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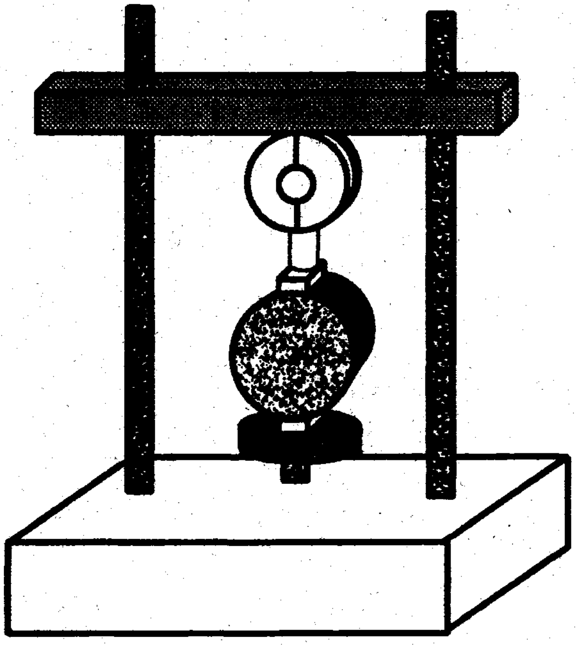

Moisture Sensitivity in Asphalt Concrete Mixtures

UNIVERSITY OF MINNESOTA

CENTER FOR
TRANSPORTATION
STUDIES

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16. Abstract (Limit: 200 words)

The research performed for this report was intended to recommend alternative mix design procedures and parameters for evaluation of asphalt mixture sensitivity, with more of an emphasis on volumetric relationships. Three Mn/DOT projects were selected to represent the following durability issues: 1) debonding of asphalt from aggregate, 2) cohesion problems, and 3) mix design problems. Materials were obtained from these construction projects and evaluated in the laboratory. Gradations were varied from the project specifications so that mixtures with more and less asphalt were evaluated along with the project mixture. Testing included the temperature susceptibility and moisture sensitivity of the mixtures, in addition to the net adsorption test on the aggregates.

The results suggested means for identifying moisture sensitivity mechanisms in mixtures during the mixture design phase, although these need to be confirmed through more extensive investigation. Aggregate mineralogy, gradation, and mixture proportioning can all play a role in improving the durability characteristics of asphalt mixtures. Recommendations are made for continued research and implementation of an improved approach to asphalt mixture design.

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Moisture Sensitivity in Asphalt Concrete Mixtures

Final Report

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INTRODUCTION

Durability is one of the greatest problems confronting the performance of flexible pavements. No amount of conservation in design can make up for a lack of resistance to weathering. Although durability problems are normally associated with a lack of bonding between asphalt and aggregate (stripping) other mixture related problems may result in moisture sensitivity.

Over the last 20 or so years, many states have mitigated moisture damage in asphalt concrete with the addition of either liquid anti-strip additives or hydrated lime. While the use of lime has proven to be the most consistently successful method for reducing moisture related accelerated pavement distresses, this additive also requires plant modifications and additional environmental and worker safety considerations. A more desirable approach would be to adjust standard mix design parameters related to pavement durability such as the asphalt film thickness and the in-place voids.

In order to determine whether an additive is required or if changes in the mix design would be sufficient to mitigate moisture related problems, a laboratory testing program capable of identifying the cause of moisture sensitivity needs to be established. While the moisture sensitivity of mixtures has been evaluated extensively over the last 20 years, only limited work has been done to specifically identify the reasons for moisture sensitivity. Before a routine program for evaluating moisture sensitivity can be added to the mix design process, current tests need to be evaluated to ensure that they identify the actual cause of the problem.

RESEARCH PROGRAM

Objectives

The main objective of this research was to recommend alternative mix design procedures and parameters for moisture sensitive mixtures. It was anticipated that these recommendations would be based on current mix design technology with an increased emphasis on volumetric relationships (i.e., voids filled with asphalt, aggregate gradation, voids in mineral aggregate, total voids).

