0.040	0.000	0.050	0.000	0.060	0.000	0.070	0.000
White	#16	#30	0.0	0.070	0.000	0.060	0.000	0.050	0.000	0.070	0.000	0.090	0.000	0.090	0.000	0.080	0.000
White	#8	#16	0.0	0.130	0.000	0.090	0.000	0.080	0.000	0.120	0.000	0.180	0.000	0.110	0.000	0.090	0.000
				M.C.,weighted =	1.4	M.C.,weighted =	1.6	M.C.,weighted =	1.7	M.C.,weighted =	1.3	M.C.,weighted =	1.3	M.C.,weighted =	1.8	M.C.,weighted =	1.6

1. Asphalt content (percent)
2. Air Voids (percent)
3. Mix Density (pcf)
4. Voids in Mineral Aggregate (VMA - percent)
5. Marshall Stability (lbs).
6. Marshall Flow

Values for these asphalt mix design variables were taken from the Georgia Department of Transportation mix design data sheets for the 21 quarries. Conventional Georgia DOT mixes studied were as follows: base, B binder, surface E, and surface F mixes. In addition, the following rut resistant mixes, developed as a part of this study, were also considered: coarse and fine base mix, and Coarse E mix. The proposed rut resistant binder mix was essentially the same as the conventional Georgia DOT base mix. Therefore the conventional Georgia DOT base mix was compared with the conventional B binder mix. For the optimum asphalt content of the specimen, as determined from the Marshall mix designs, linear interpolation from the mix design was used to obtain percent air voids, mix density, voids in the mineral aggregate (VMA), stability, and flow. These mix design variables, in addition to aggregate gradation, uniformity coefficient (C_u), and bulk specific gravity of the fine aggregate are all given in Tables 9 through 15.

INDIRECT TENSION TEST RESULTS

Indirect tension tests were performed on selected asphalt concrete mixes in accordance with ASTM D4123-82 (1987). The tests were performed on 4 in. diameter by 2.5 in. thick Marshall samples prepared by the Georgia D.O.T. Resilient modulus tests were only performed at 80°F. Testing

Table 9. Marshall Mix Design Variables for DOT Base Mix.

Quarry Name	% Asp. Con.	Air V. (%)	γ (pcf)	VMA (%)	Bulk S.G.	C_u	Stab. (lbs)	Flow
Athens	4.9	4.30	150.4	15.74	2.68	66.7	2552	11.64
Ball Gr.	4.8	4.32	151.8	15.60	2.75	50.0	2922	11.36
Barin	4.7	4.64	149.4	15.62	2.67	66.7	2324	12.18
Buford	4.9	4.54	146.2	15.68	2.61	76.5	2880	9.80
Candler	4.7	4.48	145.9	15.16	2.61	79.8	2716	9.80
Cumm.	4.8	4.36	148.8	15.60	2.80	50.0	2592	11.10
Dalton	4.5	4.40	152.1	15.10	2.68	46.9	2490	11.60
Dan	4.5	4.80	147.3	15.10	2.64	37.8	2580	9.30
Dixie	*	*	*	*	*	*	2872	11.74
Griffin	5.0	4.50	148.	16.00	2.65	43.8	3230	13.00
Kenn.	4.7	4.54	153.9	15.82	2.78	68.3	2926	10.54
Lith. Sp.	4.9	4.28	146.1	15.22	2.61	39.1	2940	11.08
Lithonia	4.4	3.04	148.5	14.28	2.61	55.7	3384	9.70
Mt. View	4.7	4.44	148.3	15.22	2.66	58.3	3122	10.56
Norcros.	4.7	4.64	152.0	15.76	2.69	80.0	2374	11.30
Palm. St.	4.7	4.48	149.2	15.50	2.65	43.8	2862	10.58
Postell	4.7	4.28	150.2	15.20	2.63	42.5	2776	10.96
Ruby	4.5	4.50	151.2	15.00	2.73	47.5	2350	13.30
Stockbrg	4.9	4.34	145.9	15.38	2.61	56.5	2688	9.50
Tyrone	4.8	4.46	147.7	15.44	2.64	38.9	3234	12.72
White	4.0	4.20	152.7	13.70	2.71	25.7	2550	13.44

Note:
% Asp. Cont. = percent of asphalt in mix
Air V. (%) = total air voids in mix
γ (pcf) = mix density in pounds per cubic foot
VMA (%) = percent voids in mineral aggregate
Bulk S.G. = bulk specific gravity of fine aggregate
C_u = coefficient of uniformity
Stab. = stability in pounds

Table 10. Marshall Mix Design Variables for Improved Coarse Base Mix.

Quarry Name	% Asp. Con.	Air V. (%)	γ (pcf)	VMA (%)	Bulk S.G.	C_u	Stab. (lbs)	Flow
Athens	5.0	4.50	149.9	16.10	2.68	83.3	2660	11.10
Ball Gr.	4.5	3.10	155.8	13.90	2.75	83.3	3030	12.20
Barin	3.9	4.30	149.9	13.60	2.67	83.3	2560	11.30
Buford	4.4	4.58	148.1	14.72	2.61	83.3	1942	9.94
Candler	4.3	4.52	146.8	14.30	2.61	83.3	*	*
Cumm.	4.6	6.30	150.8	15.94	2.80	83.3	2150	9.70
Dalton	3.7	4.32	153.4	13.10	2.68	83.3	2340	11.52
Dan	4.7	4.64	147.7	15.36	2.64	83.3	2240	11.30
Dixie	*	*	*	*	*	*	*	*
Griffin	4.7	6.20	146.6	15.78	2.65	83.3	2850	12.00
Kenn.	4.8	5.66	152.1	17.00	2.78	83.3	2740	10.62
Lith. Sp.	3.7	5.10	146.8	14.20	2.61	83.3	2426	10.18
Lithonia	4.2	4.68	147.7	14.62	2.61	83.3	3332	9.22
Mt. View	4.2	4.42	149.7	14.20	2.66	83.3	2560	10.58
Norcros.	4.1	4.52	151.2	14.18	2.69	83.3	3244	10.40
Palm. St.	4.4	4.66	149.0	14.90	2.65	83.3	2954	11.78
Postell	4.3	4.84	152.5	15.02	2.63	83.3	2764	10.50
Ruby	4.3	4.44	152.6	14.62	2.73	83.3	2638	10.12
Stockbrg	4.1	4.38	147.5	15.26	2.61	83.3	3686	10.84
Tyrone	4.6	4.58	148.5	15.28	2.64	83.3	2870	10.70
White	3.8	3.70	153.1	13.20	2.71	83.3	3080	14.00

Note:
% Asp. Cont. = percent of asphalt in mix
Air V. (%) = total air voids in mix
γ (pcf) = mix density in pounds per cubic foot
VMA (%) = percent voids in mineral aggregate
Bulk S.G. = bulk specific gravity of fine aggregate
C_u = coefficient of uniformity
Stab. = stability in pounds

Table 11. Marshall Mix Design Variables for Improved Fine Base Mix.

Quarry Name	% Asp. Con.	Air V. (%)	γ (pcf)	VMA (%)	Bulk S.G.	C_u	Stab. (lbs)	Flow
Athens	*	*	*	*	2.68	75	*	*
Ball Gr.	*	*	*	*	2.75	75	*	*
Barin	*	*	*	*	2.67	75	3182	10.00
Buford	*	*	*	*	2.61	75	*	*
Candler	*	*	*	*	2.61	75	*	*
Cumm.	*	*	*	*	2.80	75	*	*
Dalton	*	*	*	*	2.68	75	*	*
Dan	*	*	*	*	2.64	75	*	*
Dixie	*	*	*	*	*	*	*	*
Griffin	*	*	*	*	2.65	75	*	*
Kenn.	3.8	5.40	154.3	14.90	2.78	75	3090	9.70
Lith. Sp.	*	*	*	*	2.61	75	*	*
Lithonia	4.1	4.90	148.2	13.92	2.61	75	*	*
Mt. View	*	*	*	*	2.66	75	*	*
Norcros.	4.1	4.28	152.0	14.18	2.69	75	*	*
Palm. St.	*	*	*	*	2.65	75	3320	11.00
Postell	*	*	*	*	2.63	75	*	*
Ruby	*	*	*	*	2.73	75	*	*
Stockbrg	*	*	*	*	2.61	75	*	*
Tyrone	*	*	*	*	2.64	75	*	*
White	3.7	4.06	153.4	12.88	2.71	75	3026	13.06

Note:

% Asp. Cont. = percent of asphalt in mix
Air V. (%) = total air voids in mix
γ (pcf) = mix density in pounds per cubic foot
VMA (%) = percent voids in mineral aggregate
Bulk S.G. = bulk specific gravity of fine aggregate
C_u = coefficient of uniformity
Stab. = stability in pounds

Table 12. Marshall Mix Design Variables for DOT Binder Mix.

Quarry Name	% Asp. Con.	Air V. (%)	γ (pcf)	VMA (%)	Bulk S.G.	C_u	Stab. (lbs)	Flow
Athens	5.5	4.80	148.2	17.50	2.68	33.3	2960	12.10
Ball Gr.	4.7	4.14	152.5	15.34	2.76	43.8	2760	13.52
Barin	4.9	*	149.4	*	2.67	53.8	*	*
Buford	5.5	4.70	145.0	17.00	2.61	53.8	2460	10.80
Candler	5.1	4.62	144.6	16.06	2.61	56.8	2924	10.50
Cumm.	5.2	4.44	147.9	16.46	2.80	41.7	3346	11.58
Dalton	4.5	4.20	151.3	14.80	2.68	39.1	2050	11.30
Dan	5.0	4.70	147.0	16.10	2.64	32.0	2180	10.40
Dixie	*	*	*	*	*	*	*	*
Griffin	5.2	4.88	146.8	16.66	2.65	37.5	2896	11.78
Kenn.	4.8	*	151.3	*	2.78	62.5	*	*
Lith. Sp.	5.2	4.28	145.4	15.96	2.61	44.6	2736	12.22
Lithonia	4.9	4.26	146.5	15.34	2.61	50.0	2844	10.56
Mt. View	5.0	4.60	147.4	16.30	2.66	32.0	2800	10.80
Norcros.	4.7	4.18	151.6	15.36	2.69	58.3	2988	11.78
Palm. St.	4.6	3.04	148.5	14.90	2.65	58.3	2966	9.94
Postell	4.9	4.38	148.7	15.72	2.63	33.8	2718	12.82
Ruby	5.0	4.70	149.0	16.50	2.73	38.9	2300	10.60
Stockbrg	5.2	4.78	145.5	16.46	2.61	50.7	2302	10.88
Tyrone	5.0	4.50	146.9	15.90	2.64	35.0	2690	10.20
White	4.0	4.50	152.1	13.90	2.71	21.2	2900	11.50

Note:
% Asp. Cont. = percent of asphalt in mix
Air V. (%) = total air voids in mix
γ (pcf) = mix density in pounds per cubic foot
VMA (%) = percent voids in mineral aggregate
Bulk S.G. = bulk specific gravity of fine aggregate
C_u = coefficient of uniformity
Stab. = stability

Table 13. Marshall Mix Design Variables for DOT F Mix.

Quarry Name	% Asp. Con.	Air V. (%)	γ (pcf)	VMA (%)	Bulk S.G.	C_u	Stab. (lbs)	Flow
Athens	*	*	*	*	2.68	*	2216	13.30
Ball Gr.	*	*	*	*	2.75	*	*	*
Barin	5.7	*	149.4	*	2.67	25.0	*	*
Buford	*	*	*	*	2.61	*	*	*
Candler	*	*	*	*	2.61	*	2780	9.70
Cumm.	*	*	*	*	2.80	*	*	*
Dalton	*	*	*	*	2.68	*	*	*
Dan	*	*	*	*	2.64	*	*	*
Dixie	5.0	129.1	21.0	2.57	5.00	31.6	1950	13.70
Griffin	*	*	*	*	2.71	35.0	*	*
Kenn.	*	*	*	*	2.78	*	*	*
Lith. Sp.	*	*	*	*	2.61	*	*	*
Lithonia	*	*	*	*	2.61	*	*	*
Mt. View	*	*	*	*	2.66	*	*	*
Norcros.	*	*	*	*	2.69	*	*	*
Palm. St.	*	*	*	*	2.65	*	2666	10.74
Postell	*	*	*	*	2.63	*	*	*
Ruby	*	*	*	*	2.73	*	2200	11.70
Stockbrg	*	*	*	*	2.61	*	*	*
Tyrone	*	*	*	*	2.64	*	2300	9.88
White	*	*	*	*	2.71	*	2470	12.50

Note:

% Asp. Cont. = percent of asphalt in mix

Air V. (%) = total air voids in mix

γ (pcf) = mix density in pounds per cubic foot

VMA (%) = percent voids in mineral aggregate

Bulk S.G. = bulk specific gravity of fine aggregate

C_u = coefficient of uniformity

Stab. = stability in pounds

Table 14. Marshall Mix Design Variables for DOT E Mix.

Quarry Name	% Asp. Con.	Air V. (%)	γ (pcf)	VMA (%)	Bulk S.G.	C_u	Stab. (lbs)	Flow
Athens	*	*	*	*	2.68	*	2294	12.40
Ball Gr.	5.3	3.1	152.62	16.98	2.75	33.3	2856	10.54
Barin	5.4	*	148.60	*	2.67	33.3	*	*
Buford	*	*	*	*	2.61	*	2196	12.16
Candler	*	*	*	*	2.61	*	3152	9.80
Cumm.	*	*	*	*	2.80	*	*	*
Dalton	*	*	*	*	2.68	*	*	*
Dan	*	*	*	*	2.64	*	*	*
Dixie	*	*	*	*	*	*	2106	10.60
Griffin	*	*	*	*	2.65	*	2460	12.00
Kenn.	3.8	5.4	154.30	14.90	2.78	31.7	3294	13.60
Lith. Sp.	*	*	*	*	2.61	*	2770	9.00
Lithonia	4.1	4.9	148.20	13.92	2.61	38.2	2892	9.24
Mt. View	*	*	*	*	2.66	*	3020	11.18
Norcros.	5.5	4.6	150.10	17.40	2.69	44.4	2810	10.70
Palm. St.	5.5	4.2	148.10	17.00	2.65	33.3	2750	10.10
Postell	*	*	*	*	2.63	*	2760	10.48
Ruby	*	*	*	*	2.73	*	2642	9.74
Stockbrg	5.5	4.0	145.60	16.50	2.61	20.7	3000	10.30
Tyrone	*	*	*	*	2.64	*	2510	10.20
White	3.7	6.3	149.50	16.80	2.71	31.7	2940	10.58

Notes:
% Asp. Cont. = percent of asphalt in mix
Air V. (%) = total air voids in mix
γ (pcf) = mix density in pounds per cubic foot
VMA (%) = percent voids in mineral aggregate
Bulk S.G. = bulk specific gravity
C_u = coefficient of uniformity
Stab. = stability in pounds

Table 15. Marshall Mix Design Variables for Improved Coarse E Mix.

Quarry Name	% Asp. Con.	Air V. (%)	γ (pcf)	VMA (%)	Bulk S.G.	C_u	Stab. (lbs)	Flow
Athens	*	*	*	*	2.68	*	*	*
Ball Gr	*	*	*	*	2.75	*	*	*
Barin	*	*	*	*	2.67	*	*	*
Buford	*	*	*	*	2.61	*	*	*
Candler	*	*	*	*	2.61	*	*	*
Cumming	*	*	*	*	2.58	*	*	*
Dalton	*	*	*	*	2.68	*	*	*
Dan	*	*	*	*	2.64	*	*	*
Dixie	*	*	*	*	*	*	*	*
Griffin	*	*	*	*	2.65	*	*	*
Kenn.	4.8	4.04	155.04	15.60	2.78	38.4	3102	12.18
Lithia S	*	*	*	*	2.61	*	*	*
Lithonia	5.0	4.60	145.80	15.90	2.61	38.4	*	*
Mt View	*	*	*	*	2.66	*	*	*
Norcross	4.7	4.46	150.30	15.54	2.69	38.4	2810	10.00
Palmer S	5.2	4.50	148.00	16.80	2.65	38.4	2598	9.58
Postell	*	*	*	*	2.63	*	*	*
Ruby	*	*	*	*	2.73	*	*	*
Stockbrg	4.4	4.44	148.20	14.58	2.61	38.4	3440	10.70
Tyrone	*	*	*	*	2.64	*	*	*
White	3.7	4.10	153.82	12.98	2.71	38.4	3910	11.58

Notes:

% Asp. Cont. = percent of asphalt in mix
Air V. (%) = total air voids in mix
γ (pcf) = mix density in pounds per cubic foot
VMA (%) = percent voids in mineral aggregate
Bulk S.G. = bulk specific gravity of fine aggregate
C_u = coefficient of uniformity
Stab. = stability in pounds

procedures and equipment used are described in detail elsewhere [8,10]. Resilient modulus test results are given in Table 16.

LABORATORY INDEX DENSITY

Introduction

The objective of the laboratory index density testing program was to define an optimum gradation, as determined by maximum density, that could be used in an asphalt concrete mix. Index density tests were performed by Ismail [12] on selected aggregate gradations which bound those that might be used for surface E and base asphalt concrete mix designs. Aggregate from 8 selected quarries were studied. Asphalt cement was not added to the dry aggregate used in establishing the index density.

The aggregate maximum densities for the two type mixes studied were evaluated for (1) the conventional Georgia DOT power curve gradation, and (2) the Georgia Tech interpretation of the power curve gradations. Talbot n-values of 0.35, 0.40, 0.45, 0.50, and 0.55 were used in the study.

Talbot Equation For Optimum Gradation

The Georgia Tech gradations used were calculated from the Talbot power curve equation

$$P = 100\ (d/D)^n \qquad (4)$$

where

P = percent passing a given sieve size

d = the equivalent sieve opening size which P passes

D = maximum aggregate size in the gradation as defined by equivalent size opening for which 100 percent of the material passes

Note that the definition of the maximum aggregate diameter D used in equation (4) is the equivalent size for which all of the material passes.

Table 16. Summary of Resilient Moduli Test Results.

Quarry Name	DOT Base Mix	Imp Crs Base Mix	Imp Fine Base Mix	DOT Bin Mix	DOT F Mix	DOT E Mix	Imp Crs E Mix
Athens	*	341121	*	*	*	*	*
Ball Gr.	*	688892	*	*	*	*	*
Barin	426111	458381	482172	402162	508278	524867	418066
Buford	*	400186	*	*	*	*	*
Candler	*	*	*	*	*	*	*
Cumm.	*	335413	*	*	*	*	*
Dalton	*	463624	*	*	*	*	*
Dan	*	158811	*	*	*	*	*
Dixie	*	*	*	*	453625	*	*
Griffin	*	440918	*	*	*	*	*
Kenn.	472684	384747	261701	251869	*	416253	*
Lith. Sp.	*	307134	*	*	*	*	*
Lithonia	*	364984	438538	*	*	*	*
Mt. View	*	346642	*	*	*	*	*
Norcros.	*	441825	151846	*	*	*	356137
Palm. St.	*	274306	*	*	*	*	555696
Postell	*	519767	*	*	*	*	*
Ruby	*	443724	*	*	*	*	*
Stockbrg	357513	223863	*	*	*	325054	439147
Tyrone	*	378344	*	*	*	*	*
White	777364	336078	602431	685078	698719	*	682794

This definition appears to be in agreement with that used in early work involving the development of the Talbot optimum density concept. The Georgia Department of Transportation apparently uses the next smaller sieve size opening (the nominal sieve size) than the maximum sieve size to define D. This definition gives a slightly finer gradation curve than when the 100 percent passing sieve size is used in equation (4).

The Talbot equation was developed to give a maximum density for a specific top size of aggregate. Although an n-value of 0.45 is frequently used in practice, past experience has shown that the optimum value of n is not a constant but depends upon the aggregate characteristics and also other factors such as method of compaction.

Test Results

The index density test results, which are based on unbound density of dry aggregate, indicate the following:

1. E Mix Index Density. For the E mix gradations, the optimum density was usually achieved at a Talbot n- value of 0.4 or even 0.35 (Table 17 and Figure 3). Only 1 of the 8 sources (Kennesaw) exhibited the highest density at a Talbot gradation corresponding to n=0.45. For two other sources (Barin and Norcross), density for practical purposes was essentially constant for n-values between about 0.4 and 0.5.

2. Base Mix Index Density. For the 7 base mixes studied, maximum dry index density was achieved at either a gradation corresponding to Talbot's n = 0.4 (5 aggregate sources) or n = 0.45 for two aggregate sources. (Table 18 and Figure 4). For one source little difference was observed in density between n = 0.4 and n = 0.5 gradations. Thus the

Table 17. Summary of Index Density Test Results for E-Mix Gradations (After Ismail, Ref. 12).

		Summary of Index Density Test Results for E-Mix							
	MATERIAL SOURCE	TYPE	DESIGNATION			INDEX DENSITY (lb/cf)			
					GT Power Gradation				DOT Power
				n = 0.35	n = 0.40	n = 0.45	n = 0.50	n = 0.55	
	Florida Rock Industries								
1	Mount View, Ga.	Granite Gneiss	#015		135.52	132.53	130.77		132.69
	Palmer Station, Ga.	Granite Gneiss	#017		135.88	134.46	134.10		131.73
2	Southern Aggregates								
	Postell,Ga.	Granite Gneiss	#028	134.20	131.56	127.81	128.65		127.78
3	Vulcan Materials								
	Barin, Ga.	Granite Gneiss	#044		132.54	132.42	132.51		132.61
	Kennesaw, Ga.	Granite Gneiss	#046		138.49	139.38	134.31		
	Lithia Springa, Ga.	Granite Gneiss	#047		135.60	129.53	129.14	126.15	129.23
	Norcross, Ga.	Granite Gneiss	#048		137.93	137.71	137.52		134.29
4	Stoneman								
	White, Ga.	Limestone	#067	140.60	139.16	135.93			134.28

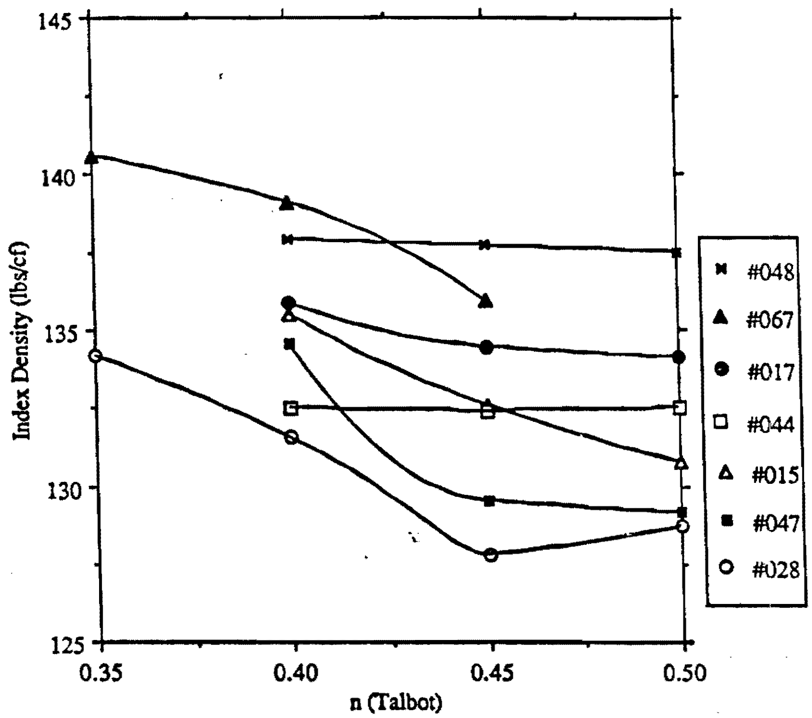


Figure 3. Index Density as a Function of n for Georgia Tech Power - E Mix Gradation: (After Ismail, Ref. 12).

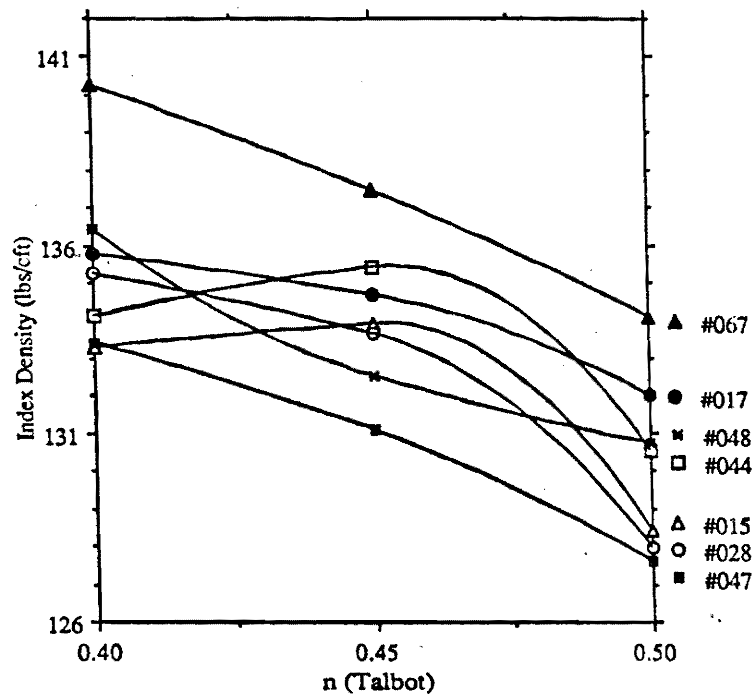


Figure 4. Comparison of n as a Function of Index Density for Base Mix: (After Ismail, Ref. 12).

Table 18. Summary of Index Density Test Results for Base Mix Gradations (After Ismail, Ref. 12).

	Summary of Index Density Test Results for BASE-Mix						
	MATERIAL SOURCE	TYPE	DESIGNATION	INDEX DENSITY (lb/cf)			
				GT Power Gradation			DOT Power
				n = 0.40	n = 0.45	n = 0.50	
1	Florida Rock Industries						
	Mount View, Ga.	Granite Gneiss	#015	133.30	133.92	128.43	133.57
	Palmer Station, Ga.	Granite Gneiss	#017	135.76	134.68	132.00	136.42
2	Southern Aggregates						
	Postell,Ga.	Granite Gneiss	#028	135.24	133.67	127.97	132.91
3	Vulcan Materials						
	Barin, Ga.	Granite Gneiss	#044	134.11	135.39	130.27	135.82
	Lithia Springa, Ga.	Granite Gneiss	#047	133.43	131.11	127.59	130.40
	Norcross, Ga.	Granite Gneiss	#048	136.42	132.49	130.71	135.72
4	Stoneman						
	White, Ga.	Limestone	#067	140.24	137.48	134.07	137.96

optimum gradation, based on dry index density, was in general obtained using similar n-values for both the E and base mixes.

3. Usually the index density obtained from the Georgia DOT power curve gradation (n = 0.45) was lower than the maximum index density obtained for the range of n-values studied. This statement was true for all the 8 sources investigated using the E mix except Barin. The Barin quarry E mix aggregate had about the same maximum density for the conventional DOT power curve gradation as compared to that for an n value between about 0.4 and 0.5. For the 7 base mix sources studied, the densities from the Georgia DOT power curve gradation were close for Barin and Norcross and slightly lower for Mt. View and Palmer Station.

These results indicate maximum unbound, dry density is generally achieved for a top size aggregate representative of an E mix at a finer gradation than that presently used by the Georgia DOT. For the maximum top size studied corresponding to a base mix gradation, maximum index density was achieved for a gradation only slightly finer or equal to that currently used by the Georgia DOT. These results also suggest that on the average the larger top size base material has a higher dry density for a slightly coarser gradation, as defined by n-value, than for the smaller top size E mix. Gradations used in the index density study are given in Table 19.

Index Density Test Procedure

The index density was obtained by shaking a standard 6 in. diameter aluminum mold filled with material having the desired gradation. This material was vibrated for 8 minutes on an electro-magnetically driven

Table 19. Aggregate Gradations Used for E and Base Index Density Tests (After Ismail, Ref. 12).

SIEVE SIZE	E-MIX GT POWER n					E-MIX DOT POWER	BASE-MIX GT POWER n					BASE-MIX DOT POWER
	0.35	0.40	0.45	0.50	0.55		0.35	0.40	0.45	0.50	0.55	
% Passing 1.5" Sieve	100	100	100	100	100	100	100	100	100	100	100	100
% Passing 1" Sieve	100	100	100	100	100	100	87	85	83	82	80	98
% Passing 3/4" Sieve	100	100	100	100	100	100	78	76	73	71	68	86
% Passing 1/2" Sieve	87	85	83	82	80	99	68	64	61	58	55	73
%Passing 3/8" Sieve	78	76	73	71	68	84	62	57	54	50	45	64
% Passing No. 4 Sieve	62	57	54	50	47	61	48	44	39	35	32	44
% Passing No. 8 Sieve	48	44	39	35	32	45	38	33	29	25	22	34
% Passing No. 16 Sieve							30	25	21	18	15	26
% Passing No. 30 Sieve							23	19	15	12	10	20
% Passing No. 50 Sieve	23	19	15	13	10	16	18	14	11	9	7	14
% Passing No. 100 Sieve							14	11	8	6	5	9
% Passing No. 200 Sieve	14	11	8	6	5	6	11	8	6	4	3	5

shaking table. The shaking table used was a Syntron Vibrating Table, (Model VP861) driven by a Syntron Vibra-Flow Vibrator (Model V86B1). The index density test was performed in accordance with ASTM Test Method D4253-83. A schematic of the apparatus used to obtain the index density is shown in Figure 5.

The shaker vertically vibrates the mold assembly, which was fixed to the vibrating table, at an average double amplitude (peak to peak displacement) of 0.013in. (+/- 0.002 in.) at a frequency of 60 Hz. or 0.019 in. (+/-0.003 in.) at 50 Hz. The vibrating table was carefully calibrated before testing to insure ASTM Test Method D4253-83 requirements were satisfied.

The material for each specimen was sieved into sizes and then re-constituted to give the desired aggregate gradation. The properly graded aggregate was then gently dropped into the mold. The mold was lightly tapped 4 or 5 times to eliminate large voids, and the surface was levelled off using a screed.

A plate was then placed on top of the aggregate in the mold and rotated several times by hand to level off the surface. Before testing, the mold was attached to the vibrating table by 4 screws. Finally, a 56.5 lb. surcharge weight was placed on top of the specimen which applied an equivalent uniform pressure of 2.0 psi.

After vibrating the specimen for 8 minutes, any fine material that accumulated on the surface of the base plate after vibration was blown off. The difference in height between the top of the mold and the base plate was measured and recorded to obtain the volume of the specimen after densification. The mold was then weighed and the gross weight of the specimen and mold was recorded. The index density was calculated by

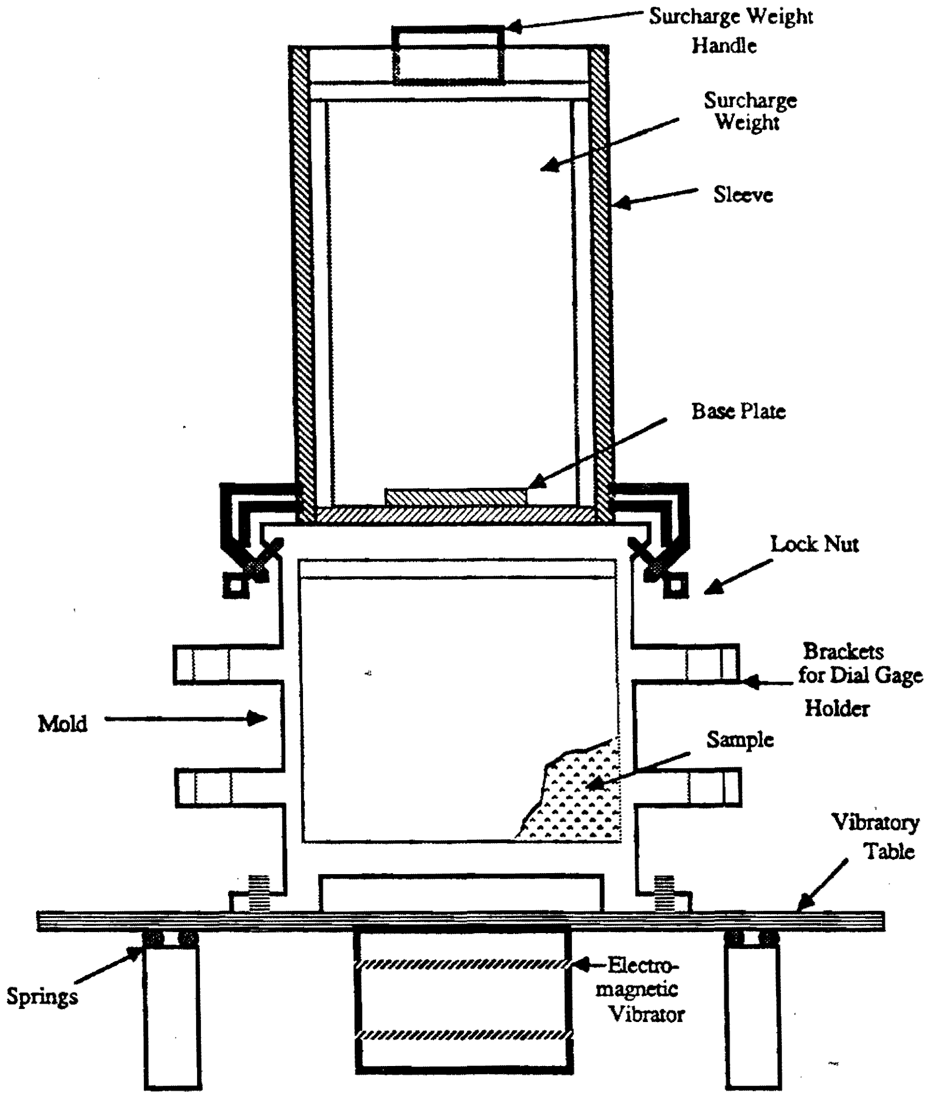


Figure 5. Typical Mold Assembly for Vibratory Index Density Test.

dividing the net weight of the material by the volume after shaking.

CONCLUSIONS

Numerous aggregate characteristics were presented in this chapter for 21 aggregate sources. Techniques, described in Appendix A, were developed for measuring aggregate roughness, shape, and surface area using a digitizing tablet and personal computer. Although these techniques are efficient, the total time involved to characterize an aggregate source is great and requires a reasonable degree of electronic technology.

The pouring test, described in Appendix B, was therefore introduced as a straightforward method for measuring the influence of aggregate surface characteristics. Both macro- and micro surface characteristics can be evaluated using the results from this relatively simple to perform test. As discussed in Chapter 4, the pouring test offers considerable promise in helping to explain the different observed levels of rutting which occur in asphalt concrete mixes prepared using different aggregate sources.

Index density tests were performed using a shaking table on unbound, dry aggregate. The index density test results indicate that the optimum aggregate gradation, as defined by the Talbot equation, usually corresponds to an n-value of 0.4 to 0.45 or less.

Chapter 3

MEASUREMENT OF FREE MICA CONTENT

INTRODUCTION

The free mica content was determined for selected samples of aggregate from each of the 21 quarries studied. Free mica is defined as mica particles which are not attached to other minerals (i.e., not part of a bigger aggregate mass). The percent free mica was determined for each of the following sieve sizes:

Designation	Sieve Size Range
Coarse	-16 to +30
Medium	-30 to +50
Fine	-50 to +100
Very Fine	-100 to +200

Procedures were not developed for determining the mica content of the -200 sieve size fraction.

RESULTS

The free mica in the fine and very fine aggregate sizes shown above were determined by petrographic examination of sprinkle slides. The medium and coarse aggregate sizes were determined by stereo microscopic examination. Several other methods investigated for evaluating mica content were not considered as reliable. Free mica content results are summarized in Table 8, given in Chapter 2, for each aggregate size studied and also weighted gradations for fine size aggregate. The free mica content present was found to increase in magnitude from the coarse to fine and very fine aggregate sizes. For the fine and very fine sizes, unweighted free mica content varied from 51 percent for Ruby and 43 percent for Griffin to 12 percent for Candler.

ELECTROMAGNETIC SEPARATION

Biotite mica exhibits magnetic properties. Therefore a Carpco Model M1H-13-111-5 electromagnetic separator was used in an attempt to develop a rapid, simple method for evaluating mica content. Three different samples for each of the four sieve sizes were separated using this method for each quarry. Microscope studies were later performed to evaluate the accuracy of this method and to correct the magnetic and nonmagnetic fractions for nonmica and mica "impurities", respectively. This study showed that magnetic separation could not be used alone as a reliable means for determining the free mica content. In general, the magnetic fraction had important amounts of nonmica materials and the nonmagnetic fraction had some biotitic (magnetic) mica and also muscovite (nonmagnetic) as well as other micaceous materials.

For this study, the fine (-50 to +100) and very fine (-100 to +200) sieve size ranges separated by the electromagnetic device were each corrected using the results obtained from the petrographic examination described in the next subsection. The free mica contents for the medium and coarse size fractions given in Table 8 were determined directly by stereomicroscopic examination as described subsequently.

In summary, the electromagnetic separation technique is simple and very easy to apply. Very consistent results were found between the samples tested. Corrections, however, are required to account for undesirable minerals being present in both the magnetic and nonmagnetic fractions. Because of the simplicity and reproducibility of results, electromagnetic separation might be used to determine when the magnetic compared to nonmagnetic mineral composition of a quarry changes. The potential for use of the electromagnetic separation technique for this purpose was not investigated.

FINE AND VERY FINE FRACTIONS - PETROGRAPHIC MICROSCOPE METHOD

Sprinkle mounts for each specimen were prepared on glass sides for use under the microscope. To prepare these slides, a vibrating spatula was used to sprinkle grains across the surface of a molten, thermally-activated glue (Crystal-Bond and/or Permount) spread on a petrographic thin-section slide. Special care was taken to avoid the formation of clumps of particles on the slide. To protect the slide, a cover slip was glued over the grains. The grains were then "point-counted" using a petrographic microscope. A minimum of 400 grains were sought on the slide, although a few slides did not have that many grains. Point-counted means that the slide was fed across the focal point of the microscope's objective, similar to the way a typewriter moves across and down a page, until 400 grains appeared under the cross-hairs. The grains were identified and separated into non-mica and free mica categories.

Point counting using the petrographic microscope was performed on slides of both the "magnetic" and "nonmagnetic" fractions of the fine and very fine sizes from each quarry. The magnetic fraction of a sample typically contained about 40 to 79 percent mica. In the nonmagnetic fraction the typical mica content was about 8 to 30 percent. These percentages of mica were determined by the petrographic microscope method.

The petrographic microscope method proved to be relatively straightforward, easy to perform, and reproducible and is suitable to use without electromagnetic separation. The disadvantage is that grains are counted and a percentage of mica is determined based on the percent of grains present rather than by weight.

MEDIUM AND COARSE FRACTIONS - STEREOMICROSCOPE METHOD

The medium and coarse size fractions had particles that were too large when mounted on a slide to place under a microscope. Therefore, the technique to determine free mica employed for the finer fractions was modified. The modified method used for the medium and coarse fractions consisted of careful inspection of the grains under incident light through a stereomicroscope. A predetermined number of grains were identified within the sample and placed in the following categories: muscovite, micaceous other than muscovite, and non-micaceous minerals.

Number of Grains to Count

To determine a suitable number of grains to count, a special study was conducted for Mt. View (015), Athens (023), and Griffin (077)quarries. This study consisted of determining the percent of mica, based on grain count, in a total of 100, 200, 300, 400 and 500 grains (Table 20). Using more than 300 to 400 grains in the count was found not to improve, from a practical viewpoint, the accuracy of the mica determination for quarries that had reasonably high mica contents, but significantly increased the time required to complete grain separation into the desired categories. Based on this study, the use of 300 to 400 grains in the count was found to give a practical procedure.

Table 20. Mica Content as a Function of Different Grain Counts and Methods.

Quarry	Number Grains	MVSC[1] Mica	Other Mica	% Mvsc of Total Mica (Grain Count)	Total % Mica (Grain Count)	Total % Mica (Weight)	Visual (Grain Count) (% total Mica)
MT. VIEW, GEORGIA - FLORIDA ROCK INDUSTRIES (015)							
Medium: -30 to +50 Sieve Size							
	200	-	-	-	-	25	-
	300	4	43	9.3	15.7	20	-
	400	2	23	8.7	6.25	16	-
	500	13	42	30.9	11.0	16	-
					11.0	19.2	8
Coarse: -16 to +30 Sieve Size							
	200	2	3	40	2.5	2.9	-
	300	1	16	5.9	5.7	2.4	-
	400	3	10	23.1	3.25	2.2	-
	500	3	12	20	3.0	2.5	-
					3.6	2.5	3
GRIFFIN, GEORGIA - FLORIDA ROCK INDUSTRIES (077)							
Medium: -30 to +50 Sieve Size							
	200	6	32	15.8	19.0	16.3	-
	300	8	54	12.9	20.7	26.7	-
	400	11	68	13.9	19.8	28.1	-
	500	13	87	13.0	20.0	26.0	-
					19.9	24.3	15
Coarse: -16 to +30 Sieve Size							
	200	2	12	14.3	7.0	15.2	-
	300	2	23	8.0	8.3	14.0	-
	400	2	33	5.7	8.75	12.6	-
	500	3	42	5.7	9.0	12.8	-
					8.3	13.7	5
ATHENS, GEORGIA - DAVIDSON MINERAL PROPERTIES (023)							
Medium: -30 to +50 Sieve Size							
	200	31	41	43.1	36.0	43.8	-
	300	34	88	27.9	40.6	37.7	-
	400	36	123	22.6	39.7	38.4	-
	500	59	124	32.2	36.6	32.2	-
					38.2	37.5	25
Coarse: -16 to +30 Sieve Size							
	200	6	25	19.4	15.5	10.6	-
	300	14	40	25.9	11.3	13.0	-
	400	25	79	24.0	26.0	16.7	-
	500	37	92	28.7	25.8	14.1	
					19.7	13.6	7

Sampling

To avoid the psychological tendency to bias the study by selecting big micaceous grains out of the undivided original sample, a pattern was rigorously adhered to of considering each grain in the undivided pile similarly to the way a typewriter moves across and down a page of paper. The technique for working with the sample under the stereomicroscope is essentially that used by micropaleontologists: a flat opaque pan contains the sample piles, and grains are manipulated for study and transfer to the categorical piles using a thin artist's brush.

Static electricity was a problem in early attempts to move the grains since the grains jumped erratically and were often lost. The use of plastic dishes and containers result in the most problems with static electricity. In early experiments, unreproducable results were obtained using these items. After these early problems were solved by using glassware, demonstratably reproducible mica content estimates were obtained.

Sample Splitting

A special technique was developed to avoid biasing of the sample by selecting a representative sample from the container. The aggregate particles sometimes segregated within the plastic sample bag in which they were stored. Segregation probably resulted during movement of the bags due to differential settling of the various constituents. Differences in specific gravity, size, and static electric charges on some of the particles resulting in their being attracted to the bag probably account for this segregation.

Initially, some of the samples were split using a micro-splitter. To accomplish splitting, samples were iteratively poured through the microsplitter several times until a sufficiently small, representative sample was obtained. This aliquot then became the undivided pile from which the grains were selected for transfer to the categorical piles under the stereomicroscope. The various processes used to treat the samples took too long to continue using the microsplitter for all of the samples. Therefore, another technique of obtaining representative samples from the bags was selected because the smaller samples could resegregate after being made up and transported from the splitter.

In other words, a sampling technique was required that allowed work to begin instantaneously after obtaining the aliquot. The technique developed to satisfy this requirement is based on the same principle as the microsplitter. Following this alternate procedure, the sample was poured out, mixed in a large pile to make it homogeneous, then sampled from several locations within the pile. The smaller samples were added together to form a smaller pile, which was remixed, then sectored by slicing radially through it as a round pizza pie is sliced. The sectoring continued until a small enough sector was obtained to serve as an aliquot. During trial runs of this sampling technique, it was found to be necessary to avoid articles made from plastic, such as soda straws, spoons, etc. The static electrical charges on these items can cause resegregation.

An experienced geologist skilled in mineral identification can identify 300 grains in about 1.5 hours. This estimate assumes that the sample has high percentages of muscovite and other types of mica. This was the actual time required for the Athens (023) coarse and medium samples.

Samples with lower mica contents can be analyzed in a shorter length of time.

Weighing

The most elaborate attempt to measure free mica content of coarse and medium sizes involved weighing the particles previously identified by the stereomicroscope method under incident light. The identified three categories of grains (muscovite mica, other mica, nonmica) were precision weighed. The grains were moved to separate piles using a thin artist's brush. The three categorical piles were then transferred to preweighed and labeled Size 1 "coin cameo envelopes" and weighed.

Weighing was conducted on a Satorius Model 1602 pan balance which was mounted on marble on a Brinkman table base. The balance has a maximum sample size of 200 grams and a nominal precision error of ±0.0001 grams. Although it is believed this technique still holds high potential for obtaining reproducible free mica fractions in the coarse and medium splits, techniques could not be developed to make weighing results reproducible. Supplementary studies indicate that static electricity and instrument drift is probably not the problem. The most likely explanation is adjustment of the sample-envelope combination to varying humidity.

Because the mica should not be very hygroscopic and because the envelope measurements showed drift when empty, the glue and the paper itself in the envelopes are perhaps the culprits. The use of envelopes made of glassine, in small stamp collector sizes, was found to reduce the drift but not enough to allow precise weight measurements.

VISUAL METHOD OF ANALYSIS

The free mica contents of the following five selected quarries were evaluated using the Visual method: Athens (023), Griffin (077), Ruby (054), Kennesaw (046), and Mt. View (015). Using this method, the free mica content was estimated using standard comparison charts for estimating percentage composition [14]. These charts are also available from the AGI as Data Sheet 15.1.

This study showed that the fine samples (-50 to 100) and very fine samples (-100 to 200) could not be classified by visual examination. For these two size ranges free mica could not be distinguished from combined mica, and biotite mica could not be distinguished from other dark minerals, or muscovite distinguished from clear feldspars.

A comparison of the Visual Method of Analysis with the Stereomicroscope Method for the coarse and medium sizes of the five selected quarries are shown in Table 21. The absolute value of the average error in the visual identification method was about 46 percent. For some practical applications, such as classification by mica content, the visual method might possibly be sufficiently accurate for low values of free mica. When the level of free mica is sufficiently high to be of importance, the recommendation is made to use the Stereomicroscopic Method of analysis for the medium and coarse sizes.

Table 21. Comparison of Visual Method with Stereomicroscope Method for Evaluating Free Mica in the Coarse and Medium Size Fractions.

	Visual Method*		Stereomicroscope Method*	
	-16 to +30	-30 to +50	-16 to +30	-30 to +50
Athens (023)	7(1)	25(3)	18.0(4.7)	40.7(11.3)
Griffin (077)	5(0)	15(2)	8.3(0.7)	19.7(2.7)
Ruby (054)	0	1(0)	0.3(0)	6.3(0)
Kennesaw (046)	1(0)	15(Tr)	3(0)	13.7(0.3)
Mt. View (015)	3(1)	8(1)	2(2)	14.3(14.3)

* Numbers in parentheses give the percent free muscovite mica present.

Summary

Reliable techniques are developed in this chapter for measuring the free mica content for aggregate varying in size from the -16 sieve to the +200 sieve. For aggregate sizes varying from the -16 to +50 size, grains from a carefully split sample are mounted on a glass slide. Individual particles are carefully examined under incident light through a stereomicroscope. For aggregate sizes between the -50 and +200 sieve, sprinkle mounts are prepared on glass slides and particles are viewed under a petrographic microscope. A minimum of 300 and preferable 400 grains should be point counted under the microscope when using either method. The

methods proposed offer a reliable, reproducible method for evaluating free mica content. These methods, as presently developed, give mica content in terms of percent of total particles counted rather than by weight.

CHAPTER 4

RUTTING AND FATIGUE FINDINGS

INTRODUCTION

Rutting results, as evaluated by the Loaded Wheel Tester, and theoretical fatigue life predictions are presented in this chapter for Base, B-binder and E surface mixes. Rutting and fatigue life are compared between standard Georgia Department of Transportation mixes and coarse mixes developed at Georgia Tech and intended to reduce rutting.

During the early part of the rutting study, new asphalt concrete mixes having both a slightly coarser and a slightly finer gradation were developed and compared with the standard ones presently used by the Georgia Department of Transportation. Early Loaded Wheel Test rutting results indicated that the coarser mixes demonstrated the greatest potential, overall, for developing more rut resistant mixes. Therefore, use of the finer mixes was abandoned relatively early since the study was not designed to include the evaluation of two new gradations. For aggregates from some quarries, a gradation resulting in a finer mix might give greater rut resistance than presently used mix designs. Therefore this line of research should probably not be completely abandoned at this time.

Notation and Design Variables

The term "coarse" or "fine" base, B-binder, and E or F surface mixes refers to the mixes proposed in this study to develop more rut resistant mix aggregate gradations. In this report, unless specifically indicated otherwise, when two mixes are compared (such as a standard DOT base compared to a new coarse mix) both the aggregate and the asphalt cement used in these mixes are the same. The Marshall mix design procedure was used to determine all mix characteristics. Therefore VMA, air voids, asphalt content, etc. varies with the aggregate gradation used.

Selection of Gradation

The more rut resistant gradations were developed using the Talbot gradation power curve considering past experience including coarser mixes used by selected state agencies and other organizations. A certain degree of judgment was also employed. The general premise was made that a larger top size mix having the maximum possible density should give improved rut resistance compared to a smaller top size mix. The results of this study indicate that this premise was indeed well founded.

The basic approach employed to develop a specific rut resistant gradation was to use the maximum aggregate size (not the nominal size) in the Talbot power curve equation. This equation is discussed in Chapter 2.

RUT TEST RESULTS

Introduction

The rut depths presented and discussed in this section and also elsewhere in this report were evaluated using the Georgia Tech Loaded Wheel Tester. The Loaded Wheel Test apparatus and test procedures are described in Appendix C. The loaded wheel test consists of subjecting a rectangular beam specimen of asphalt concrete 5 in. wide by 3.0 or 3.5 in. deep and 10 in. long (with 2.75 in. end blocks) to repeated passes of a hard rubber wheel. The rubber wheel exerts an average pressure of 124 psi on the surface of the asphalt concrete beam. A total of 8,000 wheel repetitions were applied to each beam with the wheel being moved in each direction (i.e., a two directional loading was applied). Tests were performed in a constant temperature chamber at 104°F.

Base Mixes

All of the experimentally observed rut depths for the standard Georgia Department of Transportation base mixes and the coarse base mixes developed as a part of this study are given in Tables 22 and 23. Table 22 gives just the values of rut depth measured over a short time period on companion specimens. In this series companion specimens of standard and coarse base mixes were prepared from the same sample of aggregate at the same time and then successively tested. These results are referred to as direct comparisons.

Tables 23 includes both companion specimen data and also data from specimens of standard and coarse base mixes prepared at separate times from, in some cases, samples of aggregate collected at different times from the quarry. These results are referred to as the cumulative test results.

In the early part of the study, preparation and testing of the standard base mixes were carried out first since, for most mixes, existing standard Georgia DOT mixes were used. Later, as special mix designs were developed for the coarse (or fine) mixes, they were prepared and tested. Tests performed later in the study were found to result in slightly greater amounts of rutting for apparently identical mixes. Possible explanations for this increase in rutting include:

1. Change in aggregate characteristics from one section of the quarry to another.
2. Difference in properties with time of the asphalt cement.
3. Preparation and testing of specimens by different personnel (the second engineer to prepare and test specimens was, however, carefully trained by the first).

Table 22. Wheel Track Test Rutting Results: Direct Comparison of Standard DOT Base with Coarse Base Mixes.

PRIMARY QUARRIES

QUARRY NAME	SAMPLE No	BASE DOT Mix** (in)	COARSE BASE Ga Tech Mix** (in)	PERCENT. of Stand* (%)
DIXIE	1			
	2			
	AVG			
WHITE	1	0.1087		
	2	0.1179		
	AVG	0.1133		
BARIN	1		0.2122	
	2		0.2588	
	AVG		0.2355	
KENNESAW	1			
	2			
	AVG			
STOCKBRIDGE	1		0.1479	
	2		0.1141	
	AVG		0.1310	
LITHONIA	1	0.1467		
	2	0.1414		
	3	0.1937		
	4	0.1786		
	AVG	0.1651		
NORCROSS	1	0.2701		
	2	0.2482		
	AVG	0.2592		
PALMER STATION	1	0.2170	0.1270	
	2	0.2147	0.1024	
	3	0.2560		
	AVG	0.2292	0.1147	50.0

SECONDARY QUARRIES

QUARRY NAME	SAMPLE No	BASE DOT Mix** (in)	COARSE BASE Ga Tech Mix** (in)	PERCENT. of Stand (%)
CUMMINGS	1	0.2884	0.1152	
	2	0.3778	0.1238	
	AVG	0.3331	0.1195	64.1
GRIFFIN	1	0.1943	0.2271	
	2	0.2235	0.3414	
	AVG	0.2089	0.2843	-36.1
DAN	1	0.1785	0.1165	
	2	0.1792	0.1511	
	AVG	0.1789	0.1338	25.2
RUBY	1	0.2017	0.1420	
	2		0.1573	
	AVG	0.2017	0.1497	25.8
DALTON	1	0.1020	0.0662	
	2	0.0766	0.0748	
	AVG	0.0893	0.0705	21.1
LITHIA SPRINGS	1	0.3036	0.1201	
	2	0.5376	0.1825	
	3	0.2471	0.2702	
	4	0.2773	0.2031	
	AVG	0.3414	0.1940	43.2
BALL GROUND	1			
	2			
	AVG			
ATHENS	1	0.1561	0.1459	
	2	0.1418	0.1496	
	3	0.3026	0.2862	
	AVG	0.2002	0.1939	3.1
CANDLER	1			
	2			
	AVG			
MT. VIEW	1	0.1161	0.2339	
	2	0.2640		
	3	0.2364		
	4	0.4314		
	5	0.2263		
	6	0.2723		
	AVG	0.2578	0.2339	9.3
TYRONE	1	0.2473	0.1909	
	2	0.1998	0.1369	
	3	0.1950		
	4	0.2050		
	AVG	0.2118	0.1639	22.6
BUFORD	1	0.1715	0.0630	
	2	0.2199	0.1902	
	3		0.1725	
	4		0.2176	
	AVG	0.1957	0.1608	17.8

* Positive percentage denotes improvement
** Rut depth in inches

Table 23. Wheel Track Test Rutting Results: Cumulative Comparison of Standard DOT Base with Coarse Base Mixes.

PRIMARY QUARRIES

QUARRY NAME	SAMPLE No	BASE DOT Mix (in)	COARSE BASE Mix (in)	PERCENT. of Stand* (%)
DIXIE	1			
	2			
	AVG			
WHITE	1	0.1243	0.0735	
	2	0.1685	0.0663	
	3	0.1209		
	4	0.1087		
	5	0.1179		
	AVG	0.1281	0.0699	45.4
BARIN	1	0.1826	0.1634	
	2	0.1863	0.1303	
	3		0.2122	
	4		0.2588	
	AVG	0.1845	0.1912	-3.6
KENNESAW	1	0.1012	0.1630	
	2	0.0864	0.1188	
	AVG	0.0938	0.1409	-50.2
STOCKBRIDGE	1	0.1243	0.1479	
	2	0.1881	0.1141	
	AVG	0.1562	0.1310	16.1
LITHONIA	1	0.1467	0.1083	
	2	0.1414	0.1442	
	3	0.1937		
	4	0.1786		
	AVG	0.1651	0.1263	23.5
NORCROSS	1	0.1537	0.2034	
	2	0.2133	0.1550	
	3	0.2701		
	4	0.2482		
	AVG	0.2213	0.1792	19.0
PALMER STATION	1	0.2604	0.1270	
	2	0.1644	0.1024	
	3	0.2170		
	4	0.2147		
	5	0.2560		
	AVG	0.2225	0.1147	48.4

SECONDARY QUARRIES

QUARRY NAME	SAMPLE No	BASE DOT Mix (in)	COARSE BASE Mix (in)	PERCENT. of Stand (%)
BALL GROUND	1	0.1681	0.1701	
	2	0.0948	0.0517	
	AVG	0.1315	0.1109	15.6
ATHENS	1	0.1464	0.1459	
	2	0.2361	0.1496	
	3	0.1561	0.2862	
	4	0.1418		
	5	0.3026		
	AVG	0.1966	0.1939	1.4
CANDLER	1	0.1274	0.2274	
	2	0.1612	0.1937	
	AVG	0.1443	0.2106	-45.9
MT. VIEW	1	0.2328	0.1433	
	2	0.1140	0.2260	
	3	0.1161	0.2339	
	4	0.2640		
	5	0.2364		
	6	0.4314		
	7	0.2263		
	8	0.2723		
	AVG	0.2367	0.2011	15.0
TYRONE	1	0.2473	0.1909	
	2	0.1998	0.1369	
	3	0.1950		
	4	0.2050		
	AVG	0.2118	0.1639	22.6
BUFORD	1	0.1900	0.1370	
	2	0.1968	0.0630	
	3	0.1715	0.1902	
	4	0.2199	0.1725	
	5		0.2176	
	AVG	0.1946	0.1561	19.8
CUMMINGS	1	0.1710	0.1152	
	2	0.1286	0.1238	
	3	0.2884		
	4	0.3778		
	AVG	0.2415	0.1195	50.5
GRIFFIN	1	0.1760	0.2271	
	2	0.2199	0.3414	
	3	0.1943		
	4	0.2235		
	AVG	0.2034	0.2843	-39.7
DAN	1	0.2273	0.1165	
	2	0.1785	0.1511	
	3	0.1792		
	AVG	0.1950	0.1338	31.4
RUBY	1	0.1521	0.1420	
	2	0.1090	0.1573	
	3	0.2017		
	AVG	0.1543	0.1497	3.0
DALTON	1	0.1021	0.0662	
	2	0.1020	0.0748	
	3	0.0766		
	AVG	0.0936	0.0705	24.7
LITHIA SPRINGS	1	0.3036	0.1201	
	2	0.5376	0.1825	
	3	0.2471	0.2702	
	4	0.2773	0.2031	
	AVG	0.3414	0.1940	43.2
POSTELL	1	0.1360	0.1003	
	2	0.1321	0.1265	
	AVG	0.1341	0.1134	15.4

* Positive percentage denotes improvement
** Rut depth in inches

4. Change/wear of equipment used in preparation and/or testing the specimens.

A careful review of items 3 and 4 did not find any explanation for the observed differences in rutting with time.

A sufficiently large sample of aggregate to complete the study was initially obtained from each quarry. However, the polymer sample bags were stored outside and deteriorated with time resulting in the mixing of material from different bags. This mixing made it impossible to tell, in many instances, which quarry the material came from. Hence, additional samples of aggregate had to be obtained from many quarries at a much later time during the study. Thus, to minimize all of the problems described above, the approach of preparing companion specimens (direct comparison) was adopted later in the test program for not only the base mixes but also the E mixes.

Base Test Results. The most complete set of rutting performance data was developed for the standard and coarse base mixes. A total of over 70 beam specimens were used for the standard Georgia DOT base mixes and 50 specimens for the coarse base mixes (Tables 22 and 23).

Consider the rutting test results for the companion specimens which should provide the most reliable comparisons. For the companion specimens, the average rut depth was reduced by 23 percent when the proposed coarse base was used compared to the standard base mix presently employed by the Georgia DOT. This comparison is statistically significant at the 95 percent probablility level.

For both the standard and coarse mixes, Dalton quarry aggregate generally performed best. For the standard DOT base mixes, Kennesaw quarry performed next to best while for the coarse base mixes White performed either about the same or slightly more poorly than Dalton. Lithia Springs performed the worst for the standard base mix while Griffin did the poorest for the coarse base mix.

Binder Mixes

All of the experimentally observed rut depth results for the standard Georgia DOT B-binder mixes as well as the standard DOT base mixes are summarized in Table 24 for the direct comparison mixes and in Table 25 for the cumulative results. The standard Georgia DOT B-binder mixes are compared with standard DOT base mixes because the proposed coarse binder mix was essentially the same as the standard DOT base mix. Using the rut test results for the standard base mix eliminated both the need to prepare new Marshall mix designs and to perform additional rutting tests.

Using all of the experimental data, the average rut depth was reduced by 14 percent in going from the standard binder to the standard base (an average rut depth of 0.2112 in. compared to 0.1825 in., respectively). This comparison is statistically significant at a probability level slightly greater than 85 percent. For the twelve out of the 20 quarries for which the standard base mix showed less rutting than the standard B-binder mix, the average reduction in rutting is 27 percent.

Data from tests performed during the latter part of the study, which should be most reliable (Table 24), show an average reduction in rutting of 11 percent which is slightly less than for the cumulative test results. Average measured rut depths were 0.2133 in. compared to 0.2403 in. for the DOT base (which simulates a coarse B-binder mix) and the standard DOT B-binder mixes, respectively. This comparison is statistically significant at the 80 percent probability level. The 6 quarries demonstrating the most improvement out of a total of 13 quarries show a 19 percent reduction in

Table 24. Wheel Track Test Rutting Results: Direct Comparison of Standard Georgia DOT Binder with Coarse Binder (DOT) Mixes.

PRIMARY QUARRIES

QUARRY NAME	SAMPLE No	BINDER DOT Mix** (in)	BASE DOT Mix** (in)	PERCENT. of Stand* (%)
DIXIE	1			
	2			
	AVG			
WHITE	1	0.1353	0.1087	
	2	0.0974	0.1179	
	AVG	0.1164	0.1133	2.6
BARIN	1	0.2816		
	2	0.3225		
	AVG	0.3021		
KENNESAW	1	0.3395		
	2	0.5168		
	3	0.3286		
	AVG	0.3950		
STOCKBRIDGE	1			
	2			
	AVG			
LITHONIA	1	0.4208	0.1467	
	2	0.2896	0.1414	
	3		0.1937	
	4		0.1786	
	AVG	0.3552	0.1651	53.5
NORCROSS	1	0.1468	0.2701	
	2	0.1998	0.2482	
	AVG	0.1733	0.2592	-49.5
PALMER STATION	1	0.1996	0.2170	
	2	0.2185	0.2147	
	3		0.2560	
	AVG	0.2091	0.2292	-9.7

* Positive percentage denotes improvement
** Rut depth in inches

SECONDARY QUARRIES

QUARRY NAME	SAMPLE No	BINDER DOT Mix (in)	BASE DOT Mix (in)	PERCENT. of Stand* (%)
BALL GROUND	1	0.1762		
	2	0.3504		
	3	0.2297		
	AVG	0.2521		
ATHENS	1	0.1900	0.1561	
	2	0.2329	0.1418	
	3		0.3026	
	AVG	0.2115	0.2002	5.3
CANDLER	1			
	2			
	AVG			
MT. VIEW	1	0.2122	0.1161	
	2	0.1129	0.2640	
	3	0.2786	0.2364	
	4	0.3209	0.4314	
	5		0.2263	
	6		0.2723	
	AVG	0.2312	0.2578	-11.5
TYRONE	1	0.2297	0.2473	
	2		0.1998	
	3		0.1950	
	4		0.2050	
	AVG	0.2297	0.2118	7.8
BUFORD	1	0.3206	0.1715	
	2	0.3182	0.2199	
	AVG	0.3194	0.1957	38.7
CUMMINGS	1	0.3978	0.2884	
	2	0.3378	0.3778	
	AVG	0.3678	0.3331	9.4
GRIFFIN	1	0.2135	0.1943	
	2	0.2216	0.2235	
	AVG	0.2176	0.2089	4.0
DAN	1	0.1413	0.1785	
	2	0.1596	0.1792	
	AVG	0.1505	0.1789	-18.9
RUBY	1		0.2017	
	2			
	AVG		0.2017	
DALTON	1	0.0901	0.1020	
	2		0.0766	
	AVG	0.0901	0.0893	0.9
LITHIA SPRINGS	1	0.2470	0.3036	
	2	0.2464	0.5376	
	3	0.1785	0.2471	
	4		0.2773	
	AVG	0.2240	0.3414	-52.4
POSTELL	1			
	2			
	AVG			

Table 25. Wheel Track Rutting Results: Cumulative Comparison of Standard DOT Binder with Coarse Binder (DOT Base) Mixes.

PRIMARY QUARRIES

QUARRY NAME	SAMPLE No	BINDER DOT Mix (in)	BASE DOT Mix (in)	PERCENT. of Stand (%)
DIXIE	1			
	2			
	AVG			
WHITE	1	0.1151	0.1243	
	2	0.1096	0.1685	
	3	0.1353	0.1209	
	4	0.0974	0.1087	
	5		0.1179	
	AVG	0.1144	0.1281	-12.0
BARIN	1	0.1424	0.1826	
	2	0.1958	0.1863	
	3	0.2816		
	4	0.3225		
	AVG	0.2356	0.1845	21.7
KENNESAW	1	0.1627	0.1012	
	2	0.1472	0.0864	
	3	0.3395		
	4	0.5168		
	5	0.3286		
	AVG	0.2990	0.0938	68.6
STOCKBRIDGE	1	0.1657	0.1243	
	2	0.1728	0.1881	
	AVG	0.1693	0.1562	7.7
LITHONIA	1	0.2169	0.1467	
	2	0.1601	0.1414	
	3	0.4208	0.1937	
	4	0.2896	0.1786	
	AVG	0.2719	0.1651	39.3
NORCROSS	1	0.2136	0.1537	
	2	0.2144	0.2133	
	3	0.1468	0.2701	
	4	0.1998	0.2482	
	AVG	0.1937	0.2213	-14.3
PALMER STATION	1	0.2318	0.2604	
	2	0.1786	0.1644	
	3	0.1996	0.2170	
	4	0.2185	0.2147	
	5		0.256	
	AVG	0.2071	0.2225	-7.4

* Positive percentage denotes improvement
** Rut depth in inches

SECONDARY QUARRIES

QUARRY NAME	SAMPLE No	BINDER DOT Mix (in)	BASE DOT Mix (in)	PERCENT. of Stand* (%)
BALL GROUND	1	0.1810	0.1681	
	2	0.2070	0.0948	
	3	0.1762		
	4	0.3504		
	5	0.2297		
	AVG	0.2289	0.1315	42.6
ATHENS	1	0.1900	0.1464	
	2	0.2329	0.2361	
	3		0.1561	
	4		0.1418	
	5		0.3026	
	AVG	0.2115	0.1966	7.0
CANDLER	1	0.2616	0.1274	
	2	0.2424	0.1612	
	AVG	0.2520	0.1443	42.7
MT. VIEW	1	0.1558	0.2328	
	2	0.1922	0.1140	
	3	0.2122	0.1161	
	4	0.1129	0.2640	
	5	0.2786	0.2364	
	6	0.3209	0.4314	
	7		0.2263	
	8		0.2723	
	AVG	0.2121	0.2362	-11.6
TYRONE	1	0.2191	0.2473	
	2	0.2268	0.1998	
	3	0.2297	0.1950	
	4		0.2050	
	AVG	0.2252	0.2118	6.0
BUFORD	1	0.1847	0.1900	
	2	0.1268	0.1968	
	3	0.3206	0.1715	
	4	0.3182	0.2199	
	AVG	0.2376	0.1946	18.1
CUMMINGS	1	0.3702	0.1710	
	2	0.3067	0.1286	
	3	0.3978	0.2884	
	4	0.3378	0.3778	
	AVG	0.3531	0.2415	31.6
GRIFFIN	1	0.1930	0.1760	
	2	0.1670	0.2199	
	3	0.2135	0.1943	
	4	0.2216	0.2235	
	AVG	0.1988	0.2034	-2.3
DAN	1	0.1913	0.2273	
	2	0.1401	0.1785	
	3	0.1413	0.1792	
	4	0.1596		
	AVG	0.1581	0.1950	-23.4
RUBY	1	0.1128	0.1521	
	2	0.1218	0.1090	
	3		0.2017	
	AVG	0.1173	0.1543	-31.5
DALTON	1	0.1290	0.1021	
	2	0.0708	0.1020	
	3	0.0901	0.0766	
	AVG	0.0966	0.0936	3.2
LITHIA SPRINGS	1	0.2023	0.3036	
	2	0.2470	0.5376	
	3	0.2464	0.2471	
	4	0.1785	0.2773	
	AVG	0.2186	0.3414	-56.2
POSTELL	1	0.2511	0.1360	
	2	0.1950	0.1321	
	AVG	0.2231	0.1341	39.9

rutting for the standard base mix (simulating a coarse B-binder) compared to the standard DOT B-binder mix.