Scope

The research program was developed to investigate the influence of changes in film thickness and voids in mineral aggregate (VMA) with changes in aggregate gradation on the moisture sensitivity of hot mix asphalt concrete. Three projects were selected based on preliminary testing by Mn/DOT. It was felt that each of these projects would represent one of three moisture sensitivity mechanisms: 1) true stripping (debonding of asphalt from aggregate), 2) potential cohesion problems, and 3) mix design problems. This study was designed to be a complimentary study to the durability study conducted by the Minnesota Department of Transportation (Mn/DOT). The final Mn/DOT report for this study is included as Appendix A.

Supplies of both aggregate and asphalt for each project were obtained during construction. Mixtures were first prepared using the job mix formula (JMF) asphalts and aggregates in order to compare the University of Minnesota (U of M) tensile strength results with the Mn/DOT results. Next, the JMF aggregate gradation was used with a standard asphalt cement to determine the influence of a change in asphalt cement source, and in one case a change in grade, on moisture sensitivity. The influence of film thickness was evaluated by selecting a coarse gradation that would produce a VMA similar to that of the typically fine aggregate gradation used in the JMF. A second finer gradation was used to produce mixtures with thinner film thicknesses.

Testing included determining the temperature susceptibility of each of the mixtures as well as the retained resilient modulus and tensile strengths after moisture conditioning. The net adsorption test, developed during the Strategic Highway Research Program (SHRP) was also evaluated as an additional method for identifying moisture sensitive mixtures.

Final recommendations were based on a summary of these results and those reported by MnDOT in Appendix A.

SELECTION OF PROJECTS

A preliminary laboratory evaluation of a wide range of mixtures obtained from construction projects throughout the state was conducted at the Mn/DOT laboratory. This work included an evaluation of unconditioned tensile strengths, tensile strengths after a warm soak, and tensile strengths after a freeze/thaw cycle, as well as a visual estimate of stripping (Appendix A). Based on these results, three projects exhibiting a wide range of test results were selected for further testing at the University of Minnesota laboratory.

The first project selected was from District 6 (Project No. 7904-06) because it exhibited a moderate unconditioned tensile strength, but a high level of visual stripping was noted after moisture conditioning (Table 1). The second project was selected from District 7 (Project No. 3204-60) because it had a high unconditioned tensile strength , a low retained strength ratio after freeze/thaw conditioning, and little sign of visual stripping. The third project was selected from District 8 (Project No. 6407-27) because it had a low unconditioned tensile strength, a high retained strength ratio after freeze/thaw conditioning, and little visual stripping. These projects should provide information on how changes in mix design parameters change moisture sensitivity due to 1) the debonding of the asphalt from the aggregate (true stripping - District 6), 2) loss of cohesive strength (District 7), and 3) low initial mixture strength (District 8).

Table 1. Test Results for Each District as Reported by Mn/DOT.

Property	District 6	District 7	District 8
Unconditioned (Dry) Tensile Strength	621 kPa (92 psi)	883 kPa (128 psi)	414 kPa (60 psi)
Conditioned (Wet) Tensile Strength	359 kPa (52) psi	455 kPa (66 psi)	414 kPa (60 psi)
Tensile Strength Ratio (Wet/Dry), %	56	51	100
Visual Stripping, %	30 to 40	< 3	5 to 10

MATERIALS

All original job mix formula (JMF) materials were characterized at the Mn/DOT laboratory. In order to reduce the number of variables in the University of Minnesota's research program, the asphalt source and grade were standardized.

Asphalt Cements

Table 1 shows typical values for the job mix formula asphalt cement source and grade used in each of the projects. The Koch 120/150 pen asphalt cement from the Rosemont, Minnesota refinery was selected as the standard asphalt used throughout the research program. The properties for this asphalt are also shown in Table 2.

Table 2. JMF Asphalt Cement Source, Grade, and Typical Properties.

Properties	District 6[1] SP 7904-036	District 7[1] SP 3204-60	District 8[1] SP 6407-27	Standard Asphalt
Source	Ashland	Ashland, St. Paul Park	Richards	Koch
Grade	120/150	85/100	120/150	120/150
Viscosities:				
60° (140°F), Poise	400	1,131	752	877
135°C (275°F), cSt	160	295	243	276
Penetration 25°C (77°F), dmm	120	85	122	132
% Loss	-0.16	-0.07	0.03	-0.18

1: Data Supplied by Mn/DOT

Aggregates

The aggregate gradations of the individual stockpiles used for each of the three projects are shown in Table 2. This table also shows that the project in District 6 used 4 stockpiles while the projects in Districts 7 and 8 used 3 and 2 stockpiles, respectively. A limited visual assessment of the general mineralogy of each stockpile is also shown in Table 3.