Surface E-mixes

All of the experimentally observed rut depth results for the standard Georgia DOT surface E-mixes and coarse E-mixes are compared in Table 26(a) for companion specimens (direct comparison) and Table 26(b) for the cumulative results. For the cumulative results, Table 26(b), the scatter in the standard E-mix data for Kennesaw, Stockbridge, and Norcross quarries is too great to be considered reliable. Therefore, only the direct comparison specimen data given in Table 26 (a) is discussed in this section.

The average reduction in rutting of the seven sets of companion specimens tested was 13 percent (Table 26 (a)). The probability that the results are statistically significant is slightly less than 60 percent. Five out of the seven coarse E-mixes tested showed a reduction in rutting compared to the conventional DOT mixes. For these 5 quarries, the average reduction in rutting was 20 percent. The coarse E-mix from Palmer Station and Stockbridge performed best relative to the standard E-mix. The coarse E-mix prepared for Barin and Norcross quarries did not perform quite as well as the standard E-mixes.

STATISTICAL RUTTING CORRELATIONS

Introduction

A detailed statistical correlation study was performed on the very extensive rut depth data developed using the Loaded Wheel Tester on base, B binder, and surface E asphalt concrete mixes. The purposes of this study

Table 26. Wheel Track Test Rutting Results: Direct and Cumulative Comparison of Standard DOT E with Coarse E Mixes.

(a) Direct Comparison

PRIMARY QUARRIES

QUARRY NAME	SAMPLE No	E M I X DOT Mix (in)	COARSE E Ga Tech Mix (in)	PERCENT. of Stand (%)
DIXIE	1			
	2			
	AVG			
WHITE	1	0.1400	0.0977	
	2	0.1105	0.1209	
	AVG	0.1253	0.1093	12.7
BARIN	1	0.2459	0.2364	
	2	0.1849	0.2181	
	AVG	0.2154	0.2273	-5.5
KENNESAW	1	0.4247	0.3101	
	2	0.3651	0.3430	
	AVG	0.3949	0.3266	17.3
STOCKBRIDGE	1	0.3652	0.2660	
	2	0.3433	0.2909	
	AVG	0.3543	0.2785	21.4
LITHONIA	1	0.2629	0.2112	
	2	0.3419	0.3007	
	AVG	0.3024	0.2560	15.4
NORCROSS	1	0.2692	0.2854	
	2	0.2499	0.2481	
	AVG	0.2596	0.2668	-2.8
PALMER STATION	1	0.4650	0.2588	
	2	0.3222	0.3465	
	3	0.5380		
	AVG	0.4417	0.3027	31.5

* Positive percentage denotes improvement
** Rut depth in inches

(b) Cumulative Comparison

PRIMARY QUARRIES

QUARRY NAME	SAMPLE No	E M I X DOT Mix (in)	COARSE E Ga Tech Mix (in)	PERCENT. of Stand (%)
WHITE	1	0.1400	0.0977	
	2	0.1105	0.1209	
	AVG	0.1253	0.1093	12.7
BARIN	1	0.1421	0.2364	
	2	0.3107	0.2181	
	3	0.2181		
	4	0.2459		
	5	0.1849		
	AVG	0.2203	0.2273	-3.1
KENNESAW	1	0.1740	0.3101	
	2	0.1249	0.3430	
	3	0.4247		
	4	0.3651		
	AVG	0.2722	0.3266	-20.0
STOCKBRIDGE	1	0.1201	0.2660	
	2	0.1461	0.2909	
	3	0.3652		
	4	0.3433		
	AVG	0.2437	0.2785	-14.3
LITHONIA	1	0.2637	0.2112	
	2	0.1414	0.3007	
	3	0.2629		
	4	0.3419		
	AVG	0.2525	0.2560	-1.4
NORCROSS	1	0.1962	0.2854	
	2	0.1910	0.2481	
	3	0.2692		
	4	0.2499		
	AVG	0.2266	0.2668	-17.7
PALMER STATION	1	0.4817	0.2588	
	2	0.4636	0.3465	
	3	0.4650		
	4	0.3222		
	5	0.5380		
	AVG	0.4541	0.3027	33.4

were to:

1. Identify the most important variables that influence rutting in base, B-binder, and surface E mixes.
2. Identify any cross correlations which exist between individual variables.
3. Develop general equations that can be used to predict rutting in proposed mixes or limiting criteria on certain variables that can serve to control rutting or to identify mixes having high rut potentials.

This section briefly summarizes the extensive statistical analyses carried out using the rutting data base. Both Marshall mix design variables and aggregate characteristics were considered as potential predictors of rutting. As many as 45 predictors were included in the statistical analyses.

To select significant variables as predictors, stepwise, forward selection, and backward elimination techniques were all performed on each set of rutting data analyzed. A detailed description of the statistical work is given by Siegel [11].

Base Mixes

Using the predictors selected from backward elimination, the rut depth prediction equations given in Tables 27 through 29 were developed for the DOT base, coarse base, and the combined DOT and coarse base rutting data. The general models given in these tables represent the statistical best fit of the data that could be obtained following accepted practices of statistics. That is, variables were dropped from the correlation when a reasonable level of uncertainty existed that the improvement of the correlation due to a specific variable might be due to random chance.

Table 27. Results of Regression on Backward Elimination Variables for DOT Base Mix.

The regression equation is
Rutting = 2.21 - 0.0136 x Srv (pass. No.30/ret. No.40)
- 0.00789 x Srv (pass. 1/4"/ret. No.4) - 0.128 x Smi,w
+5.2E-7 x SA, w + 0.0156 x %Mi,w + 0.387 x % AC + 0.152 x % Air V.
+ 0.0280 x Mix Dens. - 0.189 x % VMA - 1.72 x Bulk SG of fine aggr.
- 0.00151 x Cu - 0.513 x Roughness - 0.0150 x Flow

20 cases used 1 cases contain missing values

Predictor	Coef	Stdev	t-ratio	p
Constant	2.208	0.4967	4.45	0.004
Srv (40)	-0.014	0.0029	-4.67	0.003
Srv (4)	-0.0079	0.002404	-3.28	0.017
Smi,w	-0.1278	0.02463	-5.19	0.002
SA, w	5.2E-7	1.5E-7	3.46	0.013
%Mi,w	0.0156	0.00168	9.28	0.000
% AC	0.3875	0.08490	4.56	0.004
% Air V.	0.1515	0.02741	5.53	0.001
Mix Dens	0.0271	0.006225	4.50	0.004
% VMA	-0.1885	0.04221	-4.47	0.004
SG bulk	-1.7247	0.2412	-7.15	0.000
Cu	-0.0015	0.000429	-3.51	0.013
Rough.	-0.5128	0.1800	-2.85	0.029
Flow	-0.0150	0.00477	-3.14	0.020

s = 0.01561 R-sq = 97.7% R-sq(adj) = 92.7%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	13	0.0616297	0.0047407	19.45	0.001
Error	6	0.0014622	0.0002437		
Total	19	0.0630919			

SOURCE	DF	SEQ SS
Srv (40)	1	0.0020854
Srv (4)	1	0.0148138
Smi,w	1	0.0004548
SA, w	1	0.0017428
%Mi,w	1	0.0064836
% AC	1	0.0011143
% Air V.	1	0.0006965
Mix Dens	1	0.0140231
% VMA	1	0.0022477
SG bulk	1	0.0083935
Cu	1	0.0050193
Rough.	1	0.0021588
Flow	1	0.0023959

Table 28. Results of Regression on Backward Elimination Variables for Coarse Base.

The regression equation is
Rutting = 2.76 + 0.0149 x Srv (pass. 1/4"/ret. No.4) + 0.155 x Srv,w
- 0.160 x Sma, w - 0.287 Sma,w - 1.2E-7 x SA, w
+ 0.0510 x SC,w + 0.260 x % AC + 0.0439 x % Air Voids
- 0.0197 x Mix Dens. - 0.113 x % VMA - 0.950 x Bulk SG of fine aggr.
+ 2.08 x Roughness +2.9E-7 x Mr + 0.0295 x Flow

19 cases used 2 cases contain missing values

Predictor	Coef	Stdev	t-ratio	p
Constant	2.7634	0.1794	15.40	0.000
Srv (4)	0.014897	0.0023	6.61	0.003
Srv,w	0.15527	0.0178	8.75	0.001
Sma, w	-0.16028	0.0186	-8.59	0.001
Smi,w	-0.28677	0.0352	-8.14	0.001
SA, w	-1.2E-7	3.0E-8	-3.57	0.023
SC,w	0.051013	0.0042	12.15	0.000
% AC	0.25956	0.0258	10.05	0.001
% Air V.	0.043918	0.0040	10.90	0.000
Mix Dens	-0.019713	0.0025	-7.83	0.001
% VMA	-0.11267	0.0124	-9.05	0.001
SG bulk	-0.9498	0.2185	-4.35	0.012
Rough.	2.0785	0.1956	10.63	0.000
Mr	2.9E-7	2.0E-8	13.19	0.000
Flow	0.029485	0.0040	7.32	0.002

s = 0.005890 R-sq = 99.7% R-sq(adj) = 98.7%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	14	0.0489867	0.0034990	100.85	0.000
Error	4	0.0001388	0.0000347		
Total	18	0.0491254			

SOURCE	DF	SEQ SS
Srv (4)	1	0.0000661
Srv,w	1	0.0006868
Sma, w	1	0.0000060
Smi,w	1	0.0024482
SA, w	1	0.0000435
SC,w	1	0.0000462

Table 29. Results of Backward Elimination for Combined Base Mixes.

The regression equation is
Rutting = 2.20 + 0.00476 Srv(7/8) - 0.0452 Smi,w + 0.00617 %Mi,w
- 0.0134 Mix Dens - 0.115 Top Size +0.000067 Stab.
-0.000466 Sta/Flow

41 cases used 22 cases contain missing values

Predictor	Coef	Stdev	t-ratio	p
Constant	2.1963	0.3434	6.40	0.000
Srv(7/8)	0.0048	0.0022	2.14	0.040
Smi,w	-0.0452	0.0198	-2.29	0.029
%Mi,w	0.0062	0.0010	5.78	0.000
Mix Dens	-0.0134	0.0024	-5.68	0.000
Top Size	-0.1151	0.0402	-2.87	0.007
Stab.	6.7 E-5	2.8E-5	2.42	0.021
Sta/Flow	-0.0005	0.0002	-2.09	0.044

s = 0.03413 R-sq = 70.8% R-sq(adj) = 64.6%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	7	0.093293	0.013328	11.44	0.000
Error	33	0.038436	0.001165		
Total	40	0.131728			

SOURCE	DF	SEQ SS
Srv(7/8)	1	0.001146
Smi,w	1	0.000236
%Mi,w	1	0.033563
Mix Dens	1	0.043790
Top Size	1	0.007612
Stab.	1	0.001850
Sta/Flow	1	0.005096

Unusual Observations

Obs.	Srv(7/8)	Rutting	Fit	Stdev. Fit	Residual	St.Resid
12	12.5	0.34140	0.2822	0.02104	0.05920	2.20R
31	8.9	0.29430	0.2240	0.01411	0.07026	2.26R

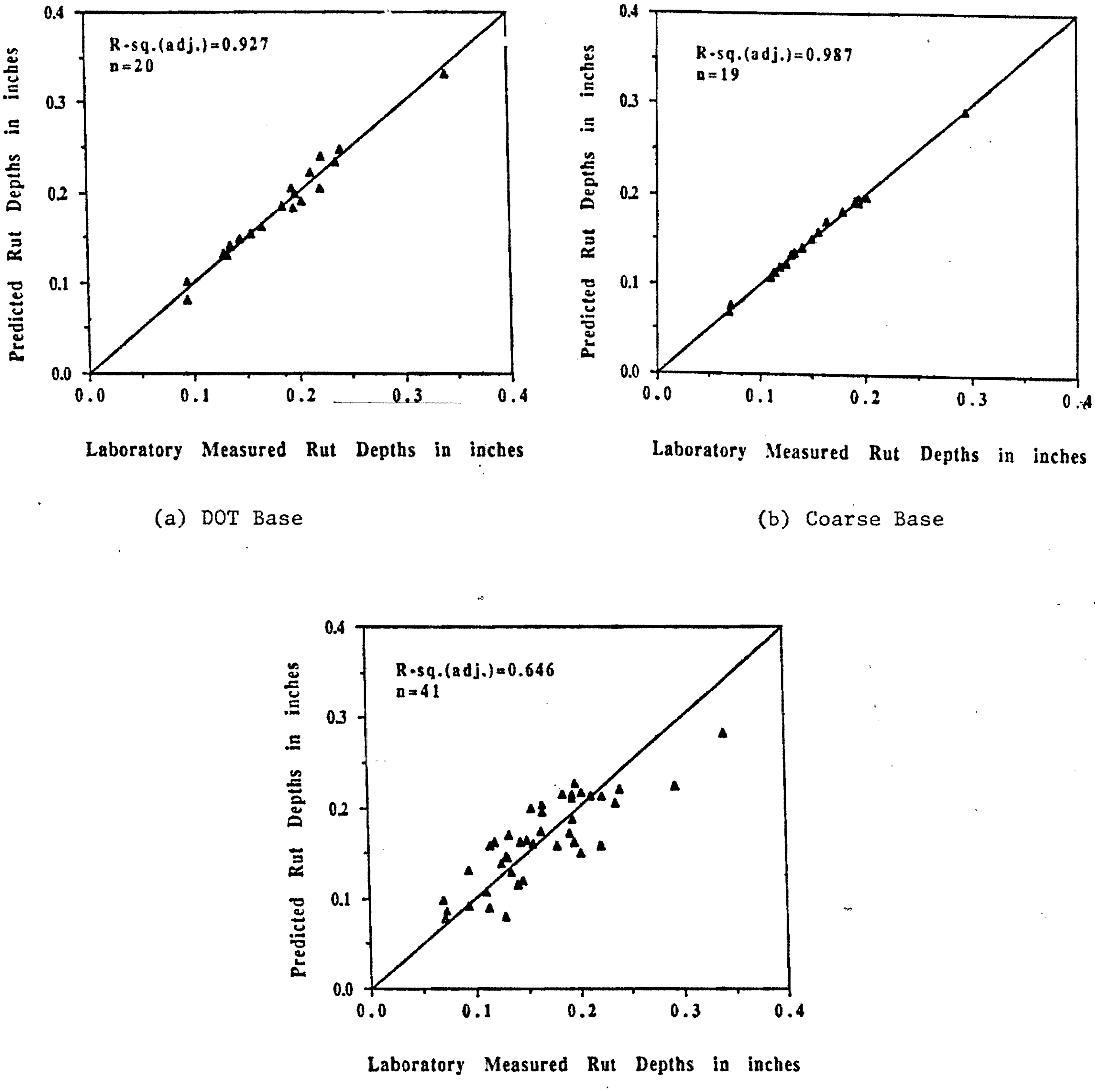
R denotes an obs. with a large st. resid.

The statistical correlation equations developed to predict rutting give the rut depth that should occur in an asphalt concrete beam subjected to the Loaded Wheel Test used in this study. The values of predicted rutting can be used to directly compare one mix with another to evaluate rutting potential. No attempt was made to relate rut depths observed in the Loaded Wheel Test to field performance.

Statistics. The general base models given in Tables 27 and 28 for predicting rutting in specific base mixes show excellent correlation with the R squared (adjusted) values varying from 92.7 to 98.7 percent. The combined model (DOT and coarse base mix data combined) has an R-squared (adjusted) value of 0.646 (Table 29). The R squared (adjusted) value indicates the amount of variation explained by the model. The absolute value of the t-ratio, also given in the statistical summary tables, indicates the relative importance of the variable. A positive t-ratio indicates that rutting increases as the value of the variable increases. A negative value indicates rutting is inversely proportional to an increase in the predictor. The curve fit of the data for the three equations is illustrated in Figure 6.

The value of p given in the tables indicates the probability that the predictor is randomly related to rutting. Hence, if $p = 0.04$ in the table the probability is 4 percent that the predictor is randomly related to rutting, and hence has a 96 percent probability that the relationship is statistically significant.

Simplied Models. Simplified models were also developed for selected rutting data sets when the general model utilized several predictors that are relatively hard to evaluate. In the simplified models, an attempt was made to eliminate some of the harder to measure predictors. Simplified



(a) DOT Base

(b) Coarse Base

(c) Combined Base

Figure 6. Level of Fit for Predicted Compared to Measured Rut Depths - Base Mixes.

models for the DOT and coarse bases are given in Table 30 which gives a general summary of all of the asphalt mix rutting models developed. The general model for combined DOT and coarse base mixes is considered sufficiently simple so that further refinement is not considered necessary. As a result of decreasing the number of variables, the accuracy of all of the simplified rutting models is reduced. The R square adjusted values are 0.424 and 0.754 for the simplified DOT and coarse base mix equations, respectively, (recall that R^2 indicates the amount of rutting that has been statistically explained). The simplified coarse base model ($R^2 = 0.754$) is much easier to use than the general model ($R^2 = 0.987$) but yet has good accuracy.

Combined Base Model. The combined base rutting model, summarized in Table 29, includes both the DOT and coarse mix data. This model explains about 64.6 percent of the rutting (R square (adj.) = 64.6 percent) which corresponds to a reasonable high correlation coefficient of 0.80. The statistical probability that the relation between a specific predictor in the equation and rutting is not random has a probability of 96 percent or higher (i.e., $p \leq 0.04$). As illustrated in Figure 6 (c), the correlation between predicted and observed rutting is reasonably good. The plot of the standardized residuals values is also random which indicates a sound statistical model.

Variables Affecting Rutting. For the combined DOT and coarse base mix model given in Table 29, the most important aggregate properties influncing rutting are weighted mica content ($t = 5.78$), which is by far the most important aggregate related variable, and aggregate top size ($t = -2.87$). The importance of the variable increases as the absolute value of t. The most important mix design variable is mix density ($t = 5.68$) with mix

Table 30. Summary of Rut Depth Prediction Equations.

Eq.	Mix Type	Analysis	Coef.	%AC	% Air V.	Cu	Flow	% Mi (100)	% Mi < 100	% Mi.w	Mix Dens.	Mr	Bough	SA (120)	SA.w	SC (120)	SC < 120
17	DOT Base	Stepwise	2.727								-0.0181					0.0319	
18	DOT Base	Backward El.	2.208	0.3875	0.1515	-0.0015	-0.0150			0.0158	0.0271		-0.5128		9.2E-07		
19	DOT Base	Simplified	1.224	0.0729							-0.0078						
20	Coarse Base	Stepwise	1.588		0.0214					0.0030	-0.0224	2.0E-07					
21	Coarse Base	Backward El.	2.783	0.2598	0.0439		0.0295				-0.0197	2.9E-07	2.0785		-1.2E-07		
22	Coarse Base	Simplified	2.597	0.1108	0.0832		-0.1187				-0.0208						
23	DOT Binder	Stepwise	-0.453	0.1104										-1.2E-05			
24	DOT Binder	Backward El.	-2.293	0.3428	-0.5710					-0.0045	0.0108				-9.0E-07		
25	DOT Binder	Simplified	-2.819	0.8817	0.0558						0.0208						
26	Combined Base Mixes	Stepwise	1.865							0.0060	-0.1184			1.1E-05			
27	Combined Base Mixes	Backward El.	2.198							0.0062	-0.0134						
28	Combined Base Mixes	Simplified	1.480								-0.0187						
29	Combined Binder Mixes	Stepwise	1.629					0.0031									
30	Combined Binder Mixes	Backward El.	2.607				0.0172			0.0073							
31	Combined Binder Mixes	Simplified	1.127	0.0457	0.0145		0.0138										
32	Combined Surf (E) Mixes	Stepwise	0.970											1.9E-05			0.0831
33	Combined Surf (E) Mixes	Simplified	-10.800	0.9827	0.4727												
34	All Mixes	Stepwise	1.988							0.0063	-0.0098						
35	All Mixes	Backward El.	-0.084	0.1279	0.0527		0.0149		0.0008								-0.0251
36	All Mixes	Simplified	0.444	0.0828	0.0187		0.0018										

Eq.	Mix Type	Analysis	SC.w	SG bulk	Sma (40)	Sma.w	Smi.w	Srv (40)	Srv (16)	Srv (4)	Srv (7/8)	Srv.w	Stab	Stab/Flow	Top Size	% VMA	R-sq (adj.)	n
17	DOT Base	Stepwise															0.483	20
18	DOT Base	Backward El.		-1.7247			-0.1278	-0.0140		-0.0079						-0.1885	0.927	20
19	DOT Base	Simplified						0.0060	-0.0175								0.424	20
20	Coarse Base	Stepwise		0.6451													0.814	19
21	Coarse Base	Backward El.	0.5101	-0.9498		-0.1603	-0.2868			0.1490		0.1553				-0.1127	0.887	19
22	Coarse Base	Simplified		0.7607				0.0099					0.0005	-0.0045		-0.0883	0.754	19
23	DOT Binder	Stepwise			-0.0138							0.0086	0.0001				0.939	19
24	DOT Binder	Backward El.	-0.0184			0.0096	0.0229						0.0001			-0.0238	0.888	19
25	DOT Binder	Simplified		-0.2733					0.0164	-0.0090	-0.0041	0.0175		0.0019		-0.2387	0.842	19
26	Combined Base Mixes	Stepwise													-0.0767		0.489	44
27	Combined Base Mixes	Backward El.					-0.4520				0.0048		8.7E-05	-0.0005	-0.1151		0.848	41
28	Combined Base Mixes	Simplified		0.6519				0.0072	-0.0062		0.0048				-0.1208		0.317	44
29	Combined Binder Mixes	Stepwise		-0.4184					-0.0131						-0.0902		0.370	48
30	Combined Binder Mixes	Backward El.		-0.8671				-0.0120							-0.0800		0.452	44
31	Combined Binder Mixes	Simplified		-0.5079					0.3660				0.0360		-0.0578		0.381	45
32	Combined Surf (E) Mixes	Stepwise															0.818	14
33	Combined Surf (E) Mixes	Simplified						0.3715		0.1829		-0.0748				-0.3950	0.592	12
34	All Mixes	Stepwise			-0.0074				-0.0059						-0.0695		0.405	79
35	All Mixes	Backward El.												0.0006	-0.0842	-0.0418	0.462	72
36	All Mixes	Simplified		-0.2083					-0.0074	0.0028			3.8E-05		-0.0872		0.383	72

stability (t = 2.42) and stability/flow (t = -2.09) being considerably less important.

Variables found to be important for the DOT base and coarse mix models (individually) are as follows as summarized in Tables 27 and 28:

1. Mix Variables: asphalt content, air voids, VMA, mix density, flow. Resilient modulus may also be very important but sufficient data was only available for the coarse base mix to identify this variable.
2. Aggregate variables: mica content, specific gravity of fines, pouring properties, roughness, weighted surface area.

Of potential significance was the fact that the weighted mica content ($M_{i,w}$) was found to be correlated to the properties of the aggregate determined from the pouring test which is described in Appendix D (rugosity, S_{rv}; macro voids, S_{ma}; and micro voids, S_{mi}). The highest correlation (R = 0.680 between weighted mica content (M_i, w) and surface macro voids (S_{ma}) was measured for the -30 to + 40 size particles. Several other correlations exist between mica content and pouring test properties having R-values almost as high. The fact that weighted mica content and the amount of macro voids are related (and also other surface aggregate properties) appears to indicate that the mica content affects the formation of the aggregate particle. From a geological viewpoint, this finding appears reasonable.

Binder Mixes

DOT Binder Models. Three statistical rutting models were developed for DOT B binder mixes. All of these models have excellent adjusted R square values varying from 93.9 percent for the simplified model to 96.8 percent for the best general model. The most accurate DOT binder model is summarized in Table 31(a) and the correlation is shown in Figure 7(a). The simplified model is given in Table 31(b).

Coarse Binder and Combined Models. The proposed coarse binder had a gradation very similar to the DOT base mix. Therefore the DOT base mix, whose rutting test correlation results are given in Table 27, is used to represent the coarse binder mix. Combined DOT binder and DOT base (simulating a coarse binder mix) results are given in Table 32 and the statistical correlation is shown in Figure 7(c). The R square (adjusted) value for this correlation is 0.452 and the probability is equal to or greater than 96 percent that the variables used are related to rutting. Simplified models for all the binder mixes are given in Table 30.

Important Binder Variables. The most important variables affecting rutting in DOT binder mixes, as indicated by the simplied model given in Table 31(b), are stability/flow ($t = 10.4$), asphalt content (AC; $t = 9.43$), VMA ($t = -8.28$), mix density ($t = 3.91$) and the combined effects of four aggregate surface properties obtained from the pouring test (S_{rv}-16; $t = 3.69$). This rutting model was selected to examine the significant variables because it uses only Marshall mix design variables and predictors from the pouring test.

Mica content did not directly enter this equation but did enter the most accurate equation (Table 31(a)). Also, recall that mica content and rugosity (S_{rv}) - the combined surface properties of the aggregate, are related.

Very important variables from the other two rutting DOT binder models are as follows:

1. Mix design variables: Stability and asphalt content.

Table 31. Results of Regression for DOT Binder Mix.

(a) General Model

The regression equation is

Rutting = - 2.29 + 0.00956 x Sma, w + 0.0229 x Smi,w + 9.0E-7 x SA, w
- 0.0184 x SC,w - 0.00448 x %Mi,w + 0.343 x % AC
- 0.0571 x % Air V. + 0.0106 Mix Dens. in pcf
- 0.0624 x % VMA +0.000103 x Stab.

18 cases used 3 cases contain missing values

Predictor	Coef	Stdev	t-ratio	p
Constant	-2.2934	0.5559	-4.13	0.004
Sma, w	0.009559	0.0019	5.12	0.000
Smi,w	0.022918	0.0072	3.17	0.016
SA, w	9.0E-7	1.5E-7	6.06	0.000
SC,w	-0.018379	0.0088	-2.09	0.075
%Mi,w	-0.004483	0.0012	-3.76	0.007
% AC	0.34284	0.0418	8.21	0.000
% Air V.	-0.05710	0.0130	-4.40	0.003
Mix Dens	0.010646	0.0031	3.41	0.011
% VMA	-0.06236	0.0216	-2.89	0.023
Stab.	0.0001034	0.00001	9.97	0.000

s = 0.01093 R-sq = 98.7% R-sq(adj) = 96.8%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	10	0.0617248	0.0061725	51.71	0.000
Error	7	0.0008355	0.0001194		
Total	17	0.0625603			

SOURCE	DF	SEQ SS
Sma, w	1	0.0000590
Smi,w	1	0.0034715
SA, w	1	0.0087709
SC,w	1	0.0020912
%Mi,w	1	0.0052015
% AC	1	0.0073870
% Air V.	1	0.0170370
Mix Dens	1	0.0012418
% VMA	1	0.0045902
Stab.	1	0.0118747

(b) Simplified Model

The regression equation is

Rutting = - 2.82 + 0.0164 x Srv (pass. No.12/ret. No.16)
- 0.00900 x Srv (pass.1/4"/ret. No.4)
- 0.00412 x Srv(pass. 1 1/4"/ret. 7/8")
+ 0.0175 x Srv,w + 0.662 x % AC + 0.0558 x % Air V.
+ 0.0208 x Mix Dens. in pcf
- 0.239 x % VMA - 0.273 x bulk SG of fine aggregate
+ 0.00178 x Sta/Flow

18 cases used 3 cases contain missing values

Predictor	Coef	Stdev	t-ratio	p
Constant	-2.8187	0.5758	-4.89	0.000
Srv (16)	0.0164	0.0044	3.69	0.008
Srv (4)	-0.0090	0.0027	-3.28	0.013
Srv(7/8)	-0.0041	0.0025	-1.65	0.144
Srv,w	0.0175	0.0039	4.50	0.000
% AC	0.66173	0.0701	9.43	0.000
% Air V.	0.05576	0.0160	3.49	0.010
Mix Dens	0.020837	0.0053	3.91	0.006
% VMA	-0.23873	0.0288	-8.28	0.000
SG bulk	-0.2733	0.2122	-1.29	0.239
Sta/Flow	0.0018	0.0002	10.38	0.000

s = 0.01457 R-sq = 97.6% R-sq(adj) = 94.2%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	10	0.0610741	0.0061074	28.77	0.000
Error	7	0.0014862	0.0002123		
Total	17	0.0625603			

SOURCE	DF	SEQ SS
Srv (16)	1	0.0009100
Srv (4)	1	0.0003206
Srv(7/8)	1	0.0062107
Srv,w	1	0.0017014
% AC	1	0.0141253
% Air V.	1	0.0094964
Mix Dens	1	0.0003999
% VMA	1	0.0029476
SG bulk	1	0.0021075
Sta/Flow	1	0.0228547

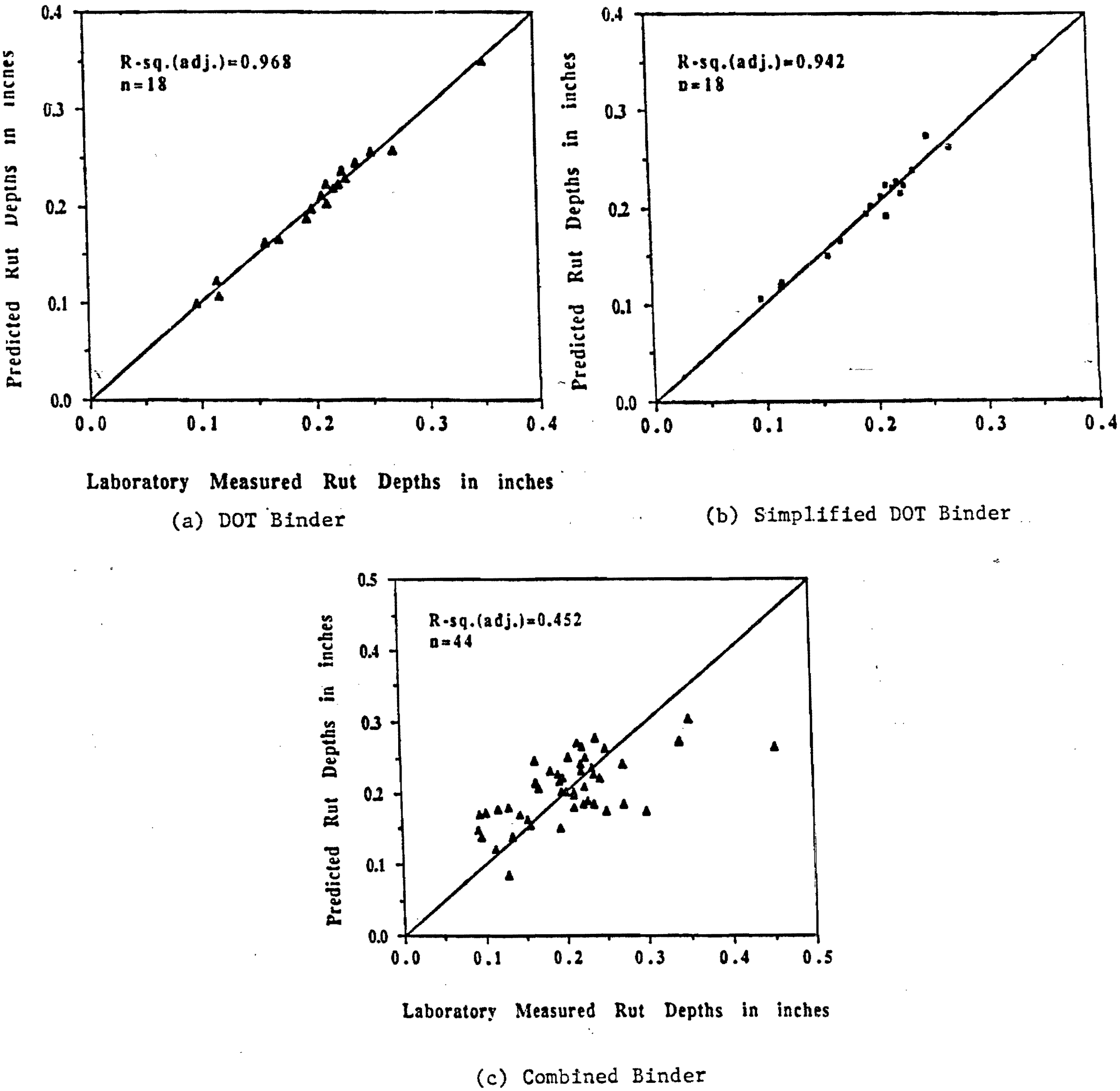


Figure 7. Level of Fit for Predicted Compared to Measured Rut Depths - Binder Mixes.