The aggregates shown in Table 3 were used to prepare samples with the JMF gradation and two additional gradations. The coarse gradation, actually the bottom of the 2340 Type 41 gradation band, was selected to fall below the maximum density line, have an increased film thickness, but with VMA similar to those for the JMF. The fine gradation was selected as the top of the Mn/DOT 2341 gradation band and was included as a means of evaluating a reducing film thickness because of an increased aggregate surface area. All gradations are shown in Table 4. Figure 1 shows that there was little difference in any of the three district JMF gradations.

The blending percentages for each stockpile for each of the fine, JMF, and coarse gradations are shown in Table 5. The blending percentages for the JMF formula used in the construction project and those used for the research samples differed somewhat due to differences in the aggregate processing procedures and limited materials available for preparing research samples.

Table 3. Stockpile Aggregate Gradations and Properties.

District	District 6 SP 7904-36				District 7 SP 3204-060			District 8 SP 6407-27	
	350 Bennet	351 Holns	352 Kohner	353 Bennett	7 Dressen	8 Dressen	9 Hodgeman	26 Dallenbach Fines	25 Dallenbach Coarse
Mineralogy	Igneous Chert	Limestone Dolomite	Igneous & Limestone	Igneous Granitic	Igneous Granitic	Igneous Granitic	Quartzite	Riverwash Mixture	Igneous Granitic
% Stockpile	33	36	23	8	75	15	10	70	30
% Passing									
3/4 in	100				100		100		100
5/8 in	100				100		92		96
½ in	100	100	100	100	96	100	55	100	61
3/8 in	91	87	99	63	89	100	13	99	30
No. 4	76	42	99	23	76	93	5	85	10
No. 10	61	23	97	17	64	81		67	10
No. 20	42	15	55	12	43	64		45	9
No. 40	22	2	45	8	24	44		25	7
No. 80	5	9	30	4	11	13		11	4
No. 200	3.5	5.6	1.8	3.1	7.1	6.5		8.6	2.8
Specific Gravity	2.610	2.612	2.604	2.614	2.569	2.598	2.629	2.529	2.623
Water Absorption %	0.90	2.10	0.40	1.32	1.78	1.26	0.47	1.80	2.02

Table 4. Aggregate Gradations.

Properties	Job Mix Formulas			Laboratory Gradations	
	District 6 SP 7904-036	District 7 SP 3204-60	District 8 SP 6407-27	Coarse Gradation	Fine Gradation
Cumulative % Passing					
18.75 mm (3/4 in)		100	100	100	100
15.63 mm (5/8 in)		99	100	100	100
12.5 mm (½ in)	100	93	98	95	100
9.5 mm (3.8 in)	89	83	93	65	95
4.75 mm (No. 4)	65	70	69	52	83
2.07 mm (No. 10)	52	54	52	37	65
0.45 mm (No. 40)	23	21	24	10	35
0.075 mm (No. 200)	4	6	6	2	10

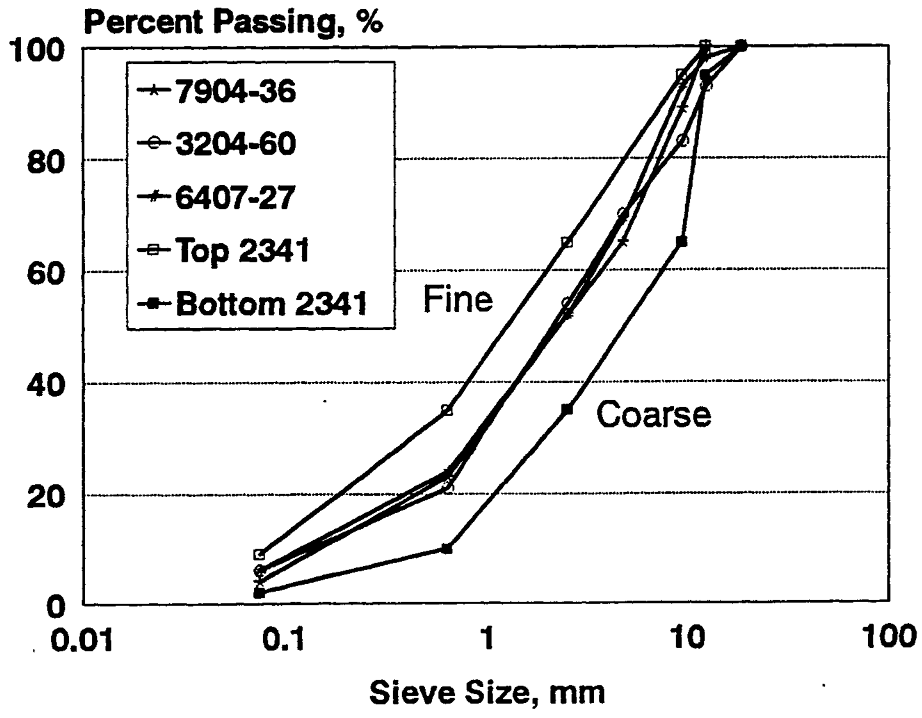


Figure 1. Aggregate Gradations.

Table 5. Blending Percentages of Stockpiles Used for Research Program.

District	Gradation	Stockpile & Percent	Stockpile & Percent	Stockpile & Percent	Stockpile & Percent
District 6	Fine	No. 350, 20%	No. 351, 14%	No. 352, 60%	No. 353, 6%
	JMF	No. 350, 30%	No. 351, 15%	No. 352, 30%	No. 353, 25%
	Coarse	No. 350, 2%	No. 351, 30%	No. 352, 15%	No. 353, 53%
District 7	Fine	No. 7, 18%	No. 8, 73%	No. 9, 9%	Not Applicable
	JMF	No. 7, 18%	No. 8, 54%	No. 9, 28%	
	Coarse	No. 7, 31%	No. 8, 28%	No. 9, 41%	
District 8	Fine	No. 26, 97%	No. 25, 3%	Not Applicable	
	JMF	No. 26, 90%	No. 25, 10%		
	Coarse	No. 26, 50%	No. 25, 50%		

MIX DESIGNS

The optimum asphalt cement contents were reported by Mn/DOT as 6.0, 5.5, and 5.0 percent for District 6 (SP 7904-036), District 7 (SP 3204-60), and District 8 (SP 6407-27), respectively. These were held constant in order to assess the influence of changes in asphalt film thickness due to changes in aggregate gradation on moisture sensitivity. While these values were held constant, Marshall mix designs were completed for all gradations so that actual asphalt contents could be compared to optimum asphalt contents. All mix design results are shown in Table 6.

The Marshall stability of the JMF and fine aggregate gradations were similar (Table 6). The coarse aggregate gradation had generally higher stability values than either the JMF or fine gradations.

Changing from the JMF and job mix asphalt cement to the JMF and standard asphalt cement resulted in a decrease in the optimum asphalt cement content for the District 6 mix, similar cement content for District 7, and an increase in the optimum content for the District 8 mix (Table 7). While these changes may appear to be due to the change in asphalt source, they were more likely due to differences in the specific stockpile percentages between the construction project and research aggregate gradations (Tables 3 and 5).

Using the coarse gradation and the standard Koch asphalt resulted in a uniform reduction in the optimum asphalt cement content of about 0.7 percent for both District 7 and 8 mixtures and little change in the District 6 mixture. The design void level of 4 percent was not achieved for the fine mixtures (Table 6). Therefore, the only observation that can be made for these mixtures is that the fine gradation resulted in an increased optimum asphalt content. The corresponding increase in VMA for the fine gradation reflects both the higher air voids as well as the reduction in asphalt film thickness due to the increased aggregate surface area.

Table 6. Mix Design Results (All Mixtures with Koch 120/150 AC).