Table 32. Results of Backward Regression Variables for Combined Binder Mixes.

The regression equation is
Rutting = 2.61 - 0.0120 x Srv (pass. No.30/pass. No.40) + 0.00729 x %Mi,w
- 0.867 bulk SG of fine aggregate
- 0.0800 x Top Size of aggregate in inches + 0.0172 x Flow

44 cases used 19 cases contain missing values

Predictor	Coef	Stdev	t-ratio	p
Constant	2.6071	0.4692	5.56	0.000
Srv (40)	-0.0120	0.0043	-2.76	0.009
%Mi,w	0.0073	0.0020	3.64	0.001
SG bulk	-0.8671	0.1768	-4.91	0.000
Top Size	-0.0800	0.0256	-3.13	0.003
Flow	0.0172	0.0081	2.14	0.039

s = 0.05252 R-sq = 51.6% R-sq(adj) = 45.2%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	5	0.111719	0.022344	8.10	0.000
Error	38	0.104799	0.002758		
Total	43	0.216518			

SOURCE	DF	SEQ SS
Srv (40)	1	0.000123
%Mi,w	1	0.020820
SG bulk	1	0.057324
Top Size	1	0.020851
Flow	1	0.012601

Unusual Observations

Obs.	Srv (40)	Rutting	Fit	Stdev.	Fit Residual	St.Resid
58	23.4	0.45410	0.27186	0.01906	0.18224	3.72R

R denotes an obs. with a large st. resid.

2. Aggregate characteristics: Macro-surface voids (S_{mi}) obtained from the pouring test and weighted surface area.

Surface Mixes

Combined Models. Because there was relatively limited rutting data for the surface E mixes, both the DOT and coarse mixes were combined for the statistical analyses. The combined model and the statistical summary of results are given in Table 33 along with the correlation fit of the data. The observed adjusted R square value for the combined model is 81.6 percent with the probability that all variables are statistically significant being equal to or greater than 97 percent.

The simplified model for the surface E mix is given in Table 34 along with the accuracy of the correlation. The R square (adjusted) value is 0.582 ($R = 0.763$) and the probability that the variables used in this model are significant is equal to or greater than 91.9 percent.

Significant Variables. The two most significant variables that influence rutting in surface E mixes, based on the general model, are surface area of the particles passing the No. 8 sieve and retained on the No. 120 and the shape classification of the particles passing the No. 120 sieve ($R = 0.868$). These two variables constitute the general model for the relatively fine surface E mixes (refer to Table 33). This finding indicates that the top size of the aggregate plays a much smaller role in rutting of a surface mix than, for example, a base mix and that particle characteristics of the finer sizes are important. The surface E mix was the only type mix for which a single variable (shape classification of the particles passing the No. 120 sieve) showed a high degree of correlation with rutting.

Table 33. Results of Regression on Stepwise Variables for Combined Surface (E) Mixes.

The regression equation is
Rutting = 0.970 -0.000019 x Surface Area (SA) in square inches per pound (pass. No.8/ret. No.120) - 0.0831 x Shape Classification (SC) (pass. No.120)

14 cases used 28 cases contain missing values

Predictor	Coef	Stdev	t-ratio	p
Constant	0.9698	0.0971	9.99	0.000
SA (120)	-0.0000	0.0000	-2.54	0.027
SC <120	-0.0831	0.0130	-6.40	0.000

s = 0.04179 R-sq = 84.5% R-sq(adj) = 81.6%

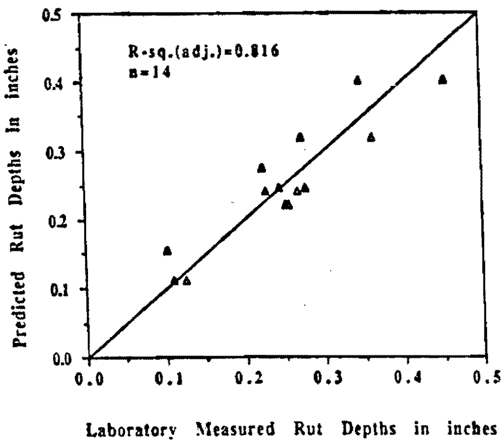


Table 34. Results of Regression for the Simplified Combined Model for Surface E Mixes.

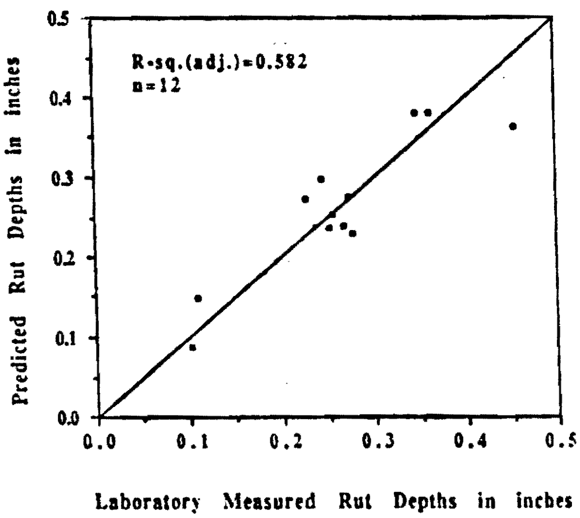
The regression equation is

Rutting = - 10.8 + 0.372 x Srv (pass. No.30/ret. No.40)
+ 0.183 x Srv (pass. 1/4"/ret. No.4) - 0.0748 x Srv,w
+ 0.963 x % AC + 0.473 x % Air V. - 0.385 x % VMA

12 cases used 30 cases contain missing values

Predictor	Coef	Stdev	t-ratio	p
Constant	-10.841	3.100	-3.50	0.017
Srv (40)	0.3715	0.1110	3.35	0.020
Srv (4)	0.1829	0.0540	3.39	0.020
Srv,w	-0.0748	0.0343	-2.18	0.081
% AC	0.9627	0.2720	3.54	0.017
% Air V.	0.4727	0.1192	3.97	0.011
% VMA	-0.3850	0.1195	-3.22	0.023

s = 0.06318 R-sq = 81.0% R-sq(adj) = 58.2%



The simplified model uses properties which are much easier to measure in the laboratory than surface area and particle shape. The simplified model (Table 34) has an adjusted R squared value of 58.2 percent with a 91.9 percent or greater probability that the variables used are significant. Air voids and asphalt content appear to be the most important variables in the simplified model. Aggregate variables that are almost as important and are obtained from the pouring test are as follows: rugosity ($S_{r,v}$) of particles from the No. 30 to No. 40 sieve, particles from the 7/16 in. to No. 4 sieve, and weighted rugosity ($S_{rv,w}$). Voids in the mineral aggregate (VMA) also plays a role in determining rutting in E mixes. Once again, the aggregate properties of the smaller size particles play an important role in rutting of the surface E mixes.

Variables Interactions. Stability/flow showed a strong interaction (R = 0.687) with rugosity measured between the 1.25 in. and 7/8 in. sieves. Mix density also correlated reasonably well (R = 0.687) with the same value of rugosity. The percent mica in the aggregate passing the No. 100 sieve and the weighted mica content both show a high corelation with the value of Marshall Stability (R = -0.783 and -0.799, respectively). Stability and VMA (R = 0.778) and also mix density and flow (R = 0.770) also show reasonably good correlations.

FATIGUE LIFE

Introduction

Theoretical studies of the fatigue life of the base, B-binder, and surface E mixes were conducted to determine the influence on fatigue of going from a conventional mix to a slightly coarser mix. Two types of fatigue life analyses were conducted:

1. Direct Comparison. A direct comparison was performed of the difference in fatigue life between the standard and coarse mixes using the Marshall mix design characteristics and the GTFATIGUE computer program (Appendix D).
2. Detailed Analysis. A detailed analysis was performed for a limited number of conditions using elastic layered theory, typical pavement structural sections, typical resilient moduli from the diametrical test, and the GTFATIGUE computer program.

The results of these two fatigue life studies are summarized in this section.

Direct Comparison

Following the direct comparison method, a tensile strain of 200×10^{-6} in/in. was assumed to exist in each asphalt concrete mix. Dynamic moduli for each mix were calculated using the RESMOD computer program (Appendix D) and the properties of the mix. Dynamic moduli, the given tensile strain level, and the Marshall mix design characteristics given in Chapter 2 for each mix were then used to calculate the expected fatigue life of each mix using the GTFATIGUE computer program described in Appendix D.

A summary of the fatigue lives predicted by the two theoretical fatigue models are presented in Tables 35 for the base, B-binder, and E surface asphalt concrete mixes. The fatigue life is given for both standard Georgia DOT mixes and the rut resistant coarse and fine mixes developed during this study. The coarse mixes have a slightly coarser gradation than standard DOT mixes and hence usually exhibit a slightly lower optimum asphalt content based on the Marshall mix design method.

Table 35. Summary of Fatigue Calculations from GTFATIGUE Program.

QUARRY	AVG. (2)	BASE	COARS BASE	RED. (3)	FINE BASE	RED. (3)	BINDE	COARS BINDE	RED. (3)	FINE BINDE	RED. (3)	E-MIX	COARS E-MIX	RED. (3)	F-MIX
WHITE	1,136	1,210	1,065	12%	995	18%	1,133	1210	-7%			2,111	1,002	53%	2,221
BARIN	1,401	1,579	970	39%			1,653	1579	4%			2,023	2,040	-1%	2,450
KENNESAW	1,713	1,795	1,407	22%	1,034	42%	1,936	1,807*	7%	1,988	-3%	2,489	2,066	17%	
STOCKBRIDGE	1,744	1,864	1,394	25%			1,974	1864	6%			2,589	1,134	56%	
LITHONIA	1,491	1,386	1,207	13%	1,108	20%	1,881	1386	26%			2,387	1,813	24%	
NORCROSS	1,668	1,967	1,178	40%	1,246	37%	1,859	1967	-6%			2,509	1,694	32%	
PALMER ST.	1,598	1,854	1,346	27%			1,595	1854	-16%			2,598	2,206	15%	
BALL GRD.	1,617	1,898	1,078	43%			1,876	1,596	15%	1,577	17%	2,334			
ATHENS	2,174	1,972	2,148	-9%			2,401	1972	18%						
CANDLER	1,536	1,614	1,102	32%			1,891	1614	15%						
MT. VIEW	1,612	1,656	1,254	24%			1,925	1656	14%						
TYRONE	1,730	1,760	1,527	13%			1,902	1760	8%						
BUFORD	1,779	1,769	1,386	22%			2,182	1769	19%						
CUMMINGS	1,825	1,745	1,555	11%			2,176	1745	20%						
GRIFFIN	1,812	2,025	1,427	30%			1,985	2025	-2%						
DAN	2,016	1,618	1,829	-13%			2,602	1618	35%						
RUBY	1,696	1,530	1,327	13%			2,230	1530	31%						
DALTON	1,389	1,593	949	40%			1,624	1593	2%						
LITHIA SP.	1,731	1,831	1,180	36%			2,182	1831	16%						
POSTELL	1,654	1,756	1,305	26%			1,900	1756	8%						
DIXIE															4,486
		1,721	1,332	23%	1,096	36%	1,945	1,702	12%	1,783	8%	2,380	1,708	28%	3,052

(1) Multiply values by 1000
(2) Quarry averages represent the fatigue life average from base, coarse base, and binder mix designs only
(3) Reduction in fatigue life in percent in going from DOT to Ga Tech mix
(4) Actual proposed coarse grading as compared to the DOT base grading used for the other coarse mixes.

Primarily as a result of these differences, the theoretical fatigue life of the coarser mixes is usually lower than for the standard DOT mixes.

Base Mixes. Assuming a constant tensile strain is developed in each mix under the applied wheel loadings, the average reduction in fatigue life for the coarse base mixes, compared to the standard base mixes, is 22 percent with a standard deviation of 11.5 percent. The calculated reduction in fatigue life varied from -13 percent (an increase in fatigue life) to +43 percent (a reduction in fatigue life). The 4 finer base mixes studied showed an average reduction in fatigue life of 29 percent. These findings suggest the presently used DOT mixes have a relatively high fatigue life compared to other possible aggregate gradings.

Binder Mixes. The coarse binder mixes exhibited a theoretical average reduction in fatigue life of 11 percent compared to the standard DOT binder mix. Note that all but 2 of the coarse binder mix fatigue lives given in Table 35 are actually DOT base mixes.

Surface E Mixes. The average reduction in the coarse E mixes, compared to the DOT E mix is 28 percent (Table 35).

Detailed Fatigue Life Analysis

Both the thin and thick pavement sections considered in the detailed fatigue life analysis are shown in Figure 8. Both of these sections were loaded with an 18 kip, single axle, dual wheel loading. Representative asphalt concrete moduli measured in the diametrical test and used in the analysis are also shown on this figure.

The tensile strain in the bottom of the E mix surface layer and also at the bottom of the asphalt concrete base were calculated using the ELSYM 5 computer program. All layers were assumed to be isotropic and linear elastic. The subgrade was assumed to be semi-infinite and have a resilient

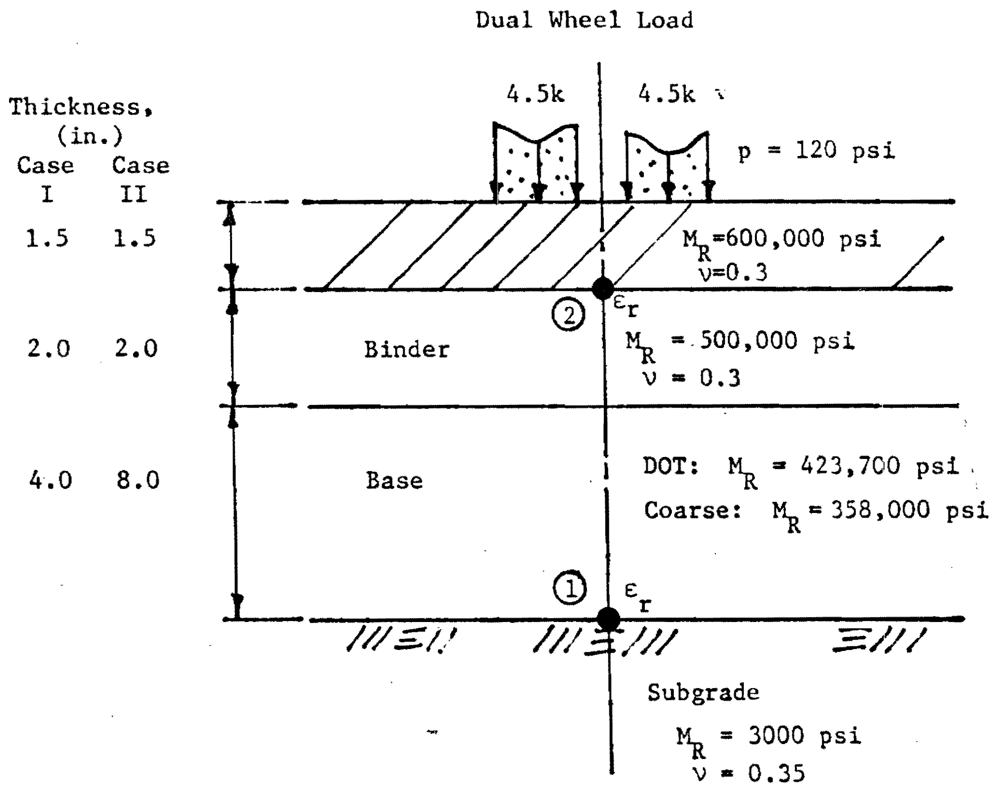


Figure 8. Summary of Material Characteristics Used in the Detailed Fatigue Analysis.

modulus of 3000 psi which is reasonable for a micaceous sandy silt subgrade. Typical asphalt concrete mix designs were used for both the standard and coarse bases. Mix design properties are summarized in Table 36.

Findings. The influence on pavement response of replacing a standard DOT base with a coarse base mix is summarized in Table 37. The influence of this change is negligible for the DOT surface E mix on both tensile strain and fatigue life. The tensile strain in the bottom of the coarse base, however, is increased by about 11 percent for both structural sections. This modest increase in tensile strain, however, causes a theoretical reduction in fatigue life of 33 to 38 percent.

Discussion. This detailed theoretical fatigue life study was partially based on resilient moduli of the asphalt concrete mixes obtained from diametral laboratory tests. These resilient moduli are significantly less than the dynamic modulus values predicted using the modified Asphalt Institute equations which are based on a cyclic triaxial compression test. The diametrical test subjects the specimen to a state of tension which accounts for the smaller moduli compared to the triaxial test. Finally, predicting the actual fatigue life of an asphalt concrete mix under service conditions is extremely difficult due to many factors including (1) traffic compaction effects, (2) environmental effects, and (3) the inability to accurately predict, by theory, tensile strain. As a result, fatigue life estimations should be considered as being only a general indication of actual field performance.

Table 36. Mix Design Data Used in Fatigue Analysis.

Property	DOT E Mix	DOT Base Mix	Rut Resistant Base
Asphalt Content (%)	5.4	4.7	4.2
Weight (pcf)	148.0	148.0	150.
VMA (%)	16.8	15.2	14.8
Absorption (%)	0.5	0.5	0.5
Air Voids (%)	4.2	4.4	4.5
R & B softening Point (°F)	122	122	122
Fatigue Constant (K)	46.06	46.06	46.06

Table 37. Comparison of Fatigue Predictions for Standard Georgia DOT Mix with Rut Resistant Mix - Rut Resistant Results Given in Parentheses.

Pavement Section	Surface			Base		
	ε_t (1)	N_f (2)	ΔN_f (%) (3)	ε_t	N_f	ΔN_f (%)
Thin Section (Case I)	152 (151)	9.01 (9.25)	+3	295 (328)	0.54 (0.36)	-33
Thick Section (Case II)	119 (120)	24.6 (23.7)	-4	144 (160)	7.79 (4.81)	-38

Notes:
1. Analytically calculated tensile strain in the bottom of the layer.
2. Predicted number of repetitions to failure - average of Nottingham and Asphalt Institute methods.
3. Change in fatigue life in going from a DOT base mix to rut resistant base mix (a negative number indicates a reduction in fatigue life).

GENERAL DISCUSSION

Asphalt Concrete Mix Design

The results of this study show that rutting in a standard Georgia DOT asphalt concrete base, B binder, and surface E mix can, on the average, be reduced by about 23, 14, and 13 percent, respectively by using a slightly coarser asphalt concrete mix. The observed beneficial effects of using a coarse mix, however, varies significantly with the type mix and quarry.

Some reduction in fatigue life of a coarse mix can generally be expected compared to the conventional Georgia DOT mixes. Considering all factors, the average reduction in fatigue life for the base, binder, and surface E mixes is hypothesized to be on the order of 22, 11, and 28 percent, respectively. The average reduction in fatigue life, similarly to reduction in rutting, varies greatly from mix to mix. An accurate estimate of the fatigue life of a mix in the field is not possible within the present state-of-the-art because of the complexity of the problem including densification under traffic compaction, hardening of the asphalt cement, and environmental effects.

Design Recommendation. The proposal is put forward to use the coarse mixes for only aggregate quarries where more than about 10 to 20 percent reduction in rutting is expected. This approach retains the generally higher fatigue life of the conventional DOT mix for cases where little or no reduction in rutting would be achieved by using a coarser mix.

Base Mixes

The most extensive laboratory rutting data is available for the base mixes studied from 20 quarries. Table 38 summarizes the performance of the coarse base mixes which showed the most reduction in rutting compared to the conventional DOT base mixes. Eight of the 20 mixes studied were given a Class I designation. A Class I mix is defined as one having a high reduction in rutting (an average of more than 29 percent for the base mixes), and a relatively low reduction in fatigue life (an average of only 8 percent reduction as determined by the direct method). Using a slightly coarser gradation for Class I base mixes should significantly reduce rutting while sacrificing very little in terms of fatigue life. The use of slightly coarser mixes for these quarries has a high potential for providing much better overall pavement performance with respect to rutting.

The 9 Class II quarries given in Table 38 all exhibit important reductions in rutting (an average of 25 percent) while also exhibiting a relatively high reduction in fatigue life (an average of 31 percent) as calculated by the direct method. For these mixes an important reduction in rutting can be achieved, but only with some sacrifice in fatigue life of the base.

B Binder Mixes

Table 39 summarizes the rutting and fatigue findings for the best 11 Class I and Class II coarse B binder mixes. Actually Table 39 compares the DOT base mixes, which simulate a coarser binder mix, with the conventional DOT binder mixes. The 4 Class 1 coarse binder mixes showed a 41 percent average reduction in rutting and only a 11 percent reduction in fatigue life. The 41 percent reduction in rutting is probably higher than would actually occur. The 7 Class II coarse binder mixes showed an average of 23 percent reduction in rutting while only an average of 14 percent reduction in fatigue life. All of the 11 Class I and II mixes could be used to reduce rutting.

Table 38. Coarse Base Mixes Showing Most Potential For Use Compared to Conventional DOT Base Mixes.

Quarry	Rutting Reduction (%)		Fatigue Life Reduction (%)
	Direct	Cumulative	
		CLASS I COARSE BASE	
White	-	45.4	12
Lithonia	43.2	23.5	13
Tyrone	22.6	22.6	13
Cumming	64	50.5	11
Dan	25	31.4	-13
Ruby	25.8	3.0	13
Average	36%	29%	8%
		CLASS II COARSE BASE	
Palmer	50	48.4	27
Buford	17.8	19.8	22
Dalton	21.1	24.7	40
Lithia Springs	-	43.2	36
Stockbridge	-	16.1	25
Norcross	-	19.0	40
Ball Ground	-	15.6	43
Mt. View	9.3	15	24
Postell	-	15.4	26
Average	25%	24%	31%

Table 39. Coarse Binder Mixes Showing the Most Potential For Use Compared to Conventional DOT Binder Mixes.

Quarry	Rutting Reduction (%) Direct	Rutting Reduction (%) Cumulative	Fatigue Life Reduction (%)
CLASS I COARSE BINDER MIXES			
Ballground	-	42.6	15
Candler	-	42.7	15
Postell	-	39.9	8
Kennesaw	-	~39	7
Average	-	41%	11%
CLASS II COARSE BINDER MIXES			
Lithonia	53.5	39.3	26
Tyrone	7.8	6.0	8
Buford	38.7	18.1	19
Cumming	9.4	31.6	20
Athens	5.3	7.0	18
Barin	-	21.7	4
Stockbridge	-	7.7	6
Average	23%	19%	14%
Combined Average	23%	27%	13%

E Surface Mixes

Five of the seven coarse surface mixes tested showed an average of 22 percent reduction in rutting (Table 40). The corresponding average reduction in theoretical fatigue life for these five mixes was 25 percent. Only the Palmer Station coarse E mix was a Class I type mix exhibiting a 33 percent reduction in rutting and only a 15 percent theoretical decrease in fatigue life. The Class II surface E mixes exhibited an average of 19 percent reduction in rutting and a corresponding 27 percent average reduction in theoretical fatigue life.

Target Aggregate Gradations

The target aggregate gradations used in the study are given in Table 41. The actual gradations achieved for specific quarries varied by ± 1 to 2 percent on some sieves. This variation in gradation was due to blending standard aggregate sizes, using the produced gradation for the specific quarry, to obtain a gradation very close to the target.

Extrapolation of Test Results

The Loaded Wheel Tester rutting results can be readily extrapolated to other quarries for the type mixes studied using the equations given in the previous section on statistical relations (refer, for example, to summary Table 30) Using this approach, rut depths for the conventional DOT mixes and the coarse mixes would both be calculated using the appropriate statistical equation. For coarse mixes showing important potential reductions in rutting, the fatigue lives of the conventional and coarse mixes could then be calculated to further aid in deciding if the coarse mix should be used. This approach requires measuring the pertinent aggregate and mix characteristics indicated in Table 30.

Table 40. Coarse E Surface Mixes.

Quarry	Rutting Reduction (%)		Fatigue Life Reduction (%)
	Direct	Cumulative	
	CLASS I COARSE E MIX		
Palmer Sta.	31.5	33.4	15
	CLASS II COARSE E MIX		
White	12.7	12.7	53
Kennesaw	17.3	-20	17
Lithonia	15.4	-1.4	24
Average	15	-	31

Table 41. Target Aggregate Gradations Used in Study.

Sieve Size	Percent Passing					
	Base		B Binder		Surface	
	Fine	Coarse	Fine	Coarse	Fine E	Fine F
1-1/2	100	100	-	-	-	-
1	85	85	100	96	100	-
3/4	76	75	87	82	100	-
1/2	64	60	73	73	88	100
3/8	57	54	66	65	75	90
4	43	39	52	47	51	60
8	33	30	40	36	38	45
16	25	21	30	28	29	29
30	18.5	15	23	22	21	22
50	14	11	17	18	14	15
100	10	8	13	11	9	12
200	7	6	8	6	6	7

Table 42. Simplified Model for Coarse Base Mix.

The regression equation is
Rutting = 2.60 + 0.00993 x Srv (pass. No.30/ret. No.40) + 0.111 x % AC
+ 0.0631 x % Air V. - 0.0206 x Mix Dens. in pcf - 0.0883 % VMA
+ 0.761 x bulk SG of fine aggregate +0.000480 x Stab. - 0.119 x Flow
- 0.00445 x Sta/Flow

19 cases used 2 cases contain missing values

Predictor	Coef	Stdev	t-ratio	p
Constant	2.5974	0.8550	3.04	0.014
Srv (40)	0.009935	0.0037	2.69	0.025
% AC	0.11057	0.0496	2.23	0.053
% Air V.	0.06315	0.0161	3.93	0.003
Mix Dens	-0.020561	0.0036	-5.64	0.000
% VMA	-0.08827	0.0274	-3.22	0.010
SG bulk	0.7607	0.1943	3.92	0.004
Stab.	0.00048	0.0002	2.64	0.027
Flow	-0.11872	0.0438	-2.71	0.024
Sta/Flow	-0.004450	0.0018	-2.43	0.038

s = 0.02591 R-sq = 87.7% R-sq(adj) = 75.4%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	9	0.0430854	0.0047873	7.13	0.004
Error	9	0.0060400	0.0006711		
Total	18	0.0491254			

SOURCE	DF	SEQ SS
Srv (40)	1	0.0079628
% AC	1	0.0002348
% Air V.	1	0.0063318
Mix Dens	1	0.0064494
% VMA	1	0.0024460
SG bulk	1	0.0119161
Stab.	1	0.0013770
Flow	1	0.0023888
Sta/Flow	1	0.0039788

SUMMARY

Using a coarse surface E, B binder, and base asphalt concrete mix for many quarries results in important reductions in rutting on the order of 15 to 30 percent. The fatigue life of these coarser asphalt concrete mixes, however, is reduced by slight to moderate levels. Therefore, the benefits derived from the reduction in rutting achieved by using a coarse mix is partly offset, to varying degrees, by a loss in fatigue life.

Physical aggregate characteristics were found to be just as important as the Marshall mix design characteristics. The most important aggregate properties include mica content, or the properties from the pouring test which are correlated to weighted mica content, as well as aggregate specific gravity. Also, aggregate top size is important for both the base and B binder mixes.

The statistical equations presented in this chapter can be used to estimate relative levels of rutting in asphalt concrete mixes using basic aggregate properties and Marshall mix design characteristics. The rutting equations presented in this chapter show for each mix which aggregate properties are most important.

Many interactions between variables can be seen by studying the statistical results developed by Siegel [11] as an overall part os this study. The approaches summarized in Appendix D are appropriate for estimating relative fatigue life of different mixes prepared from aggregate obtained from the same quarry.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The following conclusions are presented based on the results of this study:

1. Pouring Test. The pouring test described in Appendix B involves comparing the packing characteristics of spherical beads with those of aggregate particles. The pouring test does not require special equipment and is relatively easy to perform. Aggregate macro- and micro- surface properties obtained from the pouring test are statistically related to the rutting behavior of selected asphalt concrete mixes.

2. Free Mica Content Test. Reproducible techniques were developed for measuring the free mica content of fine aggregate. Free mica present in material passing the No. 50 sieve can be evaluated by the petrographic examination of sprinkle slides. Free mica in material passing the No. 16 sieve and retained on the No. 50 sieve can be evaluated using stereomicroscopic examination. The percent free mica obtained using these two methods of analysis is based on a particle count rather than weight. Weighted mica contents were determined for the fine aggregate portion of each asphalt concrete mix studied. Fine aggregate is defined as the material passing the No. 8 sieve.

3. Free Mica and Aggregate Surface Characteristics. Free mica content correlates reasonably well with selected aggregate

properties obtained from the pouring test. This finding suggests that the presence of mica influences the surface characteristics of aggregate particles.

4. Aggregate Shape, Surface Area, Roughness. Efficient techniques were developed for measuring the aggregate shape, surface area, and surface roughness. These techniques involved using a digitizer and microcomputer to collect data for individual aggregate particles. Even using a digitizer the measurement of aggregate shape and roughness characteristics are quite time consuming and require the use of a data acquisition system. The pouring test can be performed much more easily than aggregate shape, surface area, and surface roughness tests. The properties from the pouring tests also correlate well with rutting. As a result the pouring test is in general preferred over the shape, surface area, and surface roughness digitization techniques.

5. Rutting. Utilization of slightly coarser asphalt concrete mixes than presently used by the Georgia DOT show average reductions in rutting of 23, 14, and 13 percent for base, B binder, and surface E mixes, respectively. The percent reduction in rutting, however, varies significantly with the quarry. Theoretical mix fatigue life of a coarser mix is reduced on the average by 22, 11, and 28 percent for the base, B binder, and surface E mixes, respectively. Considering the variation in rut depth improvement and variable reduction in fatigue life, the selective use of

coarser gradation asphalt concrete mixes to reduce rutting appears to be the best approach.

RECOMMENDATIONS

The following recommendations are made based on the findings from this study:

1. Rutting. Consider the selective use of coarser base, B binder and E surface mixes for service conditions (environment, wheel loadings, etc.) where rutting is of concern. For well over half of the asphalt concrete mixes use of a coarser gradation has the potential for decreasing rutting by 20 to 30 percent or more. An alternative for at least the base mixes would be to use the coarse mix developed in this study for all mixes. Selection of this alternative should result in an average reduction in rutting of slightly more than 20 percent.

   Extend the results of this study to other important quarries used by the Georgia DOT. Either additional Loaded Wheel Tests or the statistical equations developed in this study can be used to accomplish this recommendation.

2. Measurement of Free Mica. Use of the microscopic techniques developed in this study is recommended as standard techniques for measuring free mica content in aggregate. A weighted free mica content based on the gradation of the fine particle sizes (material passing the No. 8 sieve) can be used for many applications. Support for the use of the proposed microscopic techniques is provided by the frequent good correlation of mica content with observed rutting in the Loaded Wheel Test.

3. Pouring Test. The use of the pouring test should be further investigated as a standard laboratory technique for evaluating aggregate surface characteristics. The surface characteristics obtained from the pouring test together with Marshall mix design characteristics can be employed for many mixes to estimate potential relative rut depth.

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Appendix A

MEASUREMENT OF PARTICLE, SHAPE, SURFACE AREA, AND SURFACE ROUGHNESS

by

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MEASUREMENT OF AGGREGATE SHAPE, SURFACE AREA AND ROUGHNESS

INTRODUCTION

Asphalt mix designs are based on many factors including the type and amount of asphalt, air voids, aggregate characteristics, aggregate gradation and mineral filler. To investigate the effects of aggregate characteristics, which are usually not fully considered, the Georgia DOT initiated, through the Georgia Institute of Technology, a comprehensive research program. In the final phase of the study, the effects of these variables will be evaluated on the rutting performance of Georgia DOT asphalt mix designs. This paper describes the measurement of aggregate shape, surface area and roughness using modern digitizing techniques taking advantage of a micro-computer.

PARTICLE SHAPE

Introduction

The shape of the aggregate influences the gradation curve obtained by sieving [1][1]. Flaky particles tend to pass sieves having square holes diagonally. Also, the shape of the particle has a significant influence on the volume of particles retained on a specific sieve. For material retained on a given sieve size, Lees [1] has shown that rod-shaped particles are about 2.5 times the size of disc-shaped particles. These differences in size affect the ability of the particles to properly fill voids of coarser size aggregate.

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[1]The numbers in brackets refer to the references given in the reference section of the main report.

Simple Classification Systems

The shape of fine and coarse aggregate particles can be divided into the following four general shape categories [1]: (1) Flaky, (2) Cuboidal, (3) Blade, and (4) Rod. British Standard BS 812 [15] separates the aggregate into the four rather broad categories given above. The method does not, however, define their exact location within each category. A special, simple gauge is used to measure the two indices required for shape classification.

ASTM [16] and the Corps of Engineers [17] also have a test method similar to BS 812 for evaluating flat and elongated coarse particles in aggregates to be used in concrete. These methods employ a specially designed caliper to determine particle shape ratios. Measurements are performed by hand to determine if particles have a certain length to thickness and width to thickness ratio; specific particle dimensions are not measured. Although simple, these methods are just classification schemes and do not permit determination of surface area. Different ratios separating aggregate classes have been proposed to describe an aggregate particle [18].

The four broad categories defined by these methods allow for quite a large range of particle shape characteristics within each classification. For research purposes these methods might give misleading results, affecting aggregate performance. Also, these classification tests are not suitable for measuring the shape of particles much finer than about the No. 12 sieve and surface area cannot be determined using the results. Classification systems which use just one aspect ratio are not suitable to define particle shape.