Asphalt Cement Content, %	JMF			Coarse Gradation			Fine Gradation		
	Marshall Stability, lb.	VMA, %	Air Voids, %	Marshall Stability, lb.	VMA, %	Air Voids, %	Marshall Stability, lb.	VMA, %	Air Voids, %
District 6 (SP 7904-036)									
4.0	NA	NA	NA	1,079	15.8	7.7	NA	NA	NA
4.5	1,043	14.6	6.0	1,170	15.4	7.3	NA	19.8	11.8
5.0	1,211	14.2	5.2	1,677	15.4	4.2	NA	17.6	10.1
5.5	1,451	13.3	1.9	1,700	15.9	4.0	NA	20.4	9.1
6.0	1,529	13.5	0.5	NA	NA	NA	NA	18.0	6.2
District 7 (SP 3402-60)									
4.0	NA	NA	NA	1,566	13.7	5.0	NA	NA	NA
4.5	1,310	13.4	6.2	1,249	13.7	3.8	1,201	16.9	9.1
5.0	1,397	14.2	5.4	1,536	12.2	1.2	1,283	16.9	7.7
5.5	1,175	13.5	3.0	1,621	12.0	1.5	1,265	16.7	6.1
6.0	1,472	13.2	1.3	NA	NA	NA	1,223	16.7	5.5
District 8 (6407-27)									
4.0	NA	NA	NA	1,566	13.2	5.0	NA	NA	NA
4.5	1,111	18.1	6.9	1,249	13.1	3.8	961	21.8	11.0
5.0	930	18.2	5.5	1,536	11.7	1.2	1,104	24.0	11.6
5.5	943	19.0	5.2	1,621	11.5	1.5	980	21.	7.3
6.0	840	18.4	3.4	NA	NA	NA	987	19.7	5.1

Table 7. Optimum Asphalt Contents.

District/Project	JMF and JMF AC	JMF and Stand. AC	Coarse and Stand. AC	Fine and Stand. AC
District 6 (7904-36)	6.0	5.3	5.5	> 6.0
District 7 (3402-60)	5.5	5.3	4.5	> 6.0
District 8 (6407-27)	5.0	5.7	5.0	> 6.0

TESTING PROGRAM

Temperature Susceptibility

The temperature susceptibility of a mixture is evaluated by determining the change in mixture stiffness with temperature. Measurements of resilient modulus determined according to ASTM D4123 at various test temperatures are commonly used to develop this relationship.

Briefly, a conventional size sample was placed diametrically in a load frame capable of applying a haversine load pulse for 0.1 seconds. This load was followed by rest periods of varying durations (0.33, 0.5, and 1 Hz) and the corresponding horizontal deformations were measured. The magnitude of the applied load was adjusted for each temperature and mixture type so that the horizontal deformation was kept between 1.25 and 3.75 μm (50 and 150 μ-in). A minimum of 10 preconditioning cycles were used prior to data acquisition. Testing was conducted at three test temperatures: 1, 25, and 40°C (34, 77, and 104°F).

ASTM D4123 specifies that both horizontal and vertical deformations be measured; these measurements are intended to be used to calculate Poisson's ratio. However research has shown that this type of total vertical displacement measurement is unreliable for this calculation. Therefore all testing using this configuration assumed Poisson's ratio to be: 0.2 for temperatures below 1°C (34°F), 0.3 for 10°C (50°F), 0.35 for 25°C (77°F), and 0.5 for 40°C (104°F) (10).

Moisture Sensitivity

The most commonly accepted measure of the loss of mixture strength due to moisture and freeze/thaw damage is defined by the ASTM D 4867, "Standard Test Method for Evaluating the Effect of Moisture on Asphalt Concrete Paving Mixtures" (1). The research behind development of this procedure has shown that there is a general correlation between laboratory results and observed moisture damage of in-service pavements. Mixtures with retained strengths less than about 70 percent tend to exhibit moisture related pavement distresses (2). This is the test method recommended for inclusion in the SHRP Level 1 mix design procedures.

A second method to evaluate the loss of adhesion at the asphalt-aggregate interface was recently developed by researchers at Auburn University for the SHRP A-003B contract. While this method looks promising, the test method was not fully developed by the end of the SHRP contract. The final procedure used to evaluate these mixtures was developed under a separate Mn/DOT research project (3).

Net Adsorption

A 134-mL sample of a 0.6 g/L solution of asphalt cement dissolved in toluene was placed in a large chromatography column and a peristaltic pump was used to continuously circulate the solution. A set of three columns were run simultaneously. Four milliliters of solution were removed from each column for an initial determination of asphalt cement concentration with a spectrophotometer. The spectrophotometer measures the light absorbed by asphalt cement molecules suspended in the toluene. A wave length of 410 nm was used since it has been found to be the most sensitive wave length.