Generalized Classification Systems

Both fine and coarse aggregate particle shape can be determined by measuring the Flatness Ratio and Elongation Ratio [1]. The Flatness Ratio (p) is the ratio of the shortest length (c) divided by the intermediate length (b), and the Elongation Ratio (q) is the ratio of intermediate length (b) divided by the greatest length (a). By determining the actual Flatness and Elongation Ratios, a continuously varying classification can be developed. This approach also permits defining a Shape Factor $F = p/q$ and Sphericity ψ. Sphericity ψ is the ratio of surface area of a sphere of the same volume as the particle divided by the surface area of the particle [1]. The proposed method is considerably more flexible for research purposes than the Corps or British classification schemes. The British and Corps classifications can be quickly obtained from the more general Flatness and Elongation Ratio method described by Lees.

Also, the surface area and sphericity of the aggregate can be determined using the more general shape classification method. The generalized shape classification concept is a method of tridimensional shape analysis where each grain is approximated by a tetrakaidekahedron [15,19]. Three mutually perpendicular particle dimensions (length, width, and thickness) are measured and used to calculate the ratio of surface area of the particle compared to that of an equivalent sphere, or else surface area is directly calculated.

Particle Shape Using a Digitizer

For shape classification, the aggregates studied in this investigation were divided by sieving into the following 4 size ranges:

1/2 in. to 3/8 in., No. 4 to No. 8, No. 8 to No. 120, and smaller than the No. 120 sieve. These size ranges were selected by a panel of engineers as being appropriate. For the two larger size aggregate ranges (the 1/2 in. to 3/8 in. and No. 4 to No. 8 sizes), an aggregate sample consisted of 150 particles of each size, with the number of particles being counted visually. In the smaller size ranges, micro-photographs and special techniques were used to measure the aggregate shape. The number of particles in each sample of smaller size particles varied from 50 to 150, based on the number of particles captured in each photograph. At least three different samples were measured for each aggregate type This approach resulted in the use of a minimum of 450 particles for each of the coarser two sizes studied and a minimum of 150 particles for each of the finer two particle sizes studied; usually 250 or more particles were included. The use of more than 150 particles is desirable but was too expensive to achieve in all cases for the microscopic size particles.

Aggregate shape was determined and numerous plots and tables produced without a human hand ever working with the data. The procedure developed for particle analysis is completely automated and uses a relatively inexpensive digitizer which automatically feeds data into an IBM-XT micro-computer.

Aggregate Greater Than No. 8 in Size

For the aggregate greater in size than the No. 8 sieve, photocopies were made of the flattest profile of the particles. A Savin 7350 copying machine was used to provide an image of 50 particles at a time which were placed in a small box. The box had a clear plastic bottom and dividers so as to give 5 rows of 10 aggregates each. The copy machine was found to not distort the photocopied image of the aggregate. By providing a profile view of the aggregates, the length and width were easily digitized directly from the photocopy using a Penpad digitizing tablet manufactured by Pencept, Inc. The digitizer has an accuracy of 0.0015 in. which is quite sufficient, particularly considering the relatively large observed variation in aggregate shape and dimensions. The length was digitized as the longest dimension of the aggregate, and the width as the average dimension, in the plane of the photocopied image, perpendicular to the length. The coordinates (x,y) of each point representing one end of a dimension were digitized, and the actual dimension was later calculated. If the original ordering of length, width, and thickness was not correct, a computer program later automatically reordered the dimensions correctly.

Shadows were created when trying to photocopy the profile of the aggregate to measure its thickness. Therefore aggregate thickness was not digitized directly from a photocopy. Instead, vernier calipers were used to measure the average thickness directly from the aggregate. The calipers, open to the proper width, were then laid on the digitizing pad and the tips of the calipers, representing thickness of the aggregate, were digitized. A pen type digitizer, as opposed to one with cross-hairs, was used which made possible digitizing the vernier caliper measurements.

This method of measuring the dimensions proved to be very efficient. With experience, an operator can digitize the three dimensions of 150 aggregates in approximately 30 to 45 minutes. After digitizing the three perpendicular dimensions for all aggregates, the data are saved as an AUTOCAD DXF file in ASCII code.

Aggregate Smaller Than No. 8 in Size

Aggregates less than the No. 8 sieve in size require the use of specially prepared optical microphotographs. Similar to the large aggregate, aggregate length was digitized directly from the photograph as the longest dimension and the width as the average dimension, in the plane of the photograph, perpendicular to the length.

Since these particles are very small, the height cannot be measured directly using calipers. Therefore, a special technique was used relating a shadow length on the photograph to particle height. As the particles were prepared for the microscope, uniform reference spheres were added to establish the scale for vertical height. A thin film of metal was evaporated onto the surface at an angle to the substrate on which the particles set to create a shadow [16]. Since the evaporation source is a relatively long distance away, the angles at which it strikes the particles and reference spheres are approximately equal. Therefore, by geometry, a unique ratio exists between the shadow lengths of the reference spheres and the aggregate particles and their heights. A special technique, described subsequently, was used to capture the shadow on the photograph.

Similar to the large aggregate, all digitized dimensions were saved as an AUTOCAD DXF file in ASCII code. A set of microphotograph data can be digitized in 25 to 50 minutes depending on the number of aggregates in a sample.

Manipulation of Data Using AUTOCAD and Lotus 1-2-3

After digitization, all dimensions were stored in an AUTOCAD DXF file. An AUTOCAD DXF file contains all the formatting, scaling, size and other information that AUTOCAD uses when displaying and working with a drawing. A BASIC program called DFXTRACT was used to remove all the unwanted formatting information and extract only the coordinates of the ends of lines defining the dimensions of the aggregates. This program then saved the data in a form that Lotus 1-2-3, or other spreadsheets, was able to readily use.

Once the endpoints of the lines representing the dimensions of the aggregates were extracted and stored in the Lotus 1-2-3 PRN file, the PRN file was imported into a Lotus 1-2-3 worksheet using the Lotus 1-2-3 import command. The lengths of the dimensions were then calculated using the coordinates of the end points and stored in a 1-2-3 worksheet file named WK1.

The conversion of endpoints to lengths defining the dimensions of the aggregate can be performed faster using BASIC as a part of the DFXTRACT program. Using the BASIC program requires about 30 sec. on an IBM-XT computer compared to 3 min. for the Lotus 1-2-3 macro. However, errors are sometimes made using the digitizer and AUTOCAD, such as adding a stray line or an extra point. The Lotus 1-2-3 worksheet approach allows examination of the data and in most cases the error can be corrected even after general processing of the data has been finished. A BASIC program would probably blow up or give useless results in the same situation. Typical results illustrating how the resulting shape measurement data can be readily presented using a spreadsheet are given in Figures A-1 and A-2.

Techniques for Three-Dimensional Measurements of Very Fine Aggregate Samples

The fine aggregate samples studied (smaller than the No. 8 sieve in size) have a broad size range which requires the use of both low and

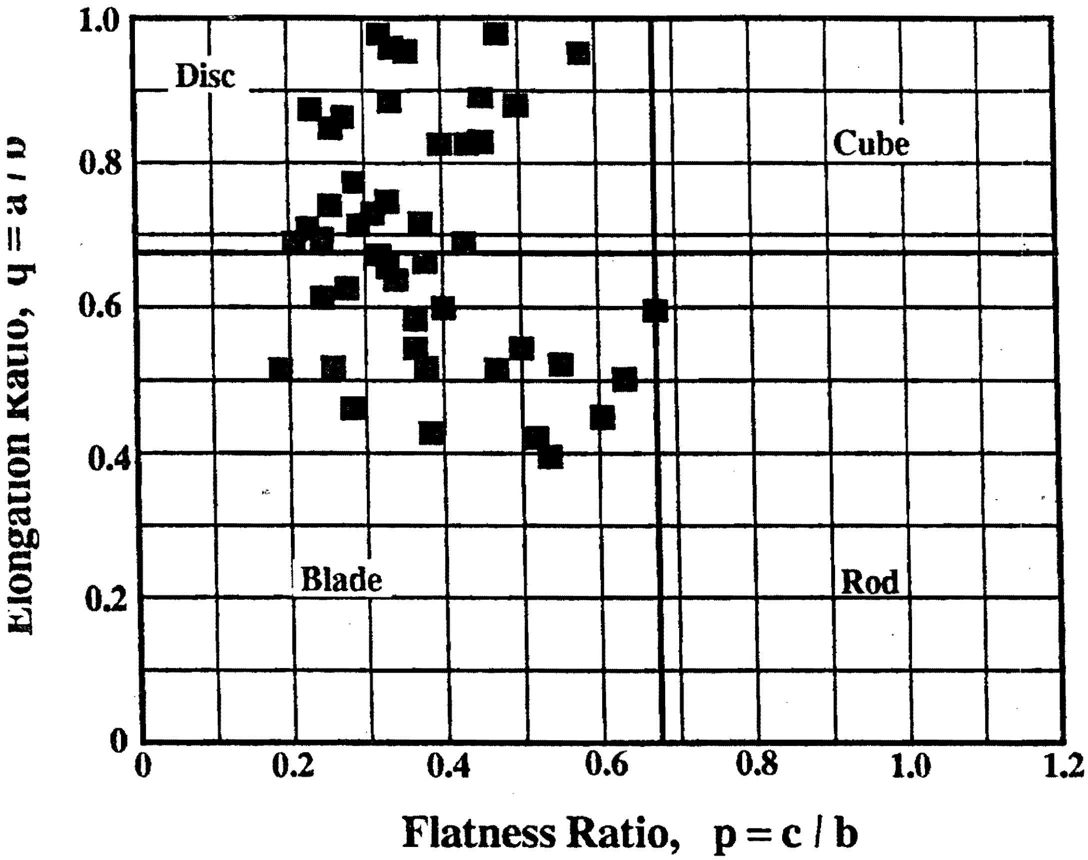

Figure A-1. Typical Shape Classification Scatter Diagram for a Selected Georgia Specimen.

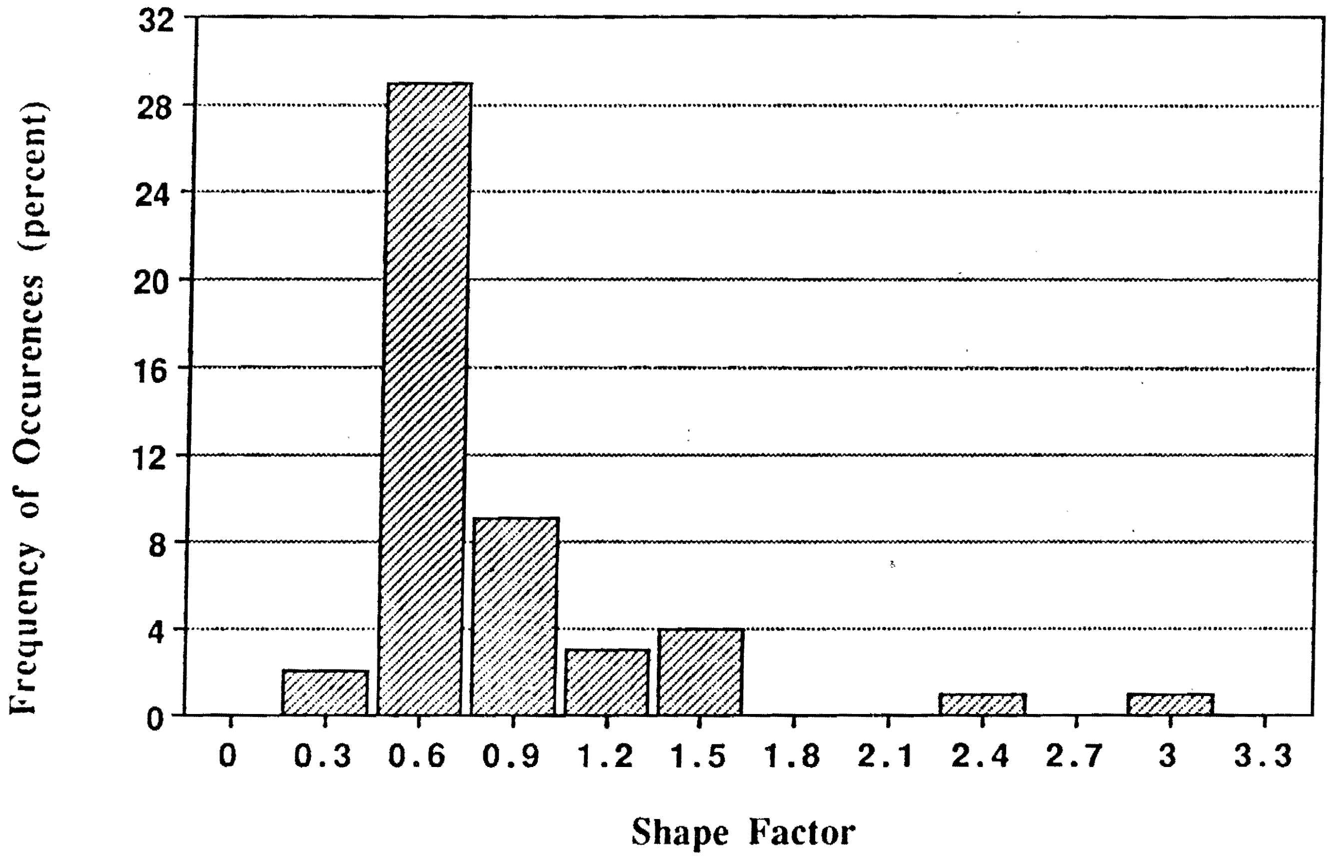

Figure A-2. Typical Shape Factor Histogram for a Selected Georgia Aggregate.

high magnification techniques which cannot be accomplished using one instrument. As a result, aggregate varying in size from the No. 8 to No. 120 sieve were treated differently than aggregate smaller than the 120 sieve. The larger fraction particle size (No. 8 to 120 sieve size) is great enough to present difficulties in direct optical measurements and especially in macro photography due to the very limited depth of field of optical techniques. If measurement of the thickness of these particles is required, a unique sample preparation problem exists.

Large Fraction - No. 8 to No. 120 Sieve Size Particles

Sample Dispersion. The solution for measuring aggregate shape of small particles is not to look at the particles themselves but to create flat silhouette representations of the particles from which measurements can be taken. If a shadow is added to the silhouette directly related to the particles' height, the three dimensions of length, width and height can easily be measured in one flat plane. The technique of vacuum evaporation of thin metal films, such as used in the preparation of samples for transmission electron microscopy (TEM), was used to prepare these flat, two dimensional representations of three dimensional samples [20]. To prepare fine aggregates so that silhouettes were obtained, aluminum was used instead of platinum which is employed in TEM preparation because of its ease of evaporation.

First, a glass microscope slide was cleaned with soap and water to insure good adherence of the evaporated film. A good dispersion of the sample particles was placed on this slide. Care was exercised to insure that the particle spacing was sufficient to allow for a shadow between the particles, and that the dispersion was representative of the true size distribution. Obtaining good sample dispersion is perhaps the hardest but most important part of the sample preparation. A wide variety of dispersion techniques can be used depending on the nature of the particulate material being studied.

For the particles used in this study, the dispersion was prepared in the following manner. Each sample was placed in a plastic bag. The sample was then mixed by shaking the bag back and forth while turning it [21]. Shaking was carried out for a sufficiently long period of time to thoroughly mix the sample. A number of small subsamples were taken from different areas of the bag and mixed to further insure a representative sample. Because the mica consisted of relatively large flakes, an anti-static spray was not required to prevent sticking of these particles to the sides of the bag. A number of cleaned glass slides were placed on a flat surface and the extracted sample allowed to drop onto the slides from a height of about 1 ft. This was performed in an area which had no air movement. A small quantity of uniform glass spheres was also dropped onto the slides. The size of the spheres was later determined by measuring their diameter on the photograph and calculating the size knowing the scale of the photograph. One of the slides which visually appeared to have the best dispersion was selected for further processing.

Evaporation of Aluminum. The slide having the best dispersion of particles was placed in a vacuum evaporation unit in which two filaments had been set up for evaporation of aluminum. One filament was located directly above the slide while the other was placed off to the side at an angle of about 30° to the slide surface. The unit was evacuated to a pressure of at least 10^{-4} mm of mercury and the aluminum evaporated. The proper amount of aluminum evaporated was determined experimentally to give the best contrast for both shadow and silhouette. For a single particle, two areas are present on the slide which may be coated by only one layer of aluminum, the shadow area and an area opposite the shadow if the particle is not square with the surface.

The slide is removed from the coating unit, and the particles are then removed from the slide by blowing them off with air. If the fine particles resist removal by blowing, the slide is placed in a beaker of water containing a small amount of wetting agent and then treated in an ultrasonic bath for a few seconds.

<u>Fine Fraction Smaller Than No. 120 Sieve</u>

Particle size measurements of the fine fraction less than the No. 120 sieve in size were made from micrographs taken using the scanning electron microscope (SEM). The particles were dispersed on a plastic substrate and the preparation coated with carbon by evaporation to prevent charging the SEM. The dispersion was then shadowed with aluminum as previously described. The particles were left in place on the slide since depth of field is not a problem in the SEM. The micrographs were taken using the backscatter signal which is very sensitive to elemental differences. Good contrast was obtained using this technique between the particle, shadow and background. Uniform glass or latex spheres were included in the dispersion for shadow/thickness determinations.

<u>Estimation of Particle Thickness</u>

After following the previously given procedures for sample preparation, all of the particle information is now represented in the single plane of the slide which can be photographed at any magnification or viewed on a projection screen where direct measurements can be made. Figure A-3 is a drawing of the shadowed silhouette of a single particle where A is the particle length, B the width, and C the shadow length. The shadow length of the spheres can be used to convert shadow length to thickness using the formula:

$$T = Sh_p \{\tan[2(\arctan r_{ap}/(Sh_{ap} + r_{ap}))]\} \qquad (A\text{-}1)$$

where:

T	=	particle thickness
Sh_p	=	particle shadow length
r_{ap}	=	sphere radius
Sh_{ap}	=	sphere shadow length.

For low shadowing angles the simpler formula

$$T = Sh_p \ (2r_{ap}/)Sh_{ap} + r_{ap})) \qquad (A\text{-}2)$$

can be used as a close approximation.

SURFACE AREA

Introduction

The surface area of the aggregate for a given quantity of asphalt has a significant effect on the asphalt film thickness and as a result can influence mix performance. Surface area can be determined by a number of methods including the (1) tridimensional approximation described by Aschenbrenner [19], (2) quantitative stereology [22], (3) surface coatings including wax and paint [22], (4) air and mercury permeability [23], and (5) Gas adsorption. The tridimensional method described by Aschenbrenner [19] has been previously summarized. In addition to this approach, the quantitative stereology and perhaps the gas (usually nitrogen) adsorption methods appear at this time to

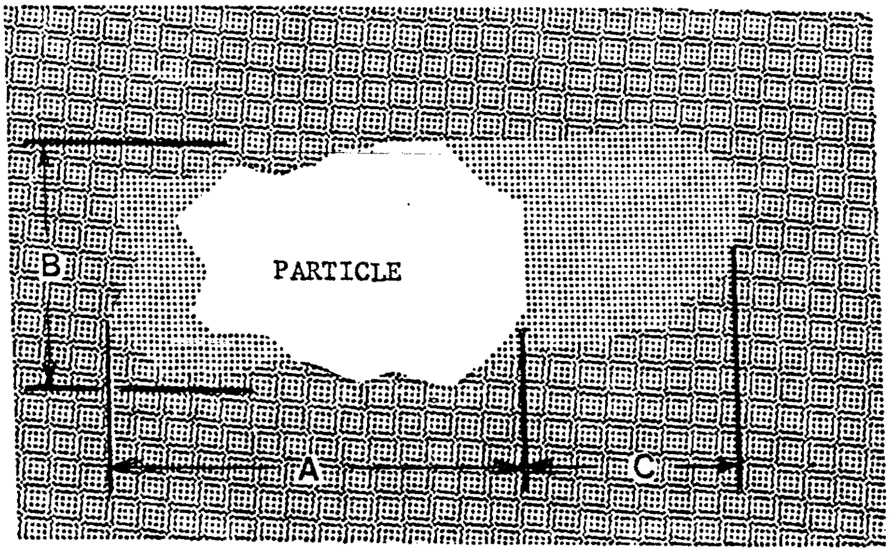

Figure A-3. Optical Presentation of Coated and Shadowed Slide with Particle Removed.

probably offer the best techniques for determining surface area. The gas adsorption method, however, indirectly measures the external surface area of the particle and also any pores greater in size than about 4A. This method requires several ideal assumptions to calculate surface area using thermodynamic principles.

Quantitative Stereology

Fundamentals

An interesting method for measuring surface area of aggregates is by using quantitative stereology [22]. Quantitative stereology is a direct measurement method and consists of preparing a random sample of N number of aggregates placed in a container of known volume. The aggregates are encased in a cementing agent such as an epoxy to form a solid block. The solid block is then sawed into several random pieces with the cuts oriented in different directions. A number of circles of radius R are inscribed on each saw cut surface, and the number of times (P) each circle intersects an aggregate boundary is counted. Now let P_L equal

$$P_L = P/2\pi R \qquad \text{(A-3)}$$

where R is the radius of the circle and P is the number of intersections. Next calculate the average value of P_L (i.e., $\overline{P}_L$) for all the circles drawn on all sections. The average surface area S of the particles inside the block of aggregate is then equal to

$$S = 2\,\overline{P}_L\,V_o/N \qquad \text{(A-4)}$$

where: S = surface area

$\overline{P}_L$ = average number of particle intersections per circle

V_o = volume of the sample

N = total number of particles in the sample

The above quantitative stereology approach makes no geometric assumptions concerning aggregate shape [22]. This method is statistically exact provided a sufficient number of measurements are performed. However, the sample must be statistically representative of the aggregate and a sufficient number of circles must be drawn on the cut faces. The best results are obtained if the particles are randomly positioned in the container, with the distribution being homogeneous. If a random distribution does not exist, more sampling planes cut through the block of aggregates at different angles are required and/or more sampling circles must be drawn on the cut faces. Even if the aggregates are not randomly oriented, the correct surface area can be obtained if a sufficient number of circles and sections are used together with a sufficiently large number of particles.

Sample Preparation

The procedure used for the quantitative stereology method is considerably more labor intensive than the computer method used to obtain aggregate shape and surface area. Approximately 500 aggregates from the 1/2 in. to 3/8 in. sieve size were counted for each sample from each of the seven selected quarries for which surface area was measured using this technique. Of these 500 aggregates, 100 were digitized in this study into the computer for analysis by the Aschenbrenner method to compare results. After digitizing was complete, these 100 aggregates were combined with the remaining 400 particles and later placed in a cylinder.

A two part epoxy glue, which was quick drying and strong, was used to bind the aggregates together. Plastic cylinders 5.25 in. high and 3 in. in diameter were used as molds. This size is convenient to work with and handle, and provides a sufficient volume to produce a representative sample of the size of aggregate studied.

After mixing, a small amount of epoxy was poured into the bottom of the mold. Several aggregates were then dropped into the mold. The mold was tapped for several minutes with a metal rod to move the aggregates into a dense packing and to drive any air bubbles present to the surface. When most of the air bubbles were out, more epoxy and more aggregates were added and tapping repeated. This preparation cycle was continued until all the aggregates were placed in the mold. Extra epoxy was also added to top off the mold and to act as a handle to hold the sample when it was cut. The mold was then placed in a warm location and allowed to harden for approximately 24 hours.

The mold was stripped away from the sample after hardening. The sample was then labeled with a permanent marker. Measurements were then taken of the height of the aggregate-epoxy specimen; the total height of the epoxy cylinder was not measured since the volume of actual aggregate is used in the formulas for calculating surface area. Next, the lower portion of the epoxy-aggregate sample from the bottom up was cut into disks approximately 1/2 to 1 in. thick. The remaining cylindrical-shaped sample was split down the center, forming two long, semi-circular sections. One side of each of the three disks and one of the flat semi-circular sides was photocopied. The data were taken from the photocopies and reduced to preserve the integrity of the original samples.

Measurements

Five circles were drawn on each cross section that was photocopied. The long flat side of the semi-circular section had twelve circles drawn on it. The number of intersections each circle made with the edges of aggregates was recorded. This large number of circles, 27 in all, was used to achieve a representative sample of the aggregates. The number of intersections per circle was then averaged and entered into equations (A-3) and (A-4) to calculate the surface area. The epoxy cylinder radius, volume of epoxy cylinder containing aggregate, and the total number of aggregates in the sample are also required. Either 3 or 5 aggregate filled specimens were studied from each quarry.

Comparison of Results

Table A-13 compares the results of the quantitative stereology method for evaluating surface area with the one described Aschenbrenner. For the stereology technique, the average standard deviation of the aggregate from the seven granite quarries included in this portion of the study is 0.030 in^2, which is 4.3% of the average measured value of 0.700 in^2 per aggregate. For the Aschenbrenner approach, the average standard deviation is 0.050 in^2 which is 6.7 percent of the average measured value of 0.749 in^2 per aggregate. The percent differences in average results vary for individual quarries from -10.7 percent to +9.2 percent. The algebraic average difference in surface area between the two methods for the 7 quarries is 2.2 percent. These results appear to indicate that the Aschenbrenner model is probably sufficiently accurate for at least most purposes, particularly considering its simplicity.

Table A-1. Comparison of Surface Area by Quantitative Stereology and Computer Surface Area Analysis - Selected Quarries.

Quarry	Sample	Aggregate Type	SA by Stereology (1) (in.^{2})	Mean	Std. Deviation	SA by Computer (1) (in.^{2})	Mean	Std. Deviation
Dixie Sand	CA1	Alluvial	0.636					
Chatt., TN	CA2	Alluvial	0.641	0.636	0.005	0.580	0.580	-
	CA3	Alluvial	0.632					
Florida Rock	EA1-1	Granite	0.767			0.752		
Mt. View, GA	EA1-2	Granite				0.715		
	EA2	Granite	0.843	0.816	0.042	0.733	0.738	0.015
	EA3-1	Granite	0.837			0.747		
	EA3-2	Granite				0.745		
Florida Rock	GA1-1	Granite	0.713			0.891		
Tyrone, GA	GA1-2	Granite				0.833		
	GA2	Granite	0.801	0.767	0.048	0.841	0.850	0.025
	GA3-1	Granite	0.788			0.830		
	GA3-2	Granite				0.853		
GA. Marble	IA1	Granite	0.809			0.823		
Buford, GA	IA2	Granite	0.827	0.821	0.010	0.747	0.759	0.059
	IA3	Granite	0.827			0.707		
GA. Marble	JA1	Granite	0.677			0.700		
Cumming, GA	JA2	Granite	0.737	0.733	0.054	0.935	0.762	0.152
	JA3	Granite	0.784			0.651		
Vulcan Materials	RA1	Granite	0.815			0.763		
Kennesaw, GA	RA2	Granite	0.774	0.813	0.038	0.825	0.789	0.032
	RA3	Granite	0.849			0.780		
Vulcan Materials	UA1	Granite	0.759			0.770		
	UA2	Granite	0.781	0.774	0.013	0.742	0.763	0.019
	UA3	Granite	0.782			0.777		

Note 1: The surface area (SA) is given for one aggregate.

SURFACE ROUGHNESS MEASUREMENT

Definition of Surface Roughness

Quantifying surface roughness is not easy, particularly for aggregates which have curved surfaces. Further, the value of surface roughness is dependent upon the magnification at which roughness is examined. Numerous definitions of surface roughness have been proposed [24,25,26]. For this study the definition developed for surface roughness (R) is as follows:

$$R = L_T/L_p \qquad \text{(A-5)}$$

where:

- L_T = true length of the segment of surface being analyzed
- L_p = length of the line of best fit for the segment of surface

This definition, which is slightly different than used for flat surfaces, was developed because using the line of best fit appears to contribute to the reduction of error caused by the curvature of an aggregate. Coupling this definition with evaluating small sections of the particle, the problems caused by curvature are minimized.

Methods of Measuring Surface Roughness

Most work in measuring microtexture has involved the roughness of flat metal surfaces. Techniques for measuring surface roughness of aggregates include [24,25]:

1. Stylus. A pen stylus is drawn over the aggregate surface. Optical, mechanical or electronic magnification is usually employed to enhance the profile and process the results.

2. <u>Cut Section</u>. The cut profile surface can be measured of an aggregate(s) embedded in an epoxy. The block of epoxy and aggregate is cut, polished and photographed at the desired level of magnification such as 15 to 125X. The surface profile is then directly measured by automatic measuring techniques.

3. <u>Casting</u>. A casting of the surface is made. The magnified image of the casting is then examined to determine the profile.

4. <u>Oblique Lighting</u>. Illuminating the surface by oblique lighting produces a shadow. A projection microscope is used to observe the shadow.

Stylus type equipment, which appears at first to be ideal, is made to measure surface roughness along a flat surface; deviation from this plane can cause measurement errors and even instrument damage. Also, a stylus-type instrument cannot follow indentations less than the radius of the stylus and cannot measure roughness where overhangs occur. Flat surfaces on an aggregate particle where measurement is possible is often limited.

Roughness Measurement

The cut section method, previously described, was used to measure surface roughness. Data were collected automatically with the same Pencept PenPad and IBM-XT computer that was employed to measure aggregate shape and surface area.

<u>Specimen Preparation</u>

A representative, random sample of thirty aggregate particles was taken from each source. The aggregate sample was then placed in a small plastic cylinder 6 in. high and 1-1/2 in. in diameter. A two part epoxy was used to bind the aggregate together within the cylinders. Magnolia Plastics Epoxy Compound 2014 and Curing Agent 346 were chosen because of their ability to hold the aggregate particles in place while cutting, good polishing characteristics, and the ability to harden within 24 hours.

Thirty particles 3/8 to 1/2 in. in size were dropped one at a time into the cylinder which was one-half full of epoxy. This technique was found to allow settlement of the particles to the bottom minimizing the number of air bubbles trapped during particle placement in the cylinder. No tapping of the cylinder was needed because the samples were small. After curing for 24 hours in a warm location, two to three rock saw cuts across the diameter were performed on each cylinder giving three or four cut aggregate surfaces suitable for measuring roughness on.

Surface Polishing

Number 120, 300 and 600 polishing grits were used to obtain a smooth aggregate surface and sharp contrast between the aggregate surface profile and epoxy. The No. 120 coarse grit was used to take out most of the unevenness due to the saw cut; at the same time it placed small grooves in the sample. The No. 300 grit was used to polish out the grooves placed by the coarse No. 120 grit. Finally, the No. 600 grit polished out any remaining tiny marks or grooves to provide a smooth, finished surface. The sample was polished a minimum of 5 minutes with each grit. The samples were washed between grit changes to prevent any contamination of the finer grit with the coarser ones.

Surface Photography

A photograph of the aggregate surface gives the surface profile in a form suitable to digitize. A scale was also photographed to accurately quantify the level of magnification used. For the purposes of this study, a magnification of approximately 20X was selected for the photo micrograph as being suitable to define the surface roughness characteristics (Figure A-4). The photographs were later blown up 50 percent using a photocopier. This procedure gave a 30X magnification of the surface while resulting in significant savings on printing costs compared with blowing the negative up to 30X during printing.

The use of other magnification levels of the surface would be expected to give different values of surface roughness. Wright, for example, suggested using 125X which perhaps is too much magnification to evaluate surface roughness of the gross surface. The appropriate value of magnification to use certainly deserves further study.

Kodak PX-125 black and white film was used for the photographs. Three aggregate particles from each quarry were evaluated for surface roughness. Pictures were taken of two different locations on the surface of each of the three particles, resulting in six photographs per quarry. In determining surface roughness, each photograph was broken into three smaller segments to minimize the curvature effects of the aggregates. This procedure resulted in 18 values of surface roughness from each quarry.

Digitization

A similar scheme of manipulating the data as employed for shape analysis was also used for roughness. A macro within LOTUS arranged the digitized points, calculated the true length of the digitized surface,

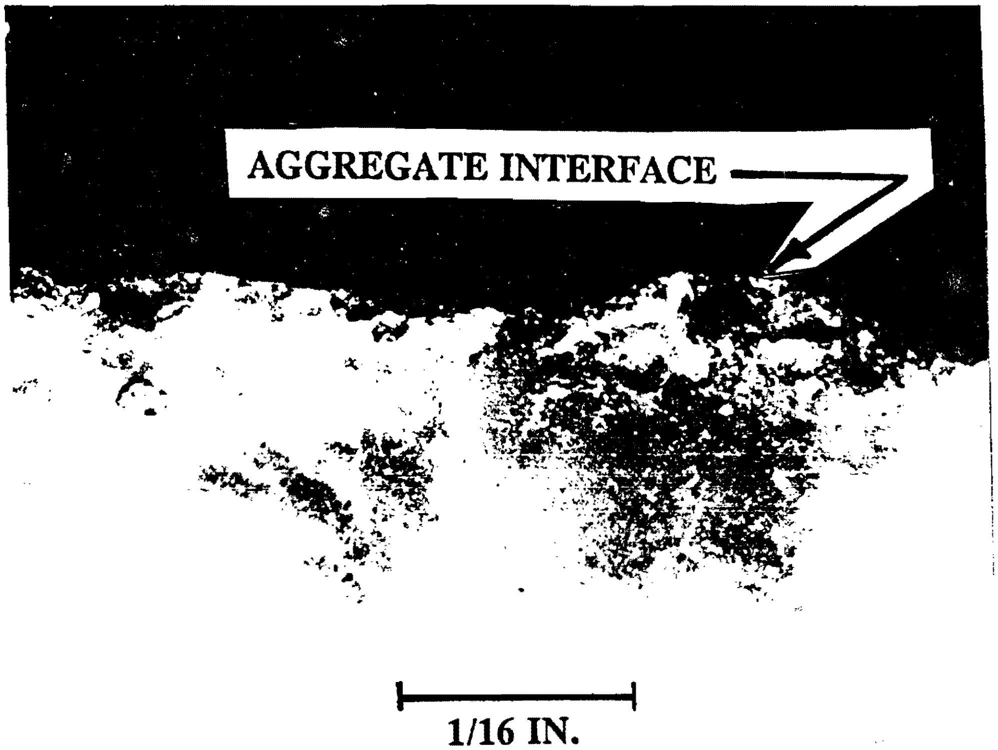

Figure A-4. Photograph of Polished Aggregate at Surface After 20X Magnification.

and calculated the line of best fit of the data. The macro also adjusted the length for magnification, calculated the surface roughness, and then created a graph of the real surface and the line of best fit or projected surface. Both the graph and the worksheet were saved on disk.