Fifty grams of graded aggregate were then added to each column and the solution was circulated through the column for 6 hours. Another 4-mL was removed from each column and the amount of adsorbed asphalt determined with a second spectrophotometer reading. Water (1150 μL) was added, and the solution and water recirculated for another 2 hours. The third and final reading was obtained at this time. This measurement is used to indicate the amount of asphalt cement that is returned to the solution due to the presence of water. The within-laboratory standard deviation was reported by SHRP as 0.14 mg/g for either washed or unwashed minus 4.75 mm (No. 4) fraction gradations.

One change was made in the original SHRP procedure. This was to use 50 g of the full aggregate gradation rather than limit the test to only the minus 4.75 mm (No. 4) fraction. This change was made in order to assess the influence of the full gradation on moisture sensitivity (3).

The amount of asphalt adsorbed from the solution at any given time is calculated by:

$$B_t = \frac{V}{M} C_o \left(\frac{A_o - A_t}{A_o} \right)$$

Where:

B_t = adsorption of asphalt cement by aggregate, mg/g

V = volume of solution in column just prior to obtaining reading,-mL

M = mass of aggregate in column, g

A_0 = initial absorbance reading

A_t = absorbance reading at time, t

C_o = initial concentration of asphalt in solution, g/ml

The amount of asphalt cement that is desorbed is the adsorption value after the water has been added to the column minus the value obtained just prior to adding the water to the column.

ASTM D4867 (Modified Lottman)

A set of six samples was prepared for each gradation and project; all samples for a given project were prepared with the same reduced numbers of blows to produce air void contents of 7 to 9 percent. Briefly, samples were separated into two sets. Air voids, resilient modulus and tensile strengths were determined for the first set (i.e., unconditioned). The second set of samples were partially saturated (55 - 80 percent), wrapped, frozen for a minimum of 15 hours, unwrapped and thawed for 24 hours in a 40°C (140°F) water bath. The samples were then brought to the 25°C (77°F) test temperature by storing in a water bath for 2 hours prior to testing. The data from this set of samples were referred to as the conditioned results. Moisture sensitivity was expressed as both the absolute values, before and after conditioning, for resilient modulus and tensile strength as well as the ratios of conditioned to unconditioned values.

Resilient modulus was determined at the 0.1-second load duration with the measurements taken over the full diameter of the sample (ASTM D4123), and test frequencies of 0.33, 0.5, 1.0 Hz. Tensile strengths were determined at a loading rate of 50 mm/min (2 in/min).

ANALYSIS

Temperature Susceptibility

Figure 2 shows that there was no consistent influence of a change of aggregate gradation on the temperature susceptibility for a given district (Table 8). There was little difference between 1 and 25°C (32 and 77°F) for either District 6 or 7 mixtures while District 8 showed that the coarse gradation increased the mixture stiffness over the entire range of test temperatures. Differences between the gradations were only seen at the warmer 40°C (104°F) temperature for Districts 6 and 7.

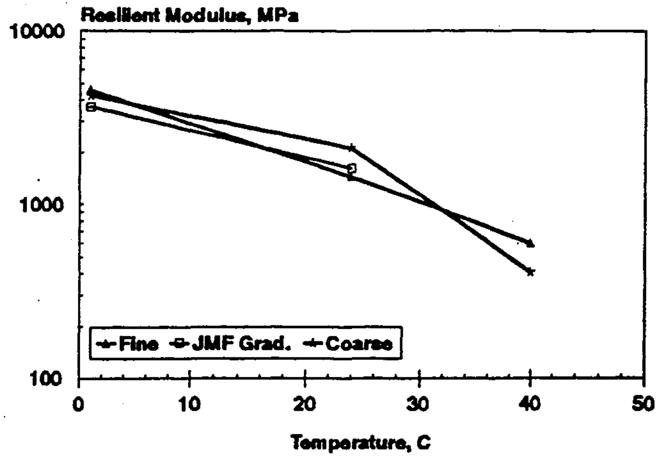
Figure 3 shows that all three individual projects had little difference in the temperature susceptibility at or below 25°C (77°F) when the fine gradation was used. There was a significant difference between all three projects at the warmer 40°C (104°F) test temperature. The differences in the temperature susceptibility became more project-specific as the coarseness of the gradation increased. Since the air voids and VMA were within a narrow range for a given gradation, any influence on the temperature susceptibility would most likely be due to differences in the aggregate stockpiles. These differences would include percent and number of crushed faces, mineralogy, and surface texture.