Calibration of Digitization Procedure

Several calibrations were performed to find any errors, problems, or limitations of the overall digitization methodology used to evaluate surface roughness. Calibrations were performed by simply comparing measured surface roughness with calculated surface roughness of surfaces having a simple, easily defined shape. The first surface used consisted of two semi-circles connected together as shown in Figure A-5. For all calibrations, points on the surface were digitized at distances on the photograph varying from 0.01 to 0.1 in.

Figure A-5 shows that an optimum spacing of digitized points of about 0.05 in. exists, which gives the minimum error for a surface consisting of two semi-circles. A closer spacing of digitization points, which intuitively would be thought to be more accurate, was actually found to be less desirable. The loss in accuracy was apparently due to very small levels of shaking of the hand (referred to as hand vibrations). A saw-tooth shaped surface was also used for calibration. The optimum digitization spacing was found to be 0.04 in. which was close to that found for the circular surface.

The calibration studies showed that a digitization increment of 0.05 in. gives good results. An average correction factor of +2.0 percent was used to correct calculated surface roughness to increase the accuracy based on the calibration studies.

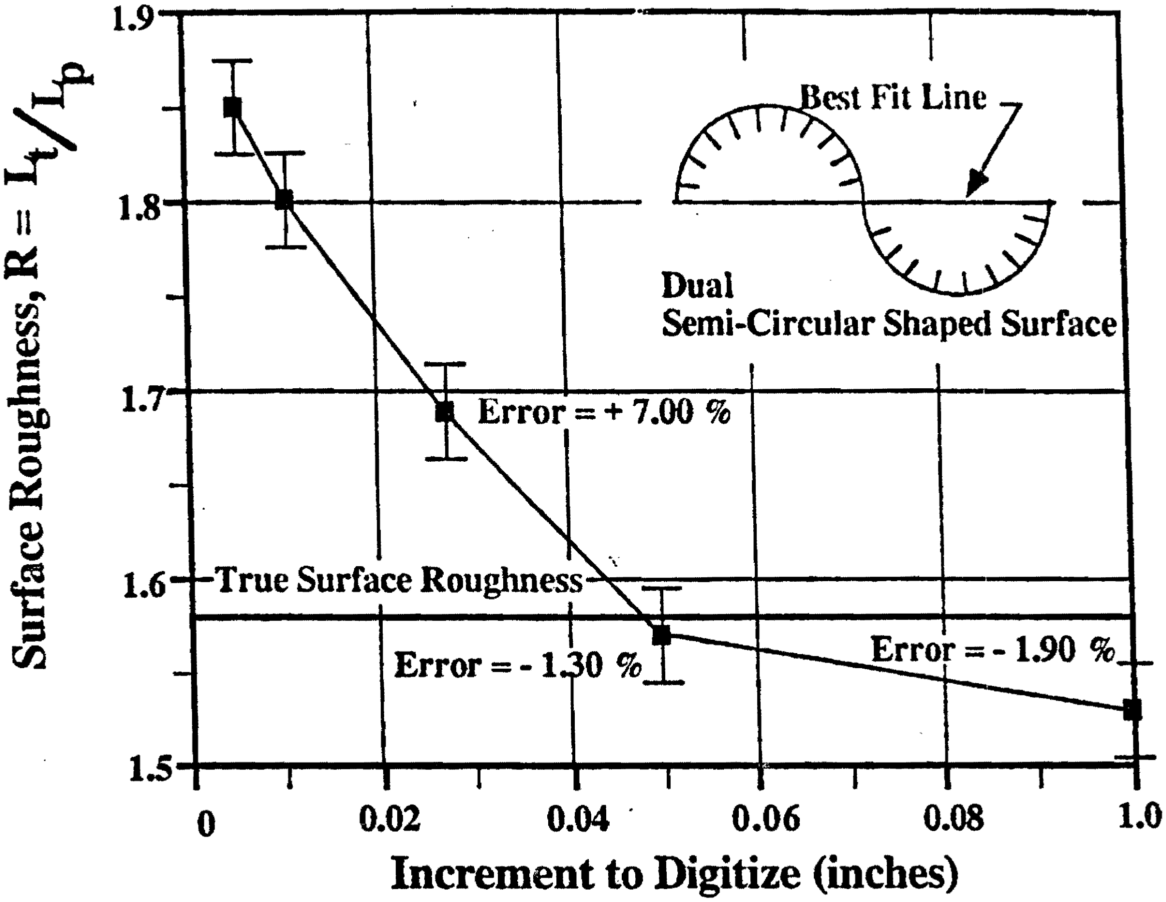

Figure A-5. Calibration of Surface Roughness Digitization Using a Sine Wave Surface.

Reproducibility of roughness measurements on aggregate surfaces obtained by a single experienced operator was found to be good. In comparing the results from three digitizer operations, only one having a high level of experience, the standard deviation of roughness was found to be 0.023 for three quarries in a supplementary study. This study indicated that the operator should become experienced using the digitizer on reference surfaces such as shown in Figure A-5.

Results

As shown in Table A-2 and in another study found by Wright [25], surface roughness varies greatly both over the surface of a single particle and from one particle to another for the same quarry. Therefore, only general trends of surface roughness should be considered and as many measurements as practical performed. Observed variations in surface roughness were as follows: 1.16 to 1.26 for 15 granite gneiss quarries; 1.13 to 1.15 for 3 limestone quarries; 1.16 for an injection quartz; and 1.13 for an alluvial gravel.

CONCLUSIONS

The use of modern data acquisition procedures, which include a relatively low-cost digitizer and micro-computer, make possible the accurate and rapid acquisition of large quantities of data. In this study these devices were used together with AUTOCAD and LOTUS 1-2-3 spreadsheet, to acquire and process large quantities of data without ever touching the data after digitization. The use of a spreadsheet makes possible easy interpretation and presentation of the data. In this paper, sample preparation and data acquisition are described for

Table A-2. Roughness Data Illustrating Variability for a Stream Deposit-

Digitization Increment of 0.05 in.; Aggregate 3/8 in. to 1/2 in.

SAMPLE	ROUGHNESS PER SAMPLE	CORRECTED ROUGHNESS	AVG. RGH PER GROUP	AVG. RGH PER AGG.	AVG. RGH PER QUARRY
CA1051	1.16	1.18			
2	1.10	1.12	1.14		
3	1.09	1.11		1.12	
CA2051	1.09	1.11			
2	1.07	1.09	1.10		
3	1.07	1.09			
CA3051	1.07	1.09			
2	1.12	1.14	1.12		
3	1.09	1.11		1.15	1.13
CA4051	1.23	1.25			
2	1.08	1.10	1.18		
3	1.16	1.18			
CA5051	1.10	1.12			
2	1.10	1.12	1.11		
3	1.06	1.08		1.13	
CA6051	1.20	1.22			
2	1.10	1.12	1.16		
3	1.10	1.12			

Mean - 1.13 Standard Deviation - 0.50

Roughness per Sample - True Length/Projected Length

Corrected Roughness - (1.0199) + Roughness per Sample

Avg. Rgh. per Group - Average roughness of samples from same picture

Avg. Rgh. per Agg. - Average roughness of 2 groups (pictures) taken from same aggregate

Avg. Rgh. per Quarry - Average roughness of 3 agg. from each quarry sample, A or B shape, surface area and roughness of aggregates. These techniques can, however, also be applied to many other materials applications.

APPENDIX B

POURING TEST

POURING TEST

Introduction

For this study, each complete pouring test required 1 to 2 hours to perform. A complete pouring tests includes tests for six aggregate size ranges. The additional time required for aggregate sieving, equipment preparation, and cleanup averaged 3 hours. Therefore, total time per aggregate source ranged from 4 to 5 hours depending on available aggregate and other variables. The calculations necessary to determine microsurface voids and macrosurface voids from the packing specific gravity, determined in the pouring test, were completed using the spreadsheet software Excel. Typically, this analysis requires about 1 hour. Therefore, a complete test, as performed for this study, takes about 5 to 6 hours including sieving, performing the pouring tests, and data reduction.

Theory of Specific Rugosity

The pouring test consists of comparing the packing characteristics of spherical glass beads with that of aggregate particles within selected narrow particle size ranges. The pouring test is based on the packing volume concept developed by Tons and Goetz [27][(1)]. The packing volume concept states that different shaped one-size particles, either smooth or rough, will compact to the same volume in bulk when they possess identical total packing volume (V_p) of the particles under identical compaction procedures. The packing volume is enclosed by an imaginary membrane

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(1) The numbers in brackets refer to the references given in the reference section of the main report.

stretched along the peaks of the aggregate surface. One-size aggregates are defined by equation (B-1).

$$(d'/d)^2 \leq 2 \tag{B-1}$$

Where

d' - maximum particle size

d - minimum particle size

The packing specific gravity (G_p), which is also based upon the packing volume concept, is defined as $G_p = W/V_p$ in which W is the dry weight of the aggregate. Since V_p and ΣV_p are assumed constant for one-sized particles, then equation (B-2) is valid:

$$\Sigma V_p = \frac{\Sigma W_1}{\Sigma G_{p1}} = \frac{\Sigma W_2}{\Sigma G_{p2}} = \frac{\Sigma W_i}{\Sigma G_{pi}} = \text{constant} \tag{B-2}$$

Where

W_i - weight of the ith aggregate (all particles are the same size range)

G_{pi} - packing specific gravity of the i^{th} aggregate

Using the pouring test, the packing specific gravity (G_p) of a one-size aggregate can be determined by correcting the packing specific gravity of glass beads. Because glass beads theoretically do not have macro- or micro surface voids, their packing specific gravity is equal to their apparent specific gravity. The absorption of glass beads is assumed to be zero. Therefore, an aggregate's packing specific gravity can be determined by:

$$G_{px} = \frac{G_{ps}\Sigma W_x}{\Sigma W_s} \tag{B-3}$$

Where

G_{px} = packing specific gravity (G_p) of aggregate

G_{ps} = packing specific gravity (G_p) of glass beads

W_x = weight of aggregate in container after pouring

W_s = weight of glass beads in container after pouring

Once the packing specific gravity has been determined, the micro surface voids, macro surface voids, and specific rugosity can be calculated. The equations for micro surface voids (S_{mi}) and macro surface voids (S_{ma}) are, respectively:

$$S_{mi} = 100\ G_p[(G_{ap} - G_{ag})/G_{ag}G_{ap})] \qquad \text{(B-4)}$$

$$S_{ma} = 100[(G_{ag} - Gp)/G_{ag})] \qquad \text{(B-5)}$$

Where

G_{ap} = apparent specific gravity of aggregate as determined by ASTM C127 and C128

G_{ag} = dry bulk specific gravity of aggregate

The specific rugosity (S_{rv}) is the sum of the micro surface voids and the macro surface voids as given by the following equation:

$$S_{rv} = S_{mi} + S_{ma} \qquad \text{(B-6)}$$

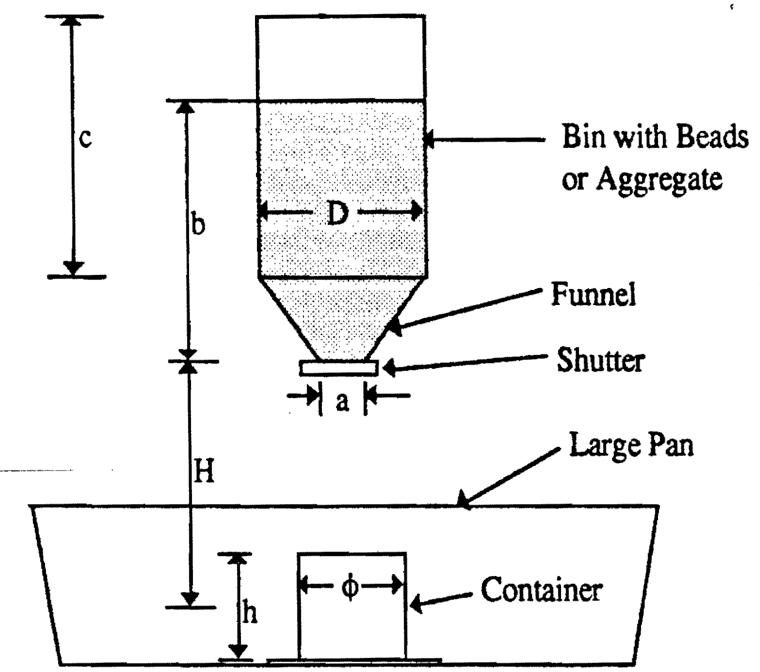
Test Procedure

Overview. The initial step in performing the pouring test is to adjust the funnel height and select the appropriate container and orifice for the aggregate particle sizes to be tested. The critical equipment dimensions used in this study are given in Table B-1 and illustrated in Figure B-1. The next two steps are to (1) close the orifice shutter and (2) fill the aggregate discharge storage bin to the specified aggregate head level. The

Table B-1. Critical Dimensions Used in Pouring Test

Aggregate Passing	No. 45	No. 30	No. 20	No.12	1/4"	5/8"	1 1/4"
Aggregate Retained	No. 60	No. 40	No. 30	No. 16	No. 4	7/16"	7/8"
Bin Dia.(D)mm	93	93	93	93	102	155	205
OrificeDia.(a)mm	9.5	9.5	9.5	9.5	50	100	150
Agg. Head (b)mm	110	110	110	110	125	80	140
Pouring Ht.(H)mm	210	210	210	210	210	210	210
Cont. Ht. (h)mm	72	72	72	72	95	150	175
Cont. Dia. (ϕ) mm	72	72	72	72	95	105	153
Glass Bead Dia.* mm.	0.30	0.50	0.71	1.5	5	12.7	25.4

* Average Value



D = Bin Diameter
a = Funnel Orifice
c = Bin Height
b = Aggregate Head
H = Pouring Height
ϕ = Container Diameter
h = Container Height

Figure B-1. Pouring Test Apparatus.

container receiving the aggregate is placed directly beneath the orifice, and the shutter is removed. The aggregate is allowed to free fall into the receiving container and overflow the sides.

Next the aggregate is struck off at the top of the container using a metal rule. When testing larger aggregates, it is necessary to remove the excess particles by hand. The weight of the aggregate retained is then weighed using a scale having a 0.1 gram sensivity. An example data sheet used in the pouring test is given Table B-2.

The values for aggregate apparent (G_{ap}) and bulk (G_{ag}) specific gravity are obtained from standard tests performed on the aggregate. The apparent specific gravity for the glass beads used in this study was obtained from the manufacturer. The apparent specific gravity for beads of two sizes (1.5 mm and 5 mm) were verified by laboratory determination.

Equipment. A schematic of the required pouring test apparatus is shown in Figure B-1. The pouring test apparatus consists of a support for the pouring bin having an adjustable clamp and height adjustments. The following additional equipment and containers are required:

1. A steel straight edge.
2. Containers of various sizes to receive the aggregate (Table B-1).
3. Funnels of various sizes from which to pour the aggregate.
4. A scale.
5. Large container or bin to contain overflow of aggregate.

Table B-2. Example Data Sheet For Pouring Test.

ATHENS
9/7/91

EQUATION: Gpx=(Gps/Avg of Ws)*Avg of Wx
Gpx=Packing Specific Gravity of the Aggregate
Gps=Packing Specific Gravity of the Beads
Wx=Weight of Aggregate
Ws=Weight of Beads

			WEIGHT IN GRAMS					AVG
DESCR	PASS SIEVE	RET SIEVE	W1	W2	W3	W4	W5	WT
BEAD	#45	#60	452.3	451.8	451.2	454.5	451.7	452.3
BEAD	#30	#40	465.0	464.7	464.7	467.6	463.7	465.1
BEAD	#20	#30	469.0	467.8	470.4	469.1	474.1	470.1
BEAD	#12	#16	487.9	493.6	492.8	488.7	486.9	490.0
BEAD	.25"	#4	1002.0	1005.5	1004.4	1002.4	1005.9	1004.0
BEAD	.625"	.4375"	1819.1	1839.7	1819.1	1815.7	1825.9	1823.9
BEAD	1.25"	.875"	4465.8	4464.9	4507.9	4393.2	4485.7	4463.5

			WEIGHT IN GRAMS					AVG	SPEC GRAV	PACKING SPECIFIC
DESCR	PASS SIEVE	RET SIEVE	W1	W2	W3	W4	W5	WT	OF BEADS	GRAVITY OF AGGREGATE
AGGREGATE	#45	#60	334.6	335.7	335.1	334.8	334.3	334.9	2.48	1.84
AGGREGATE	#30	#40	349.6	350.0	350.4	349.6	349.3	349.8	2.49	1.87
AGGREGATE	#20	#30	369.9	369.9	369.8	369.7	369.1	369.7	2.49	1.96
AGGREGATE	#12	#16	401.9	401.9	400.0	400.9	400.9	401.1	2.52	2.06
AGGREGATE	.25"	#4	854.3	858.2	854.4	856.1	850.0	854.6	2.52	2.14
AGGREGATE	.625"	.4375"	1681.2	1653.0	1678.9	1657.4	1696.1	1673.3	2.46	2.26
AGGREGATE	1.25"	.875"	4097.5	4233.3	4061.7	4008.1	4077.7	4095.7	2.60	2.39

6. Glass beads of various sizes. The glass bead sizes used in this study and the combinations of container sizes and drop heights are given in Table B-1.
7. Aggregate sieved into the desired size ranges. The sieve size ranges used for this study are given in Table B-1.

Step-by-Step Procedure

1. Select and adjust the pouring apparatus to the appropriate height (refer to Table B-1).
2. Fill the aggregate storage bin to the required head H with glass beads (refer to Figure B-1 and Table B-1).
3. Position the receiving container directly beneath the orifice so that it will be filled by the falling glass beads.
4. Carefully remove the orifice cover and allow the beads to fill and overflow the receiving container.
5. Once all of the beads have fallen, carefully strike off the excess beads above the top of the container.
6. Weigh this volume of glass beads.
7. Repeat steps 2 through 6 four more times and use the average value in the mathematical relationships.
8. Repeat steps 1 through 7 for each particle size range to be tested. In this study the 5 particle size ranges given in Table B-1 were tested.

APPENDIX C

RUTTING TESTS

RUTTING TESTS

INTRODUCTION

The Loaded Wheel Test has been used by the Georgia Department of Transportation for a number of years to evaluate the rutting behavior of asphalt concrete mixes. Lai [28] has described the modification of the Georgia DOT Loaded Wheel Tester (LWT) and the evaluation of asphalt mixes using this approach.

A Loaded Wheel Tester was used to perform rutting tests on selected asphalt concrete base, B binder, E and F surface mixes. Specimens were prepared from aggregate obtained from the 21 quarries included in this investigation. This chapter describes the Loaded Wheel Tester, preparation of asphalt specimens, and testing procedures. The results of the Loaded Wheel tests are given in Chapter 4.

LOADED WHEEL TESTER

A Loaded Wheel Tester (LWT) was designed, fabricated and used during the present laboratory investigation. This device operates on a different principal than the LWT used by the Georgia DOT. The Georgia DOT LWT employs a wheel that moves back and forth across a stationary asphalt concrete beam. For the LWT device used in this study, the asphalt concrete beam moves back and forth while the wheel, through which the load is applied, remains stationary.

Description of Loaded Wheel Tester

The Loaded Wheel Tester is shown in Figure C-1 and C-2. Load is applied to a rectangular asphalt concrete specimen by a 1.125 in. wide

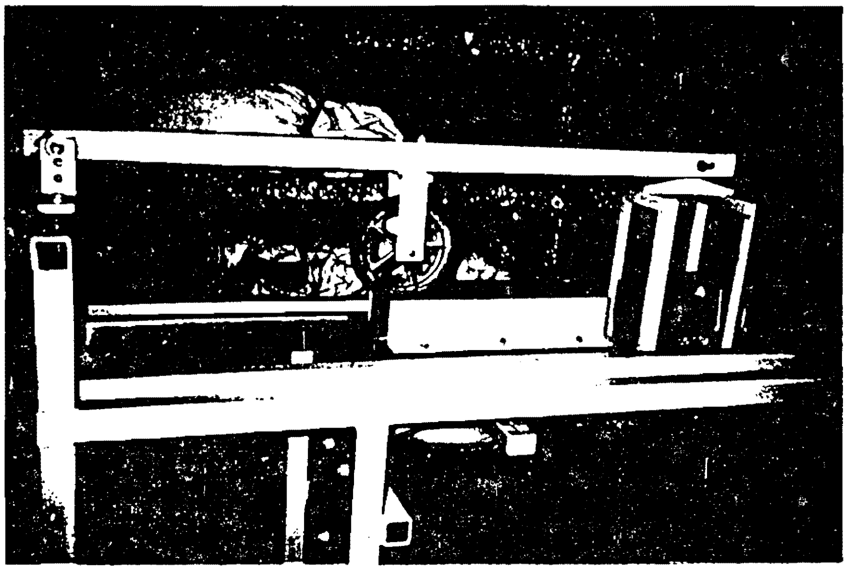


Figure C-1. Loaded Wheel Tester.

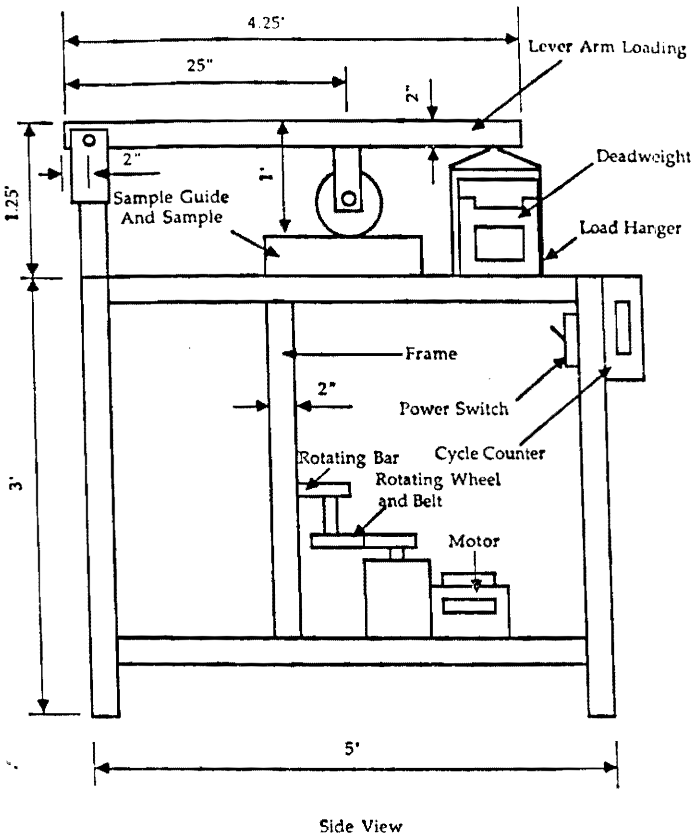


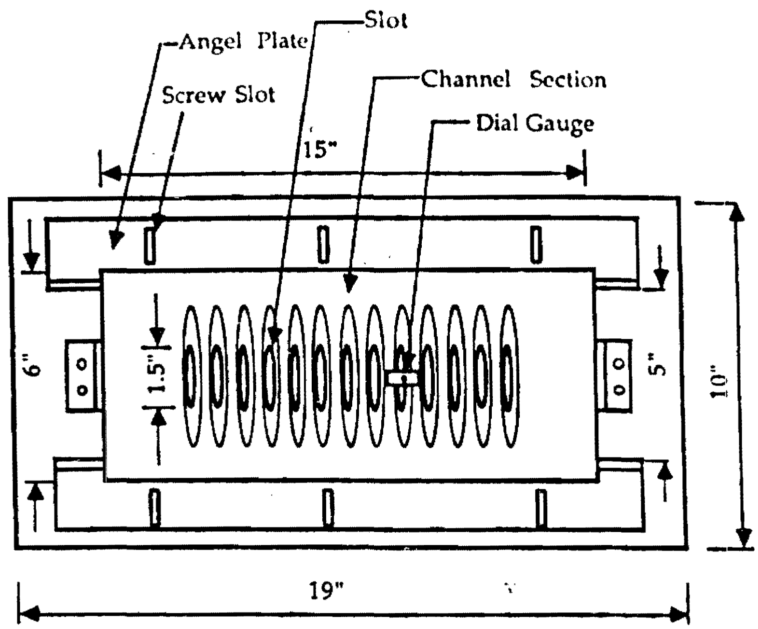
Figure C-2. Loaded Wheel Tester - Elevation View.

wheel having an 8 in. diameter. The wheel has a hard rubber cover. The asphalt concrete specimen moves horizontally back and forth on a flat steel plate. The steel plate is supported by 4 small ball-bearing wheels. A constant dead load weight is applied to the wheel through a lever arm arrangement as shown in Figures C-1 and C-2. The lever arm is attached to a test frame which is about 5 ft. long by 2 ft. wide by 3 ft. high.

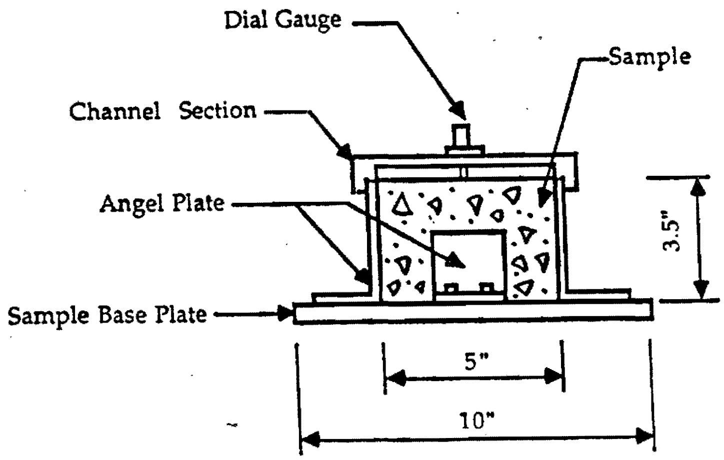
The flat steel plate, and hence the asphalt concrete specimen, is pulled back and forth through a 12 in. long travel path by a 2.5 hp motor operating at a speed of 1750 rpm. The asphalt concrete specimen is driven back and forth at 50 cycles per minute by two belt driven pulleys which reduce the speed of the motor. The rate of specimen movement can be adjusted, if desired, by changing the diameter of the two pulleys.

Rut Depth Measurement Template

Since rut depth was measured at a number of load repetitions, a template was required that could be repositioned on the asphalt concrete beam specimens at exactly the same location each time. To accomplish this, a rectangular template is placed on top of an adjustable box, made from steel angles which holds the asphalt concrete specimen in place (refer to Figure C-3). The template, which is machined from aluminum, has 13 slots oriented perpendicular to the direction of the wheel movement. Each slot, which is 1 in. apart, is 1.5 in. long and 3/8 in. wide. To measure rut depth, a 0.001 in. dial indicator is placed successively in each slot and slowly moved across the transverse rut profile. The largest observed dial reading is recorded as the maximum rut depth. The transverse rut profile has been observed to be, at some locations, nonuniform due to the presence of aggregate particles near the surface. As a result, measuring the



(a) Plan Showing Measurement Template



(b) Side View

Figure C-3. Rutting Profile Measuring Device (After Sheng, Ref. 9).

maximum rut depth in this manner tends to decrease the scatter in test results.

To very accurately reposition the template on the specimen after each series of load repetitions, both the template and the steel angles which hold the asphalt concrete specimen in position has notches in them so that the template fits into the notched angles exactly the same way each time.

SPECIMEN PREPARATION

The asphalt concrete beam specimens used in the rutting tests were 12 in. in length and 5 in. in width. The E and F asphalt concrete beams specimens were 3 in. deep to simulate the thickness of a typical E mix layer while the B binder and base specimens were 3.5 in. thick.

Replicates

During the first part of the rutting study, two identical asphalt concrete specimens were fabricated at a time for each mix tested (i.e., either a standard Georgia DOT mix or a proposed mix). This approach was followed since mix designs for the proposed coarse/fine mixes were not initially available. During the latter part of the rutting study it was realized that much more reliable comparisons could be made if two specimens each of both the standard Georgia DOT mix and the new mixes were prepared at the same time. This modified procedure eliminates any variation in aggregate quality, specimen preparation differences, etc. Aggregate property variation may have been a problem since additional material had to be obtained during the study.

Aggregate Gradation

The aggregate used to prepare the beams was sieved into the required sieve size ranges and the resulting sizes were stored separately according to their source. The weight of materials used for preparing the beam were calculated based on the density of each mix obtained from the Georgia DOT Marshall Mix Design sheets, and the known volume of the beam mold. The aggregate required to prepare each sample was carefully weighed from each size fraction and put into a container and thoroughly blended. This aggregate was then weighed into 3 batches sufficient to fill 1/3 of the beam volume. A total of 6 batches (two beams per mix) were prepared at a time.

Mix Preparation

The aggregate and asphalt were heated separately at 380°F and 330°F, respectively. Normally the aggregate samples were heated in the oven for 8 to 10 hours before mixing with asphalt, and the asphalt was heated in the oven for 2 to 4 hours. The mixing temperature was around 340°F. The mold, base plate, and loading lid were all heated to 380°F. All raw materials and equipment used in mixing the asphalt concrete were also preheated.

During mixing, the first batch of aggregate was removed from the oven, placed in a large stainless steel bowl, weighed, and the correct amount of asphalt added. The contents were then thoroughly mixed in the bowl. The same procedure was followed for the second and third batches. The three batches were then combined and thoroughly mixed together quickly. The temperature of the mix was measured during the mixing process. Materials and equipment were always kept in an oven except during the time of mixing.

Beam Preparation

The mold was removed from the oven, and the base plate was set down and covered by a piece of filter paper. The hot asphalt mixture was placed in the heated mold in three layers. Each layer was very lightly compacted by three to four passes of a spoon along the length of the beam. Another piece of filter paper was placed on top of the asphalt concrete, and a steel loading plate was placed on top of the filter paper.

The asphalt concrete beam was statically loaded for three cycles with each cycle going from 0 to 100,000 lbs and back to 0. Sometimes the maximum machine load of 120,000 was reached. After three cycles, the load was kept on the maximum level for 6 minutes before unloading. The mold was designed such that when the steel plate was flush with the top of the mold, the specimen was the correct height to achieve the desired density.

The beams were stored at normal room temperature for seven days, or slightly longer, on a surface ground steel plate. Just before testing they were placed in the constant temperature room for 24 hours.

RUT TEST PROCEDURE

Load Repetitions. A total of 8000 wheel passes were applied to each asphalt concrete specimen. Load was applied to the beam specimens with the wheel moving in each direction (i.e. two directional loading was used). A longitudinal rut depth profile was measured at the end of 0, 500, 1000, 2,000 and 8,000 load repetitions. An Eagle Signal programmable controller was used to automatically stop the test at the end of each load sequence. Use of the programmable controller greatly minimized the time required to moniter the test.

Rut Measurements

The maximum rut depth was measured at the middle 6 slot locations on the measurement template (refer to Figure C-3(a)). Since the spacing between slots is 1 in., rut depths were measured in the middle 5 in. of the beam. The maximum rut depth was determined at each slot location by sliding the dial indicator, while positioned in the appropriate slot of the template, across the rut transverse to the longitudinal axis of the beam.

The asphalt concrete filler blocks, which were 4 in. long, were placed on each side of the beam to allow the Loaded Wheel Tester to travel through its normal 18 in. of wheel travel. End effects due to the wheel starting and stopping, as well as the transition to the filler blocks, was found to influence the readings outside of the middle 6 slots.

An analysis of a large amount of rutting data also indicated that use of the maximum rut depths measured in the middle 3 slots gave slightly more consistent results than for the middle 6 slots. Hence average rut depths for the middle 3 slots were used throughout this report. Typical measured longitudinal rut profiles are shown in Figure C-4 and C-5. Typical comparisons between rut depths measured for the middle 3 slots and middle 6 slots are shown in Figures C-6 and C-7 as a function of the number of load repetitions.