Table 8. Resilient Modulus at Various Test Temperatures.

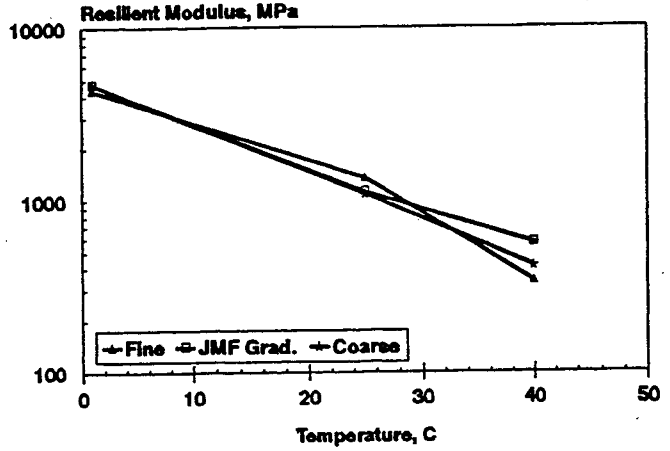
(All Mixtures with Standard 120/150 Pen Asphalt)

Temperature	Resilient Modulus, MPa (ksi)								
	Project								
	District 6 7904-36			District 7 3204-60			District 8 6407-27		
	Gradations								
	Fine	JMF	Coarse	Fine	JMF	Coarse	Fine	JMF	Coarse
1°C (34°F)	4,607 (668)	3,662 (531)	4,283 (621)	4,379 (635)	4,724 (685)	4,752 (689)	4,055 (588)	4,021 (583)	4,731 (686)
25°C (77°F)	1,442 (209)	1,607 (233)	2,110 (306)	1,352 (196)	1,124 (163)	1,083 (157)	1,255 (182)	1,076 (156)	1,614 (234)
40°C (104°F)	593 (86)	NA	407 (59)	338 (49)	566 (60)	414 (60)	422 (61)	462 (67)	524 (76)

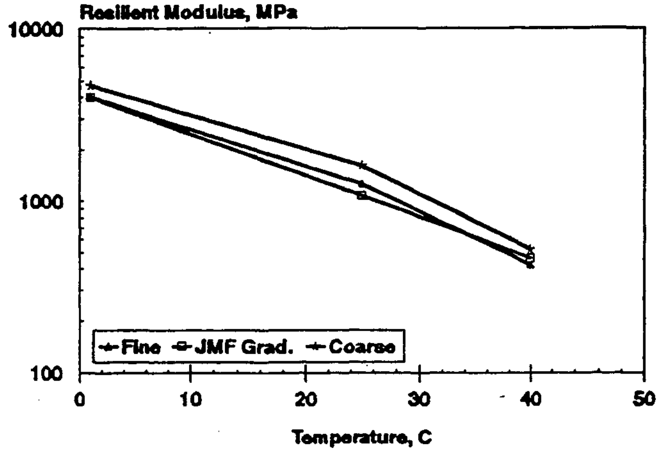
NA:Samples too soft to test.



District 6 (Project 7904-36)