Wheel Loading

The asphalt concrete beams were subjected to a 131 psi average tire pressure through a solid rubber tire. The rubber tire was dead loaded by means of 50 lbs. of lead weight suspended from a loaded hanger. The weight of the load hanger and lever arm which supported the load hanger was also included in determining the total weight applied to the specimen. Load on

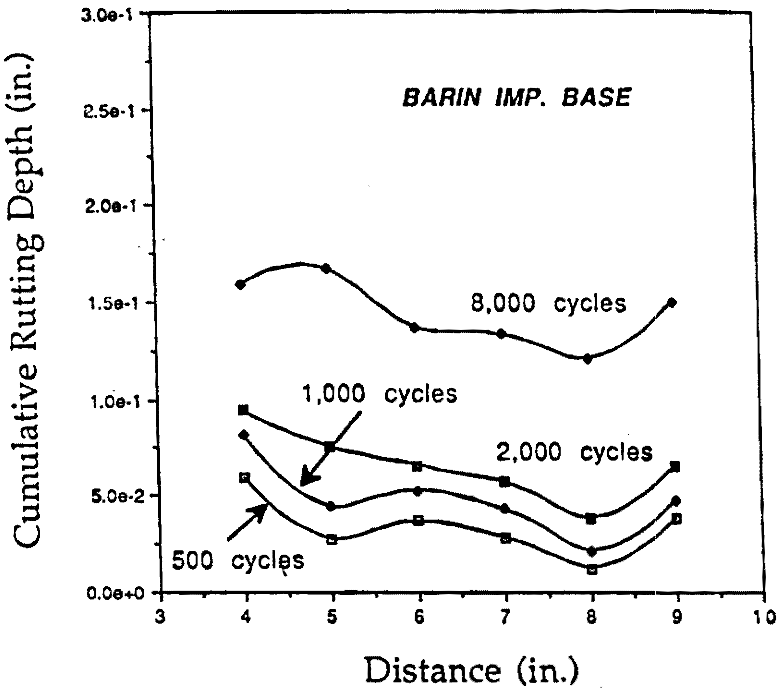


Figure C-4. Rutting Profile Along the Longitudinal Centerline (After Sheng, Ref. 9).

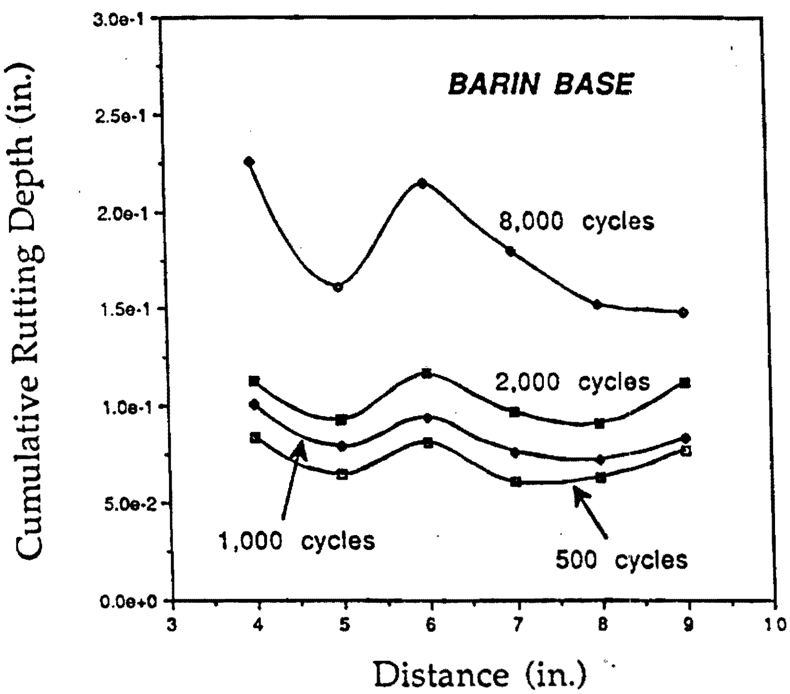


Figure C-5. Rutting Profiles Along the Longitudinal Centerline (After Sheng, Ref. 9).

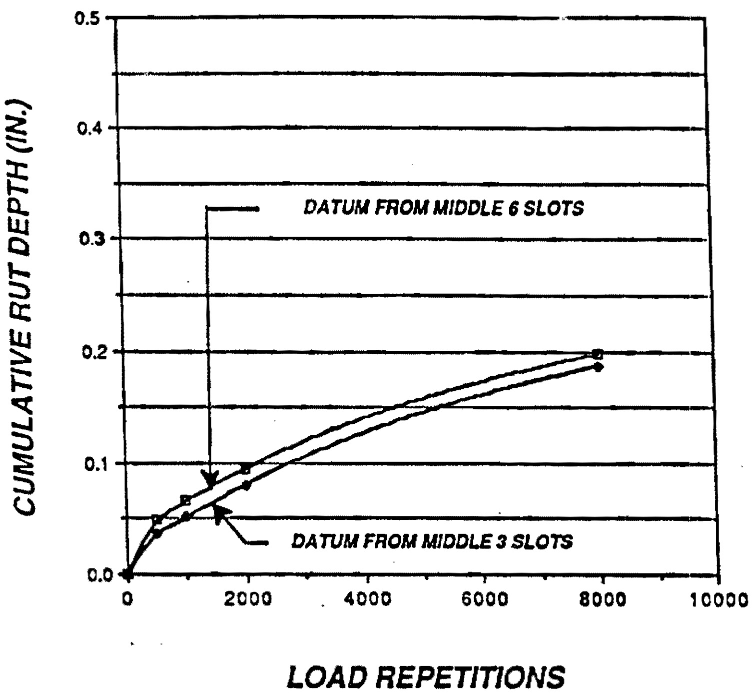


Figure C-6. Rut Depth as a Function of Load Repetitions - Athens B (After Sheng, Ref. 9).

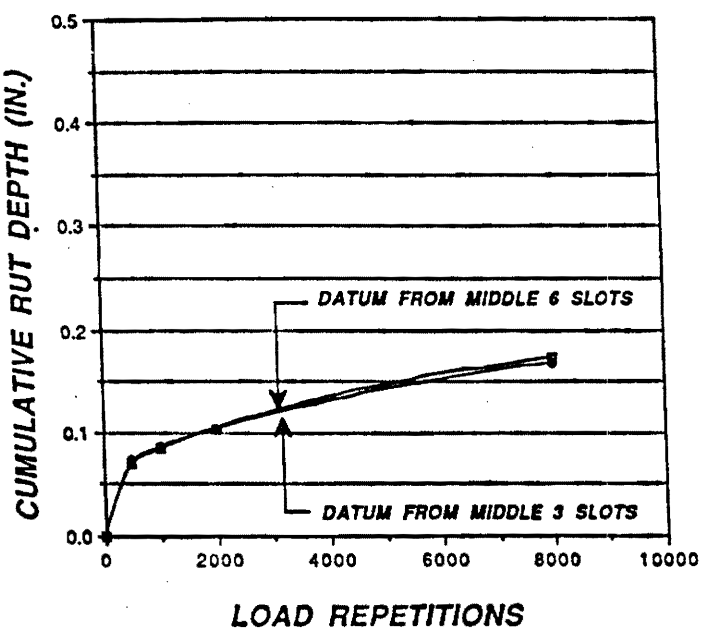


Figure C-7. Rut Depth as a Function of Load Repetitions - Ball Ground Base (After Sheng, Ref. 9).

the specimen was accurately measured by temporarily replacing the wheel with a calibrated proving ring.

Temperature

The Loaded Wheel Tests were performed in a large constant temperature room. An electric heater with a precision Fenwell thermostat temperature controller was used to heat the room to 104°F with a fluctuation of +/- 1°F. After a slight modification to the control system was made, the temperture was maintained at 104°F (+/- 0.2°F) for the latter part of the study.

Placement of Specimen In Tester

The asphalt concrete beam (and filler blocks) were tightly held on the horizontally sliding plate by means of four removable 3.5 in. by 2.0 in. steel angles. The leg of each angle which rested on the horizontally sliding plate was slotted so that after adjustment the angles were screwed to the horizontally sliding plates. Using this arrangement, the angles were tightly pressed against the asphalt concrete specimen to provide lateral support during the test.

SUMMARY

The Loaded Wheel Tester proved to be an excellent method for measuring rutting in asphalt concrete specimens. This equipment is relatively inexpensive to fabricate, easy to use, and required very little maintenance throughout the extensive rutting test phase of this study. In addition, the test is easy to set up and complicated electronic instrumentation is not required. For best results, rutting specimens to be directly compared should all be prepared and tested at the same time. When this procedure is followed, good reproduciblity of test results can be obtained.

APPENDIX D

FATIGUE LIFE PREDICTION

FATIGUE LIFE PREDICTION

INTRODUCTION

The development and use of a computer program is described for predicting the fatigue life of asphalt concrete mixes. A computer program is also described for estimating the dynamic modulus of asphalt concrete mixes when resilient modulus values are not directly evaluated in the laboratory as a part of the mix design process. The resilient modulus or the dynamic modulus for this type application, is one of the input variables used in the theoretical fatigue model.

FATIGUE MODELS

A commonly used relationship to define the fatigue life of an asphalt concrete mix has the general form

$$N = a[1/\epsilon_t]^b \qquad \text{(D-1)}$$

where

N = number of load applications to cracking

ϵ_t = tensile strain repeatly applied by traffic loading

a,b = coefficients from laboratory fatigue tests often modified to reflect in-situ pavement performance

To predict fatigue life, the stiffness of the asphalt concrete mix must be known. The modulus of elasticilty is used to characterize mix stiffness. For dynamic pavement type loads, either the resilient modulus or the dynamic modulus, which are both forms of the modulus of elasticity, can be used in a fatigue analysis.

Modified Finn Fatigue Model

The fatigue life predicition model, originally developed by Finn et. al. [29] and later modified [30] for use by The Asphalt Institute, was used as one of the two theoretical fatigue models incorporated into the GTFATIGUE computer program developed as a part of this study. This fatigue model is expressed as follows:

$$N = 18.4\ (C)\ [4.325*10^{-3}\ (\epsilon_t)^{-3.291}\ (|E^*|)^{-0.854}] \qquad (D\text{-}2)$$

Where

N = number 18,000 lb. equivalent single axle loads

ϵ_t = tensile strain in asphalt layer (in./in. or mm/mm)

$|E^*|$ = asphalt mixture stiffness modulus, (psi)

C = a material parameter which is a function of air voids, (V_v), and asphalt volume, (V_b)

The above expression is similar in form to equation (D-1) but modificiations have been included for the effects of asphalt mixture stiffness, asphalt content and air voids [30]. This expression is applicable to mixes prepared using either asphalt cements or cured asphalt emulsions. Equation (D-2), without the factor C, was obtained from laboratory fatigue test data [29,30] adjusted to provide an indication of approximately 20 percent or greater of fatigue cracking observed in selected pavement sections of the AASHO Road Test. Fatigue cracking is based on total pavement area.

The correction factor C is determined from:

$$C = 10^M \qquad (D\text{-}3)$$

Where

$$M = 4.84\ [(V_b/(V_v+V_b))-0.69] \qquad \text{(D-4)}$$

V_b = volume of asphalt (percent)

V_v = volume of air voids (percent)

The term M in equation (D-4) was obtained from laboratory fatigue data developed by Pell and Cooper [31] and Epps [32]. The value of C is equal to one when V_b=11 percent and V_b=5 percent. Figure(D-1) compares, for reasonably similar mixes, the fatigue life predicted by the modified Finn fatigue model (V_b=11%, V_v=5%) with the Shell fatigue model for mixes with moderate asphalt and air void contents.

University of Nottingham Model

Pell and his associates at the University of Nottingham conducted a large number of laboratory fatigue tests on a wide range of mixes during approximately the last 25 years. These fatigue test results have been incorporated into the following general fatigue life prediction model for use in flexible pavement design [33]:

$$\log \epsilon_t = \frac{14.39 \log V_b + 24.2 \log SP_i - K - \log N}{5.13 \log V_b + 8.63 \log SP_i - 15.8} \qquad \text{(D-5)}$$

Where

K = 46.82 for load repetitions to critical fatigue conditions

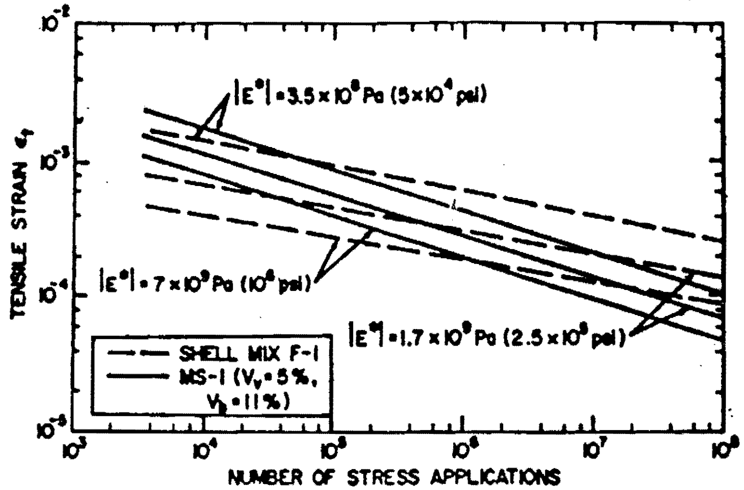
K = 46.06 for load repetitions to fatigue failure

ϵ_t = tensile strain in the asphalt concrete mix (in microstrain)

V_b = volumetric propotion of binders in percent (refer to Figure D-2)

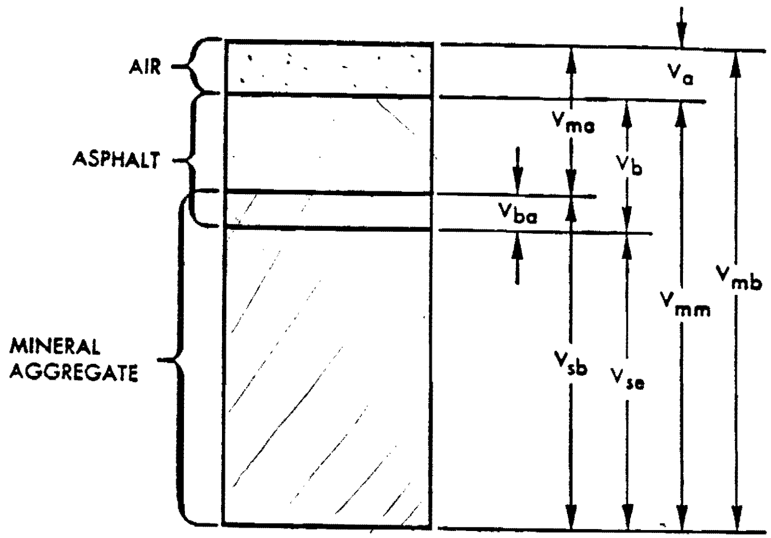
SP_i = initial softening point of binder (°C).

N = number of load applications (in millions) to fatigue distress



(After Finn, Shook, Witczak, and Monismith, 5th Int. Conf. Structural Design of Asphalt Pavements, Vol. 1, pp. 17-42)

Figure D-1. Tensile Strain Criteria for Fatigue.



V_{ma} = Volume of voids in mineral aggregate
V_{mb} = Bulk volume of compacted mix
V_{mm} = Voidless volume of paving mix
V_a = Volume of air voids
V_b = Volume of asphalt
V_{ba} = Volume of absorbed asphalt
V_{sb} = Volume of mineral aggregate (by bulk specific gravity)
V_{se} = Volume of mineral aggregate (by effective specific gravity)

W = Weights, subscripts have same meaning as above

Figure D-2. Representation of Weights and Volumes in a Compacted Asphalt Specimen (Reference 38).

The above equation, although based on laboratory fatigue test results, has been empirically adjusted to give better agreement with observed fatigue behavior of pavements. A nomograph solution of equation (D-5) has also been developed.

FATIGUE COMPUTER PROGRAM

Introduction

The GTFATIGUE computer program was developed to provide a rapid solution for predicting fatigue life (load repetitions to fatigue failure) by the Finn and Nottingham methods. A users manual for the program is given at the end of this Appendix. The GTFATIGUE program is written in Microsoft advanced basic language (BASICA) and can be used on a personal computer operating under the MS DOS disk operating system. The program is interactive, and the required input data is requested by the program as it runs.

In the Nottingham method, use of a fatigue condition constant of K=46.06 is suggested which corresponds to a failure condition in the asphalt concrete mix. A fatigue failure condition is a more severe fatigue condition (i.e., requires a greater number of repetitions to failure) than for K=46.82 which can also be used in the fatigue analysis as an option.

Input Tensile Strain

Either a calculated or assumed value of the tensile strain in the bottom of the asphalt concrete layer for which fatigue life is being estimated must be input to the GTFATIGUE Program. Note that the tensile strain input to the program is in micro strain. Hence, if the actual strain is 0.000200in./in., a value of 200 must be input into the program. Theoretically, the tensile strain in the asphalt concrete mix should be computed using layered theory which requires determining appropriate resilient or dynamic moduli for each layer. As a convenient but perhaps less accurate alternative, two mixes can be compared more readily using the same assumed tensile strain level. In the fatigue analyses conducted for this study 200 microstrain was used when this alternative was followed.

RESILIENT MODULUS PREDICTION

To predict fatigue life using the modified Finn model given by equation(D-2), the resilient modulus (M_r) or else the dynamic modulus $|E^*|$, must be known. These moduli can be experimentally determined from laboratory tests such as the diametral or triaxial test, or estimated using empirical expressions based on statistical correlations with laboratory experimental results.

Shell Method

The Shell Nomograph [34] and the Asphalt Institute Method [35] are probably the two most commonly used approaches for estimating the stiffness of asphalt concrete mixes. The Shell method, which was developed first, involves estimating the stiffness of the asphalt cement from the well-known Shell Nomograph. The stiffness of the asphalt is then corrected using another nomograph for the influence of the aggregate in the asphalt concrete mix by considering the volume percentage of aggregate present in the mix. The Shell method uses the asphalt cement content, softening point, and penetration, the temperature, and frequency of load application.

Asphalt Institute Method

The Asphalt Institute method for predicting the dynamic modulus $|E^*|$ was originally developed in 1969 by Kallas and Shook [35] and greatly improved by Witczak [36] in 1978 and by Miller, Uzan, and Witczak in 1983

[37]. The 1978 version of the equation was used in the Asphalt Institute MS-1 pavement design guide. The 1983 version of the equation is as follows [37]:

$$\log_{10} |E^*| = C1 + C2\ P_{ac} - P_{opt} + 4.0)^{0.5} \qquad \text{(D-6)}$$

where

$|E^*|$ = dynamic modulus (10^3 psi)

$C1 = 0.553833 + 0.028829(P_{200}/f^{0.17033}) - 0.03476V_v, +0.070377\eta_{(10^6,70)} + (0.931757/f^{0.02774})$

$C2 = 01000005T \exp(1.3 + 0.49825 \log_{10} f) - [0.00189T \exp(1.3 + 0.49825 \log_{10} f) f^{1.1}]$

P_{200} = percentage passing the No. 200 sieve

f = loading frequency (Hz)

V_v = volume of voids (%)

$\eta(10^6, 70°)$ = viscosity of asphalt cement at 70°F (megapoises)

T = temperature of pavement (°F)

P_{ac} = percentage of asphalt cement by weight of mix

P_{opt} = Marshall optimum asphalt cement content (percent)

For equation (D-6) to be valid, the following restrictions should be observed on the asphalt content of the mix:

$$P_{ac} - P_{opt} \geq -1.5 \text{(minimum)} \qquad \text{(D-7a)}$$

$$P_{ac} - P_{opt} \leq -2.5 \text{ (maximum)} \qquad \text{(D-7b)}$$

The above equation can be used to estimate the dynamic modulus $|E^*|$ for asphalt concrete mixes comprised of the following types of aggregates: crushed stone, gravel, slag, and sand. For this range of aggregate types, the predicted mean square error of the dynamic modulus varies from 13 to 29 percent with the average being 21 percent. The value of r^2, which indicates the amount of explained variation in results, varies from 0.856 to

0.947. The data base from which the expressions were developed had 810 data points.

RESMOD Computer Program

The RESMOD computer program makes possible the rapid calculation of the dynamic modulus using equation (D-6). The users manual for the RESMOD computer program is given at the end of this appendix. Three methods are given in the program for calculating the dynamic modulus. Method 2, which uses an equation (D-6) type solution, or Method 2, which considers the aggregate gradation, should give the most reliable predictions of dynamic modulus [37].

COMPUTER PROGRAMS

SIMPLIFIED USERS INPUT GUIDE

PROGRAM: GT FATIGUE

BY: Richard D. Barksdale
Jon Sheng

PURPOSE: Estimate the fatigue life of asphalt concrete mixes subjected to a constant level of load repetitions

COMPUTER: HP Vectra 486/25T
BASICA Program Language

METHOD: Fatigue in terms of repetitions N to failure are estimated by the Asphalt Institute Method and the University of Nottingham fatigue equation.

TO RUN GT FATIGUE PROGRAM:

1. Boot the PC system up from the hard drive (drive C) or else place a DOS Disk in drive A and turn the power supply switch on.

2. If an IBM or other compatible IBM identical computer is booted up from the hard drive, type "BASICA" (or "BASIC") to bring up the BASIC operating environment. The BASIC operating environment is active when the prompt displays "OK".

3. After entering the BASIC environment, place the disk on which GT FATIGUE is located in the A drive of the computer.

4. Press the special function key "F3" and then type: A:GTFATIGUE

5. To run the program type: RUN and the program will start asking the user to enter data into the computer. After typing the data in, remember to press the RETURN key.

ENTER THE FOLLOWING DATA AND PRESS THE RETURN KEY:

1. Input General Accounting Information:

Number of Mixes to be Analyzed: ________________

Month, Day, Year: _______, ________, ________

Quarry Name: ____________________________

Quarry Number: ____________________________

Mix Design Number: ____________________________

2. Asphalt mix properties:

Asphalt Content: ____________________ %

Asphalt absorption into aggregate: _________ %

Unit weight of asphalt mix: _________ pcf

Voids in mineral aggregate (VMA): _________ %

Calculated or assumed tensile strain in pavement or mix-in microstrain (Example 200): _________ microstrains

Modulus of elasticity (M_R) of mix (calculated or measured): _________ psi

Ring and ball softening point of binder: _________ ^oF

Fatigue Condition Constant K: 46.06
For repetitions to failure
K = 46.06
For repetitions to critical condition K = 46.82

RESMOD PROGRAM

APPLICATION: Calculate the dynamic resilient modulus of asphalt concrete at various temperatures and vehicle speeds. Three methods are used requiring different input data.

SOURCE: Programmed for the IBM PC in compiled form. Program uses the Asphalt Institute Equations by Witczak.

To get RESMOD going on IBM PC:

1. Boot IBM system up by placing DOS Disk in drive A and turning power supply switch on.
2. Remove DOS Disk from the A drive and replace with the RESMOD disk. Type in "RESMOD"

Required Input Data for Each Method:

Method 1

Fines _______ (%)

Volume of Voids _______ (%)

Viscosity of Asphalt at 70°F _________ (Millions of Poises)

Loading Frequency _______________ (h_3)

Inplace Temp. of Asphalt Concrete __________ (°F)

Asphalt Content __________ (%)

Optimum Asphalt __________ (%)

Method 2

Volume of Voids ________ % Total Vol.

Aggregate Retained on 3/4" Sieve _______ % Total wt. of Agg.

Aggregate Retained on 3/8" Sieve _______ % Total wt. of Agg.

Aggregate Retained on #4 Sieve _______ % Total wt. of Agg.

Aggregate Passing #200 Sieve ___________ % Total Wt. of Agg.

In-Place Temp. of Asphalt Concrete ________ °F

Effective Asphalt Content ___ ___ % Vol. of Mix

Asphalt Absorbed by Agg. ________ % Wt. of Agg.

Viscosity of Asphalt at 70°F ________ Millions of Poises

Loading Frequency ________ Hertz

Method 3

Temperature ________ °F

Method 1

Specify the desired aggregate in the mix.

1 = TAI Crushed Stone (Asphalt Institute)

2 = UM Crushed Stone (University of Maryland)(see references)

3 = Gravel

4 = Slag

5 = Sand - low P200

6 = Sand - high p200

RESMOD PROGRAM PARAMETERS

Shook, et al., 5th ICSDAP, p.23

Mean Annual Air Temp.	AC to Use
7°C 45°F	AC-5; AC-10
15.5°C 60°F	AC-10; AC-20
24°C 75°F	AC-20; AC-40

Asphalt Grade	η 70°F 10^6 Poises
AC-5	0.3
AC-10	1.0
AC-20	2.5
AC-40	5.0

See Ref. (26)

Shook uses $p_{200} = 5\%$ and $f = 10$ hz

Mix	V_v	V_b
Surface Course	4	11
Base	7	11

A fixed percentage of p = 200 = 5% and f = 10 hz were used.

V_b = % volume of asphalt

APPENDIX E

THIN SECTION AND X-RAY SAMPLE DESCRIPTIONS

Thin Section and X-Ray Sample Descriptions

Sample | Description

FLORIDA ROCK INDUSTRIES, TYRONE, GA. (014)

General Description:

014-57A Light colored medium grained granite with biotite disseminated throughout. Quartz and alkali feldspars predominate although percentages vary. Quartz grains <5mm, Alkali feldspars <10mm. Rare reddish brown rounded grains, possibly garnet. Muscovite generally not distinguishable in hand specimen.

Rock Type: Muscovite Biotite Granite Gneiss with Amphibolite

014-57A-1 Quartz 38% - Fractured grains ranging from 0.1-5mm.
Alkali feldspars 29% - Large, irregularly shaped grains up to 6 mm.
Plagioclase 18% - Grains smaller than alkali feldspars, 2-3 mm and less irregularly shaped.
Biotite 10% - Occurs in clusters of crystals 1-2 mm in size. Little or no foliation noted.
Muscovite 5% - Associated with the biotite clusters though not as common. Also occurs as very fine grained sericite associated with alteration of plagioclases.

014-57A-2 Quartz 18% - Occurs as very coarse grains, approximately 5 mm or much smaller grains of 0.5-1 mm. Large grains are often highly fractured.
Alkali feldspars 23% - Few grains present but those that are are relatively large, 3-4 mm.
Plagioclase 50% - Medium to coarse grains, 1-5 mm, showing moderate alteration and some zonation.
Biotite 8% - Medium grained, 1-2 mm, occuring in a few relatively large clusters.
Muscovite 1% - Very highly eroded crystals approximately 1 mm in size associated with biotite.

014-57A-3 Quartz 41% - Highly fractured medium to large grains 1-6 mm.
Alkali feldspars 17% - Anhedral crystals, few in number but relatively large 3-5 mm. Pericline twinning predominates with some Carlsbad.
Plagioclase 33% - 2-3 mm crystals showing Albite twinning, often altered to sericite. Alteration

concentrated in centers of crystals indicating some zoning of crystals.
Biotite 9% - Crystals approximately 0.5 mm occur in clusters throughout the sample. Very small amounts of muscovite associated with these clusters along with some sericite.

014-57B Light colored medium grained with biotite throughout. Some samples show relatively high biotite content > 10%. There is some very light green staining possibly from the biotite weathering. Muscovite is present only in very small amounts.

Rock Type: Muscovite Biotite Granite Gneiss

Dark gray to black, dark minerals > 60%, fine grained, thinly foliated. Foliation not perfect. Hornblende and biotite dominate.

Rock Type: Biotite Hornblende Amphibolite

014-57B-1 Quartz 46% - Crystals range from 0.05-5 mm but avg 2-3 mm.
Fracturing less intense than 014-57A but still present throughout.
Alkali feldspars 21% - Occurs as small, irregular grains with occasional larger grains up to 2 mm.
Plagioclase 21% - Anhedral grains, 1-2 mm, showing zoned crystals whose centers are frequently fractured and altered to sericite along cleavage planes.
Biotite 6% - Crystals, <1 mm, occur in clusters sometimes associated with larger 2-3 mm muscovite and accessory calcite and hornblende.
Muscovite 4% - Larger crystals, 2-3 mm often associated with biotite clusters.
Epidote 1% - Occurs as single grains distributed sparsely throughout.
Opaque Trace

014-57B-2 Quartz 30% - Unfractured grains up to 0.2 mm but usually <0.1 mm. Size varies somewhat with location in sample, larger grains toward center.
Plagioclase 3% - Very small grains <2 mm dispersed throughout sample.
Hornblende 56% - Anhedral to euhedral crystals 0.02-0.5 mm. Some foliation defined by larger crystals in center of sample.
Biotite 11% - Crystals up to 0.5 mm help define foliation along with hornblende.

FLORIDA ROCK INDUSTRIES, MT. VIEW, GA. (015)

General Description:

015-57A Light colored fine to medium grained. Biotite content varies widely within sample from < 5% to about 15%. High biotite samples exhibit good foliation and schistose texture, low biotite samples show no foliation and granitic texture. Hornblende content varies between 0-20%. Substantial muscovite content in several samples. Some samples show contact between rock types.

Rock Type: Biotite Granite Gneiss with Schist Stringers

015-57A-1 Quartz 38% - Anhedral, unfractured grains <1 mm.
Alkali feldspars 24% - Anhedral grains showing polysynthetic twinning, up to 2mm located primarily at one end of sample
Plagioclase 27% - Small to medium size grains 0.5-2 mm, albite twinned, present throughout sample.
Biotite 4% - Present throughout sample in very small laths, <0.5 mm.
Muscovite 7% - Uncommon but relatively large grains, 1-2 mm, with some embayed grains present.

015-57A-2 Quartz 45% - Anhedral, unfractured grains <1 mm, similar to 015-57A-1 but with higher percentage of finer grains.
Alkali feldspars 20% - Irregularly shaped grains disseminated throughout showing polysynthetic twinning.
Plagioclase 28% - Small to medium sized grains 0.5-2 mm showing pericline twinning and less ordered albite twinning.
Biotite 7% - More abundant and slightly larger grains than 015-57A-1 but with very rare muscovite.
Epidote Trace.

015-57A-3 Quartz 36% - More common on one half of slide, <1 mm rounded grains.
Plagioclase 30% - Small to medium sized grains 0.5-2 mm showing albite twinning.
Hornblende 20% - Present throughout but much more common in dark half of slide. Small to medium grains 0.5-2 mm.
Biotite 11% - Present throughout but concentrated along with the hornblende.
Opaques 3% - Fine grained 0.05-0.5 mm present primarily in dark half of sample.

015-57B Light colored fine to medium grained quartz rich with some accessory pyrite and garnet. Biotite content varies considerably from 1-10%. Biotite rich samples show some foliation. One biotite rich sample contained approximately 5% of a light green glassy mineral, possibly epidote. Others show same as rare grains. Some samples contain significant hornblende, up to 20%.

Rock Type: Biotite Hornblende Granite Gneiss

015-57B-1 Quartz 43% - Anhedral unfractured grains, 0.5-2 mm dominate sample.
Alkali feldspars 20% - Small to medium size grains 1-2 mm showing pericline twinning. Most grains rounded with occasional irregular shapes.
Plagioclase 31% - Fine grained, disseminated throughout sample. Albite twinned with little or no alteration.
Biotite 6% - Crystals up to 1 mm common throughout sample. Some foliation present but not well defined.

015-57B-2 Quartz 47% - Quartz dominates sample with fine to medium grains, 2-3 mm common. Some fracturing present but not severe.
Alkali feldspars 9% - Small to medium grains 0.5-2 mm showing mostly pericline twinning.
Plagioclase 36% - Uncommon, fine grained < 1 mm. Albite twinning dominates. Little alteration present.
Biotite 8% - Similar to 015-57B-1 but slightly more abundant and showing slightly better foliation.
Opaques < 1% - Very fine grained accessory opaques present but very rare.

FLORIDA ROCK INDUSTRIES, PALMER STATION, GA. (017)

General Description:

017-57A In the light-colored bands: Light colored medium grained rock with a very low, <5%, dark mineral content. Grain size varies considerably from approximately 1 to 5 mm. No foliation noted.
Small amounts of accessory titanite appear in some specimens.

In the dark-colored bands: Dark colored fine grained biotite and hornblende rich rock. The amount of dark minerals varies from approximately 20 to 50%. Quartz usually occurs as rounded grains, <1 mm, although the percentage varies substantially. Accessory garnet and epidote present in small amounts.

Rock Type: Biotite Granite Gneiss with Amphibolite Stringers

017-57A-1 Quartz 35% - Occurs as large elongate crystals up to 6 mm in length. More rounded grains occur up to 4 mm. Some minor fracturing.
Alkali feldspars 15% - Few grains but those present are 2-5 mm in size.
Plagioclase 45% - Size ranges from 0.5-3 mm. Alteration slight to moderate.
Biotite 5% - Occurs as a large cluster of grains approximately 1 mm in size with single grains distributed sparsley throughout.
Muscovite <1% - Traces found associated with biotite.

017-57A-2 Plagioclase 48% - Small rounded grains, 0.5-1 mm distributed throughout with no fractures or alteration.
Biotite 10% - Primarily small laths of approximately 0.5 mm. Some larger crystals of up to 1 mm. No foliation exhibited.
Hornblende 42% - Crystals average 0.5 mm with some up to 2 mm. Some fracturing present.
Epidote <1%

017-57A-3 Quartz 14% - Crystals of 2-3 mm common. Fracturing generally light with occasional exceptions.
Alkali feldspars 72% - Dominates specimen. Crystals of up to 10 mm with 4-5 mm common.
Plagioclase 12% - Crystals of 2-3 mm showing moderate alteration along twin boundaries.
Biotite 2% - Rare small grains, < 1 mm with traces of muscovite associated.

FLORIDA ROCK INDUSTRIES, GRIFFIN, GA. (077)

General Description:

077-57A Light to medium gray, medium to coarse grained granite. Most specimens are very rich in biotite with crystals up to 2-3 mm often occurring in relatively large clusters that are easily broken from the surface. No foliation noted. Some specimens are very coarse grained relative to most with quartz and alkali feldspars crystals of up to 10 mm.

Rock Type: Biotite Granite Gneiss

077-57A-1 Quartz 20% - Medium grains, 1-2 mm, dominate with very few smaller grains present. Moderate fracturing present.
Alkali feldspars 29% - Crystals of 2-3 mm common throughout.
Plagioclase 28% - Crystals, 2-3 mm, often substantially

altered. Alteration products muscovite and calcite are much coarser grained than the sericite common in other altered plagioclase.

Biotite 21% - Crystals of between 1-1.5 mm common, often in clusters with random orientation. Many crystals have irregular shape.

Muscovite 2% - Occurs as relatively large, 1 mm, single crystals or as alteration product within plagioclase crystals, 0.05-0.2 mm.

Calcite <1% - Occurs as fine grained, up to 0.2 mm alteration product within plagioclase crystals.

Opaque <1%

077-57A-2 Quartz 37% - Irregularly shaped grains up to 5 mm, sometimes highly fractured. 2-3 mm grains most common.

Alkali feldspars 37% - Grains of 2-3 mm common with occasional alteration.

Plagioclase 13% - Grains of 1-3 mm showing light to heavy alteration in a manner similar to 077-57A-1.

Biotite 6% - Crystals of approximately 1 mm occuring in clusters showing some degree of foliation.

Muscovite 8% - Occurs as alteration product and as medium sized, up to 1 mm, single crystals. Some larger crystals are present but are highly eroded.

Calcite <1%

077-57A-3 Quartz 48% - Very coarse grained. Several crystals in excess of 10 mm. Crystals of 2-5 mm are more common. Most crystals are highly fractured.

Plagioclase 40% - Crystals of 2-4 mm showing light to heavy alteration similar to 077-57A-1.

Biotite 6% - Crystals of up to 2 mm usually occurring singly though sometimes in small clusters. No foliation noted.

Muscovite 4% - Occurs as single crystals of up to 1.5 mm sometimes associated with biotite and as alteration product. The larger crystals are sometimes eroded somewhat.

Calcite 2% - Occurs as an alteration product.

DAVIDSON MINERAL PROPERTIES, INC., ATHENS, GA. (023)

General Description:

023-57A Medium grained light to dark gray rock often rich in plagioclase and biotite. Quartz often is not very common. Biotite often occurs in relatively large clusters and has been weathered to a dark brown. Foliation is sometimes found in the finer grained specimens although it is never very well developed.

Muscovite occurs in some specimens as relatively large flakes, 2-3 mm in size. Pyrite is a common accessory mineral.

Rock Type: Biotite Granitoid Gneiss with Schist Stringers

023 57A-1 Quartz 35% - Crystals of 0.5-2.5 mm often with irregular sawtooth boundaries when bordering other quartz grains.
Alkali feldspars 19% - Occurs as rare but large grains, 3-5 mm.
Some alteration present.
Plagioclase 32% - 2-4 mm grains commonly altered though not severely. Alteration usually concentrated at grain boundaries.
Biotite 11% - Crystals up to 1 mm occur singly or in small clusters. No foliation noted.
Muscovite 2% - Crystals up to 1 mm associated with biotite.

023-57A-2 Quartz 37% - Crystals up to 5 mm though generally 1-2 mm. Slight fracturing.
Alkali feldspars 4% - Very rare. Present only at one edge of specimen.
Plagioclase 36% - Crystals of 1-3 mm. Fractures common. Alteration varies from none to moderate and is more common on one end of specimen.
Biotite 19% - Occurs in med to large clusters of 0.5-1 mm crystals.
Muscovite 4% - crystals of up to 2 mm common in clusters with biotite. little or no foliation.
Opaque <1%

023-57A-3 Quartz 39% - 0.1-0.5 mm rounded, unfractured grains common.
Plagioclase 41% - Size and shape similar to quartz.
Light alteration exhibited throughout.
Biotite 18% - Small crystals 0.1-0.3 mm occur singly throughout. Crystals show some foliation though not well developed.
Muscovite 2% - Similar size and shape as biotite but not as common.

DAVIDSON MINERAL PROPERTIES, INC., CANDLER, GA. (024)

General Description:

024-57A Light colored generally fine grained rock with some specimens containing larger, 3-4 mm orthoclase grains. Some specimens show some foliation though it is not well developed. Muscovite is usually the dominant mica. Some quartz rich specimens appear to have been metamorphosed slightly and have a quartzitic texture. Very few accessory minerals present with the exception of very rare garnets.

Rock Type: Biotite Granite Gneiss

024-57A-1 Quartz 44% - Rounded grains 0.1-0.2 mm dominate though grains of 0.5-1 mm are relatively common. Rare grains up to 2 mm. Little or no fracturing. Larger grains occur in poorly developed bands.
Alkali feldspars 38% - Smaller grains 0.1-0.2 mm dominate with some grains up to 1 mm.
Plagioclase 13% - Unaltered grains up to 0.3 mm usually occur in small clusters.
Biotite 1% - Small crystals up to 0.2 mm occur singly throughout.
Muscovite 1% - Crystals slightly larger than biotite but not as common.
Opaque <1%

024-57A-2 Quartz 52% - Rounded grains 0.1-0.2 mm dominant though larger grains up to 2 mm occur. Some banding occurs among larger grains similar to 024-57A-1.
Alkali feldspars 33% - Fine grained, 0.1-0.2 mm, with occasional grains up to 1 mm.
Plagioclase 10% - Grains up to 0.3 mm showing little or no alteration.
Biotite 2% - Small laths up to 0.2 mm occur singly and in occasional small clusters.
Muscovite 2% - Crystals up to 0.4 mm sometimes associated with biotite but not very common.
Opaque 1%

VULCAN MATERIALS COMPANY, DALTON, GA. (013)

<u>Rock Description:</u> Dark Dolomitic Limestone

013-57A-1 X-ray - Dominant minerals are calcite and dolomite in roughly equal percentages along with quartz. Very small amounts of chlorite also present. The insoluble residue comprised a very large percentage of the total, approximately two thirds.

013-57A-2 X-ray - Dominant minerals are calcite and dolomite with calcite being much more common than the dolomite. Quartz and chlorite also present although in much smaller quantities than Dalton-013-571-1, approximately 10%.

013-57A-3 X-ray - Dominant minerals are calcite and dolomite with calcite being much more common than the dolomite. Quartz and chlorite also present and again in relatively small quantities, approximately 10%.

VULCAN MATERIALS COMPANY, BARIN, GA. (044)

General Description:

044-57A Light to dark gray medium grained rock with a relatively low quartz content. Banding is sometimes noticeable and some of the more biotite rich specimens exhibit a schistose texture while others show no foliation. The crystal size of the biotite tends to increase with the amount of biotite present in the specimen. Accesory minerals include garnet and epidote in very small amounts.

Rock Type: Biotite Granite Gneiss

044-57A-1 Quartz 29% - Medium grained, 1-2 mm, showing a moderate amount of fracturing.
Plagioclase 54% - Grains commonly 1-2 mm showing some fractures and minor alteration. Alteration is often more severe near grain boundaries when in contact with biotite crystals.
Biotite 17% - Occurs singly and in small clusters of crystals, 0.5-1 mm. Crystals are somewhat aligned within the clusters but not over the entire slide.

044-57A-2 Quartz 38% - Large irregularly shaped grains of 2-4 mm common. Some fracturing noted, especially in the larger grains.
Alkali feldspars 1% - Occurs in very small amounts as small crystals, <1 mm.
Plagioclase 54% - Medium grained, 2-3 mm, often showing light fracturing and alteration.
Biotite 6% - Single crystals of moderate size, up to 2 mm occuring disseminated throughout.
Epidote <1% - Trace.

044-57A-3 Quartz 24% - Most crystals are approximately 1 mm in size with occasional grains up to 2.5 mm. Larger grains exhibit a moderate amount of fracturing.
Alkali feldspars 33% - Most grains 1-1.5 mm with occasional large grains up to 5 mm.
Plagioclase 41% - Medium grained throughout, 2-3 mm, usually showing large numbers of small fractures and some alteration along the fractures although not severe.

Biotite 2% - Small laths occurring singly averaging 0.5 mm in size.
Opaque 1% - Occurs as irregular crystals <1 mm.

VULCAN MATERIALS COMPANY, KENNESAW, GA. (046)

General Description:

046-57A Dark gray fine to medium grained relatively homogeneous sample. Quartz content comparatively low. Biotite content relatively high, approximately 10%, hornblende common throughout. Accessory epidote and rare garnets present. Some foliation evident but not well developed.

Rock Type: Biotite Hornblende Granitoid Gneiss

046-57A-1 Quartz 25% - Generally fine grained, approximately 1 mm, exhibiting some fracturing though not severe.
Plagioclase 43% - Fine grained 0.5-2 mm grains showing light to moderate alteration and moderate fracturing.
Hornblende 20% - Anhedral, highly fractured crystals, 1-2 mm common throughout sample.
Biotite 11% - Commonly occurring in clusters with crystals approximately 1 mm.
Muscovite < 1% - Small amounts associated with clusters of biotite.

046-57A-2 Quartz 27% - Fine grained, 0.5-1 mm. Larger grains often have very irregular shapes.
Plagioclase 43% - Coarser grained than quartz with 1-2 mm grains common. Alteration is light to moderate.
Hornblende 21% - Anhedral crystals to subhedral crystals 1-2 mm.
Biotite 8% - 1 mm crystals occurring in some clusters and disseminated throughout sample.
Epidote 1%

046-57A-3 Quartz 37% - Unfractured grains of approximately 0.5 mm dominate though grain sizes of .05-3 mm are common throughout.
Plagioclase 38% - Mostly fine grained, 0.5-1 mm, with some grains up to 3 mm. Little or no alteration evident.
Biotite 12% - Crystals up to 2 mm in size often eroded occur in clusters usually associated with hornblende.
Hornblende 13% - Anhedral to subhedral crystals up to 2 mm. Usually fractured and eroded.

VULCAN MATERIALS COMPANY, LITHIA SPRINGS, GA. (047)

General Description:

047-57A Medium to coarse grained, light colored rock containing quartz, white alkali feldspars, muscovite and biotite. Most specimens exhibit fairly well developed banding except those containing pink orthoclase alkali feldspars which are unbanded. Muscovite and biotite occur together in crystals of 1-2 mm.

Rock Type: Mica Granite Gneiss

047-57A-1 Quartz 41% - Grain size ranges from 0.1-4 mm with 1-2 mm most common. Minor fracturing occurs mostly in larger grains.
Alkali feldspars 40% - Occurs mainly as large clusters of irregularly shaped smaller grains, 1-2 mm in size. Occasional grains up to 3 mm.
Plagioclase 15% - Occurs throuhgout as unaltered grains 1-2 mm. Albite twinning common with some carlsbad.
Biotite 3% - Primarily occurs as small, <1 mm, single crystals or in small clusters associated with muscovite.
Muscovite 1% - Occurs with biotite in slightly larger though less common crystals.
Calcite <1%

047-57A-2 Quartz 42% - Moderately fractured grains of 1-2 mm dominate with some up to 4 mm.
Alkali feldspars 35% - Occurs in clusters of 1-2 mm grains.
Plagioclase 19% - 1-2 mm crystals showing slight alteration of some grains.
Biotite 3% - Small laths up to 1 mm occur singly or in small clusters similar to 047-57A-1.
Muscovite 1% - Uncommon crystals up to 1 mm usually occur with biotite.
Calcite <1%

047-57A-3 Quartz 54% - Medium to coarse grained, 2-5 mm, with some smaller grains. Larger grains are concentrated in several bands running across the slide. Fracturing is light.
Alkali feldspars 22% - Several large grains, up to 5 mm, and large groups of small grains dominate. Banding similar to that shown by the quartz.
Plagioclase 15% - Occurs as smaller grains of 0.5-1 mm with some slight alteration.
Biotite 5% - Crystals of 0.5-1 mm are foliated parallel to the larger quartz and alkali feldspars bands.
Muscovite 3% - Occurs as masses of very small crystals usually associated with biotite.

Epidote 1%

VULCAN MATERIALS COMPANY, NORCROSS, GA. (048)

General Description:

048-57A Light to medium gray fine to medium grained with occasional plagioclase grains up to 5 mm. Banding generally not well developed. Some specimens contain large, up to 4 mm, hornblende crystals. Epidote present throughout in small quantities. Accessory garnets also common in small amounts. Muscovite is present though rare.

Rock Type: Biotite Granitoid Gneiss

048-57A-1 Quartz 30% - Rounded grains of all sizes up to 1 mm with rare larger grains of 2-3 mm. Moderate fracturing noted in larger grains.
Plagioclase 42% - Grains of 1-2 mm dominate with some light alteration.
Biotite 9% - Often associated with hornblende in crystals up to 1 mm.
Hornblende 16% - Occurs as medium sized, up to 2 mm, highly fractured crystals or as masses of eroded and embayed crystals, also highly fractured.
Epidote 2%
Opaque 1%

048-57A-2 Quartz 42% - Medium size grains, 1-3 mm, showing only minor fractures.
Plagioclase 47% - Crystals of 1-2 mm are often rounded somewhat and show slight alteration.
Biotite 9% - Occurs as small irregularly shaped masses or as small laths up to 1 mm.
Hornblende <1% - Trace
Epidote 2% - Small rounded crystals occuring in small groups.

048-57A-3 Quartz 51% - Wide size distribution, 0.1-3 mm common. Larger grains tend to cluster together and are often elongated. Very little fracturing noted.
Plagioclase 40% - Grains are more uniform in size, 1-2 mm, and are evenly distributed. Very litle fracturing or alteration.
Biotite 8% - Crystals up to 1 mm occur singly and in small clusters associated with muscovite. Some clusters show some alignment parallel to elongated quartz crystals although this is not well developed.
Muscovite 1% - Crystals up to 1 mm usually occur with

biotite though much less common.
Epidote <1% - Trace.
Opaque <1% - Trace.

VULCAN MATERIALS COMPANY, STOCKBRIDGE, GA. (050)

General Description:

050-57A White to medium gray, fine to medium grained. Biotite common in most specimens though almost completely lacking in a few. Some foliation evident in biotite rich samples though not well developed in most. In many specimens the alkali feldspars have undergone substantial weathering and generally have a chalky feel. Accessory garnet and epidote are sometimes present.

Rock Type: Bioite Granite Gneiss

050-57A-1 Quartz 53% - Grain sizes of 0.1-5 mm occur throughout. Larger grains are often irregularly shaped and exhibit greater fracturing than smaller grains.
Alkali feldspars 17% - Irregularly shaped grains 0.5-1 mm, occasionally up to 2 mm.
Plagioclase 26% - Very similar to the alkali feldspars but somewhat more common and showing slight alteration.
Biotite 3% - Very small crystals of 0.1-0.3 mm occuring singly throughout.
Hornblende <1%
Epidote <1%

050-57A-2 Quartz 33% - Medium to coarse grains of 1-4 mm with moderate to heavy fracturing especially on the larger grains.
Alkali feldspars 18% - Primarily rounded grains of 1-3 mm.
Plagioclase 34% - 1-2 mm grains common showing moderate to heavy alteration with calcite, muscovite and sericite as alteration products.
Biotite 6% - 0.1-0.5 mm crystals occur singly for the most part with some small clusters.
Muscovite 8% - Occurs as larger grains, up to 2 mm, usually associated with biotite and often highly eroded.
Calcite <1%
Opaque <1%

050-57A-3 Quartz 18% - Fine grained, < 1mm, showing some fracturing though not severe. Some alteration noticeable. Quartz sometimes difficult to distinguish from plagioclase.
Plagioclase 41% - Albite twinned, 0.5-1mm, usually

alterered to some degree though not severe. Sericite present along fractures and sometimes follows twin boundaries. No zoning apparent.

Biotite 26% - Present throughout in laths up to 1 mm. Crystals generally occur singly and show no foliation.

Hornblende 12% - Crystals slightly larger than biotite, 1-1.5 mm, disseminated throughout.

Epidote 3%

MARTIN MARIETTA AGGREGATES, RUBY, GA. (054)

General Description:

054-57A Dark colored fine grained rock with a greenish tint. Most specimens are very biotite rich. The green color is possibly due to alteration of biotite to chlorite. Several specimens are coarser grained with an abundance of orthoclase alkali feldspars and a very low quartz content. Titanite is common as an accessory mineral. No foliation noted.

Rock Type: Biotite Granite Gneiss

054-57A-1 Quartz 20% - Primarily very small crystals of 0.05-0.5 mm. Some crystals up to 1 mm.

Alkali feldspars 18% - Few crystals but quite large, up to 5 mm, showing some very slight alteration.

Plagioclase 45% - Crystals up to 3 mm. showing some zonation. Alteration and fracturing range from light to extreme. Extreme alteration occurs mostly in one half of the slide and involves almost total replacement of plagioclase with sericite.

Biotite 13% - Occurs mostly in clusters of small crystals, up to 1 mm. Some grains show evidence of alteration to chlorite.

Titanite 1% - Euhedral to anhedral crystals up to 1 mm usually occuring with biotite.

Muscovite <1% - Trace amounts of small crystals associated with biotite.

Opaque <1%

054-57A-2 Quartz 32% - Fine grained, 0.05-0.5 mm, with little or no fracturing.

Alkali feldspars 3% - Small grains, up to 1 mm distributed sparsley throughout.

Plagioclase 54% -Grains of 1-1.5 mm common. Alteration varies from moderate to extreme. Heavier alteration occurs near edges of slide.

Biotite 5% - Very small single crystals of up to 0.5mm

Hornblende <1% - Small rounded grains up to 0.5 mm occuring singly.

Chlorite 5% - Occurs in elongate masses up to 2 mm long composed of very small crystals.
Titanite <1%
Opaque <1%

054-57A-3 Quartz 23% - Occurs in clusters of very small crystals, 0.1-0.2 mm, with some up to 1 mm.
Alkali feldspars 41% - Coarse grained with crystals of 3-5 mm common. Some slight alteration present.
Plagioclase 32% - Crystals of 1-2 mm showing moderate to heavy alteration. Some zoned plagioclase crystals present show substantially less alteration than most others.
Chlorite 3% - Mostly small grains of less than 0.5 mm formed as alteration product of biotite.
Opaque 1%

GEORGIA MARBLE COMPANY, LITHONIA, GA. (011)

General Description:

011C-57A Fine to medium grained light colored granite very rich in alkali feldspars. Biotite content is generally quite low. Some specimens show poorly developed banding with small amounts of pyrite concentrated in the dark bands. There is very little variation within the sample in contrast with other samples.

Rock Type: Muscovite Biotite Granitoid Gneiss

011C-57A-1 Quartz 37% - Medium grained throughout, 1-2 mm with some larger grains up to 6 mm. Fractures common though not severe. Smaller grains ,0.2 mm, disseminated throughout.
Alkali feldspars 43% - Medium to coarse grains, 1-3 mm, common.
Some fracturing present though not as severe as in the quartz.
Plagioclase 16% - Fine grained, 0.1-1.5 mm with some fracturing and slight alteration.
Biotite 2% - Small laths, 0.2-0.5 mm with some larger flakes of approximately 1 mm. Generally occuring separately and showing no foliation.
Muscovite <1% - Very rare with grains up to 0.2 mm.
Epidote <1%
Opaque 1%

011C-57A-2 Quartz 28% - Finer grained, 0.5-1.5 mm, with few fractures.
Alkali feldspars 33% - Unfractured grains of 1-2 mm.

Plagioclase 31% - 1-2 mm grains exhibiting very slight alteration
Biotite 4% - Small to medium sized grains and laths, 0.5-1 mm occuring singly or in small clusters showing no foliation.
Muscovite 2% - Associated with biotite in clusters with small grains up to 0.2 mm.
Epidote 1% - Occurs in small clusters.
Opaque 1%

011-57A-3 Quartz 30% - Grain sizes range from 0.1-2 mm with larger grains showing some fractures.
Alkali feldspars 34% - Somewhat larger grains than quartz, evenly distributed 0.5-2 mm.
Plagioclase 30% - Grains of 0.5-1 mm common. Little or no alteration, some fractures though not severe.
Biotite 5% - Occurs singly or in small cluster of 2-3 crystals 0.5-1 mm in size.
Muscovite 1% - Uncommon, occurs as occasional large crystals up to 2 mm or as very small thin laths.
Epidote <1%

011C-57B-1 Quartz 18% - Somewhat rounded grains of 0.5-2 mm with smaller grains <0.1 mm common. Larger grains show some fracturing.
Alkali feldspars 40% - Medium to coarse grains of 1-4 mm.
Plagioclase 32% - Mostly small crystals, <1 mm, with occasional larger crystals up to 2 mm. No alteration and little or no fracturing.
Biotite 5% - Small laths, <0.5 mm, sometimes intergrown with muscovite.
Muscovite 1% - Small laths, <0.5 mm.
Opaques 2% - One large crystal, 3 mm, and one smaller crystal, 1 mm.

011C-57B-2 Quartz 22% - Mostly smaller grains, < 1 mm with occasional larger grains, approximately 3 mm. Some fracturing but not severe.
Alkali feldspars 46% - Very common in one-half of specimen as 2-3 mm crystals occuring with smaller grains of less than 1 mm. Alkali feldspars is less abundant in the other half occurring as crystals of less than 1 mm.
Plagioclase 18% - Occurs mostly in the alkali feldspars rich zone though it is not very abundant. Moderate alteration in some grains.
Biotite 12% - Occurs in large clusters of grains up to 1 mm. Some clusters show good alignment though not throughout the specimen. Biotite occurs primarily in the alkali feldspars poor zone.
Muscovite 2% - Occurs in clusters along with biotite. Crystals usually somewhat larger than biotite, up to

1 mm.
Opaque <1%

GEORGIA MARBLE COMPANY, CUMMING, GA. (038)

General Description:

038-57A Light to medium gray, medium to coarse grained. Biotite content from 1-10% or more. Biotite rich samples approaching schistose texture. Most alkali feldspars grains <5mm though some large, > 1cm, alkali feldspars grains present.
Relatively fine grained muscovite present in varying amounts 1-9%. Some samples contain accessory garnet.

Rock Type: Biotite Granite Gneiss with Schist Stringers

038-57A-1 Quartz 40% - Very fine grained quartz <0.1 mm often surrounds large alkali feldspars grains. Elsewhere size distribution is more random 0.05-2 mm. Grains are for the most part unfractured.
Alkali feldspars 29% - Wide size distribution, 0.1-7 mm with larger grains dominating but fine grains common.
Plagioclase 23% - Fine grained, <1 mm, and rare. Albite twinning common, unaltered.
Biotite 5% - Fine grained, <0.5 mm. Sparse but present throughout. Some alignment of grains though less noticeable than in muscovite due to small grain size.
Muscovite 3% - Coarser grained than biotite, up to 1 mm. Occurs less randomly than biotite, primarily as long thin grains or masses of smaller grains.

038-57A-2 Quartz 48% - Quartz in one half of sample occurs as long linear grains approximately 1 x 5 mm, aligned parallel to one another. Elsewhere quartz occurs as fine rounded grains <0.5mm.
Alkali feldspars 1% - Present only in coarse end of sample in 1-2 mm grains
Plagioclase 13% - Fine grained <1 mm, present throughout sample. Unaltered showing albite and some pericline twinning.
Biotite 1% - Fine grained uncommon. Found primarily in fine grained portion of sample.
Hornblende 32% - Occurrence and character very similar to quartz. Coarse grains define foliation, fine grains occur elsewhere.
Opaque 4% - Occurs as small grains, <0.5 mm, distributed throughout the specimen.

038-57A-3 Quartz 33% - Occurs in all sizes from 0.1-3 mm. The larger grains are usually elongated and aligned parallel to one another.

Alkali feldspars 29% - 1-2 mm grains are most common with occasional grains up to 6 mm. Most grains are rounded though others show some elongation.

Plagioclase 28% - Rounded grains of 1-2 mm common showing moderate to heavy alteration with calcite and fine grained muscovite as alteration products.

Biotite 5% - Fine grained, occurs in small clusters sometimes associated with muscovite.

Muscovite 9% - Present as medium sized grains, 1-2 mm as well as very fined grained sericite in areas of alteration.

Calcite <1% - Accessory mineral associated with plagioclase alteration zones.

GEORGIA MARBLE COMPANY, DAN, GA. (041)

General Description:

DAN-041C-57A-1 Quartz 33% - Two large quartz veins dominate top portion of slide. Veins are composed of small to medium grains up to 4 mm in length with 1-2 mm grains common. Also large numbers of very small, 0.05-0.1mm, grains present throughout. The larger grains tend to be elongated parallel to one another and to the long axes of the veins.

Alkali feldspars 60% - Dominant mineral except in the quartz veins. Grain size ranges from 1-5 mm. Some grains show perthitic texture though usually not well developed. Several rounded alkali feldspars grains present within the quartz veins.

Plagioclase 7% - Present as small grains of approximately 1 mm located primarily at the upper end of slide in the region of the quartz veins.

Rock Type: Highly Variable - probably quartz-injected granitoid

DAN-041C-57A-2 Quartz 30% - Occurs primarily in parallel quartz rich veins as elongate grains of 1-2 mm and very small grains <0.1 mm. The veins are generally much smaller than those in DAN-041C-57A-1.

Alkali feldspars 58% - Predominantly fine grained, 0.5-1 mm, showing some weathering and occasional sericite along fractures.

Plagioclase 4% - Occurs as fine grains, <1 mm distributed sparsely throughout.

Hornblende 7% - Occurs as small grains of approximately 0.5 mm and sometimes as clusters of fine grains.

Biotite 1% - Occurs rarely as fine grains similar to hornblende.

DAN 041C-57A-3 Quartz 69% - Medium grains of 1-2 mm surrounded by more abundant fine grains of approximately 0.2 mm with indistinct boundaries. Some flow patterns evident.
Alkali feldspars 23% - Medium grains of 1-2 mm showing substantial weathering and rounding.
Muscovite 6% - Wide size range from thin shreds of 0.2 mm to crystals of 2mm. Crystals are aligned in the direction of apparent flow.
Opaques 2% - Occur as relatively small irregularly shaped crystals.

GEORGIA MARBLE COMPANY, BALL GROUND, GA. (112)

General Description:

112-57A Light to dark gray fine-grained marble. Bands of white calcite alternate with darker biotite-rich bands, but the size of the bands is such that fragments in this sieve split are normally all within one band.

Rock Type: Biotite Marble

112-57A-1 Plagioclase 39% - Altered to blebs of quartz, calcite, and epidote. Mostly in ovoids and augen that sometimes show faint twinning and zonation in the distribution of the alteration products. Mica and calcite swirl around the ovoids. From 0.05 mm to 2 mm.
Calciate 26% - Ubiquitous, but also segregated into pure bands, wherein the grain size is distinctly larger, by about 5X. From 0.03 mm to 2 mm.
Biotite 21% - Red to pale yellow-pink pleochroic. Fresh mostly, except for a few grains that are chloritized. Concentrated with feldspar. From 0.01 mm to 0.6 mm.

Quartz 11% - As blebs in altered plagioclase (finest grains - <0.01 mm) and as independent fine (to 0.1 mm) grains.

Muscovite 2% - Independent flakes - infrequently in optical alignment with biotite. 0.2 mm to 0.5 mm.
Epidote 1% - Same distribution and size as quartz.
Pyrite Trace - 0.01 mm to 0.25 mm.

112-57A-2 Calcite 49% - Ubiquitous, but also segregated into pure bands, wherein the grain size is distinctly larger (by about 2X) and also more nearly equant. Outside the pure bands, the grains are elongated, with the long dimension 0.05 mm to 1 mm.

Plagioclase 23% - Altered to blebs of quartz, calcite, and epidote. Mostly in ovoids and augen that sometimes show faint twinning and zonation in the distribution of the alteration products. Mica and calcite swirl around the ovoids. From 0.05 mm to 1 mm.
Biotite 16% - Red to pale yellow pleochroic. Fresh mostly, except for a few grains that are chloritized. Concentrated with feldspar, but to a lesser degree than in 112-57A-1. From 0.01 mm to 0.6 mm.
Quartz 7% - As blebs in altered plagioclase (finest grains - <0.01 mm) and as independent fine (to 0.1 mm) grains.
Muscovite 4% - Independent flakes - infrequently in optical alignment with biotite. 0.2 mm to 0.5 mm.
Epidote 1% - Same distribution and size as quartz.
Pyrite 1% - 0.01 mm to 0.25 mm.

112-57A-3 Calcite 65% - Essentially as in 112-57A-1 and 112-57A-2, except banding is slightly less obvious.

Plagioclase 11% - Altered blebs of quartz, calcite, and epidote. Mostly in voids and augen that sometimes show faint twinning and zonation in the distribution of the alteration products. Mica and calciate swirl around the ovoids. From 0.05 mm to 1 mm.

Biotite 10% - Red to pale yellow-pink pleochroic. Fresh mostly, except for a few grains that are chloritized. Concentrated with feldspar, but to a lesser degree than in 112-57A-1. From 0.01 mm to 0.6 mm.
Muscovite 8% - Independent flakes - infrequently in optical alignment with biotite. 0.2 mm to 0.5 mm.
Quartz 5% - As blebs in altered plagioclase (finest grains - <0.01 mm) and as independent fine (to 0.1 mm) grains.
Epidote 1% - Same distribution and size as quartz.
Pyrite Trace - In bands parallel to foliation.

Apparently there is no particular association with other constituents. 0.01 mm to 0.25 mm.

GEORGIA MARBLE COMPANY, BUFORD, GA. (102)

General Description:

102-57A Light to medium gray, primarily fine grained granite with some larger, >5 mm orthoclase grains present in some specimens. Some banding noticeable. Schistosity noted on some surfaces although it does not dominate due to insufficient mica content. Both muscovite and biotite present. Some specimens contain accessory opaques magnetite and pyrite. Epidote also present in small amounts.

Rock Type: Biotite Granite Gneiss

102-57A-1 Quartz 51% - Present throughout primarily as very fine grains, 0.02-.1 mm with some bands containing larger grains, 1 mm. Grains gererally unfractured and show little or no alteration.
Alkali feldspars 36% - primarily fine grained with coarser grained band similar to quartz. Maximum grain size approximately 2 mm.
Plagioclase 2% - Crystals,<0.5 mm, rare, usually altered somewhat and fractured.
Biotite 6% - Thin laths 0.5-1.5 mm long ocurring singly.
Muscovite 4% - Larger crystals than biotite, 2 mm, and usually deeply embayed.
Epidote 1%

102-57A-2 Quartz 40% - primarily occurs as fine grains, 0.05-0.2 mm, up to 0.5 mm common. Sparse larger grains up to 2 mm also present. Some fracturing noted in larger grains.
Alkali feldspars 41% - common throughout mostly as 0.1-1 mm grains, occaisional larger grains up to 2 mm.
Plagioclase 9% - Poorly twinned, altered grains up to 0.5 mm.
Biotite 5% - common as thin laths, 0.3-1mm in length distributed singly throughout. Some foliation evident, though not well developed.
Epidote <1%

102-57A-3 Quartz 28% - Primarily fine grains, 0.01-0.2 mm dispersed in a fine grained alkali feldspars rich groundmass. Rare larger grains of 2-3 mm also present.
Alkali feldspars 40% - Dominant both in groundmass and as phenocrysts. Crystals generally 0.5-1 mm with some slightly larger.
Plagioclase 4% - Rare, somewhat altered grains, poorly twinned in most cases.
Biotite 1% - Rare as very small laths, <0.2 mm.
Muscovite 3% - Singly occurring, often embayed grains up to 0.5 mm.
Groundmass 24%

THE STONE MAN, INC., WHITE, GA. (067)

Rock Description: Dark Limestone

067-57A-1 X-ray - Calcite dominates with traces of dolomite and small amounts of quartz, chlorite and muscovite present. Insoluble residue accounts for about 5% of the total. Hand samples are covered with a thin coating of fine grained rock dust.

067-57A-2 X-ray - Very similar to 067-57A-1 with calcite and small amounts of dolomite, quartz, chlorite and muscovite. Insoluble residue of <5% and similar fine grained coating on hand samples.

067-57A-3 X-ray - Very similar to 067-57A-1 with calcite and small amounts of dolomite, quartz, chlorite and muscovite. Insoluble residue of approximately 4% with fine grained coatings on hand samples.

SOUTHERN AGGREGATES, INC., POSTELL, GA.- Auxiliary (028)

General Description:

028-5A-1-P-AUX Quartz 20% - Primarily fine grained 0.1-0.5 mm with some grains up to 1 mm.
Alkali feldspars 25% - Occurs in medium to coarse grains of 2-3 mm with with some grains up to 8 mm. Some weathering is evident though not severe.
Plagioclase 40% - Medium grained 2-3 mm crystals showing some weathering and alteration to sericite. Some crystals are zoned and alteration is concentrated in these zones.
Biotite 13% - Occurs in clusters of small crystals of approximately 0.5 mm. Very small amounts of chlorite are also present. No foliation evident.
Titanite 1% - Occurs rarely as euhedral crystals of approximately 1 mm.
Opaques 1% - Occur rarely as small irregular crystals.

Rock Type: Biotite Granite Gneiss

028-5A-2-P-AUX Quartz 23% - Disseminated throughout as small crystals 0.1-0.5 mm, occasionally up to 1 mm.
Alkali feldspars 14% - Occurs in masses of poorly formed and weathered crystals of <1 mm.
Plagioclase 48% - 1-2 mm crystals common with some up to 3 mm. Somewhat weathered and altered and frequently fractured. Some larger crystals are zoned.

Biotite 1% - Occurs rarely as very small grains scattered throughout.
Hornblende 5% - Relatively common in on half of the sample as small, 0.5-1 mm, fractured crystals.
Chloritized hornblende 9% - Associated with unaltered hornblende - anomalous blue color - wispy stringers leading from and around hornblende grains.

028-5A-3-P-AUX Quartz 32% - Ranges in size from 0.1-0.5 mm with the smaller grains more common.
Plagioclase 58% - Dominant mineral present in all sizes from 0.2-3mm common. Some weathering noted. Larger grains are fractured parallel to cleavage planes. Some zoning of crystals noted though not common.
Biotite 10% - Relatively common in small clusters of fine laths up to 0.5 mm. Some foliation noted.