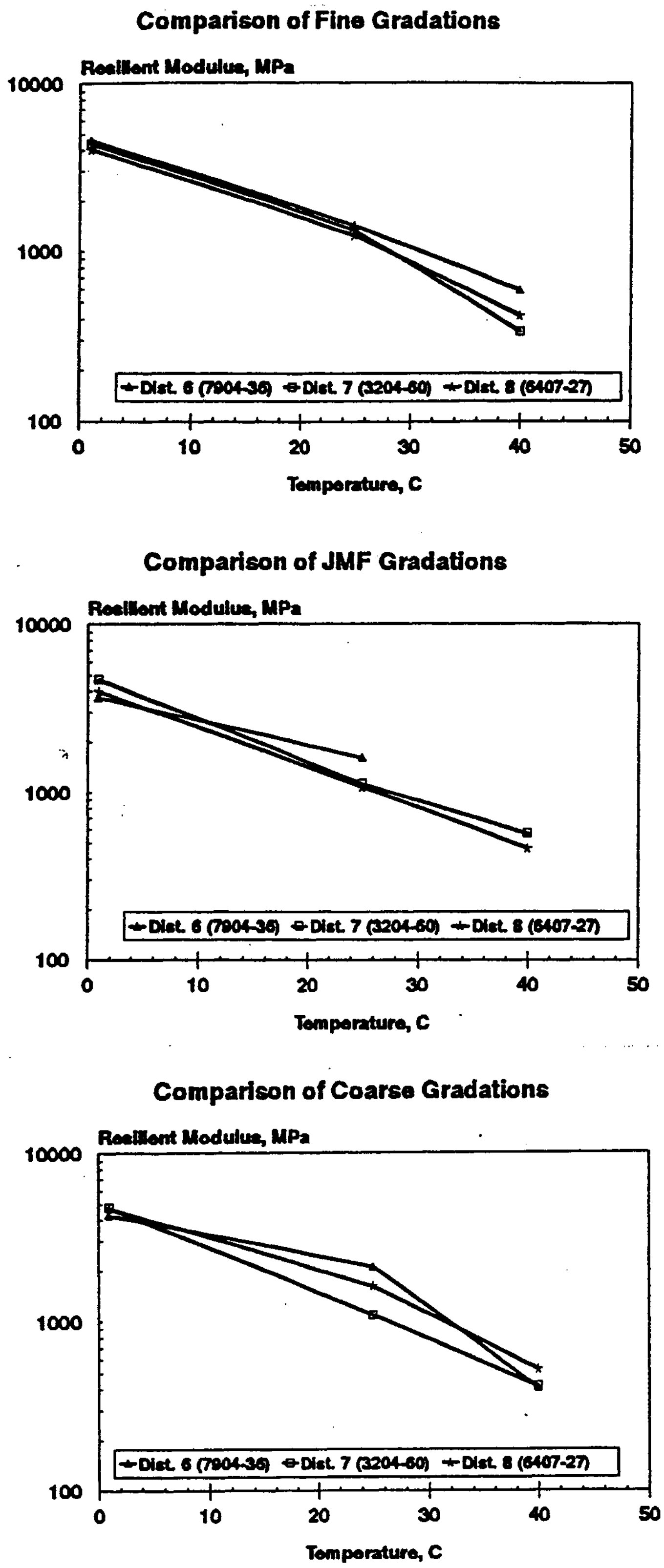


District 7 (Project 3204-60)



District 8 (Project 6407-27)

Figure 2. Comparison of Different Gradations for Each District.


Comparison of Fine Gradations

Comparison of JMF Gradations

Comparison of Coarse Gradations

Figure 3. Comparison of Different Aggregate Sources (Districts) for Each Gradation.

Moisture Sensitivity

Net Adsorption

The District 6 project was selected to represent a true stripping mixture. Since the original JMF aggregate and asphalt showed a visual stripping of between 30 and 40 percent (Appendix A) the net adsorption results were expected to show a low net adsorption value. However Table 9 shows that net adsorption results for the JMF were well above the 1.00 mg/g tentative limit for acceptable results (3). While this appears to contradict the original mixture results, the difference can be traced to the influence of one particular aggregate source.

Although the reason is unclear, previous research has indicated that poor performing limestones have high water absorption capacities (4). The original JMF gradation used by Mn/DOT contained approximately 36 percent of a high-water-absorption dolomitic limestone (Table 3) but the JMF gradation used by the University of Minnesota, while the same as that used by Mn/DOT, contained only 15 percent of this stockpile (Table 5). As the percentage of this aggregate source increased to 30 percent in the coarse gradation (Table 5), the net adsorption values dropped well below the 1.00 mg/g limit. While some decrease in the net adsorption results were expected due to the decrease in aggregate surface area (i.e., an increase in coarseness), the large change in the net adsorption results appears to agree with the visual stripping reported by Mn/DOT.

The District 7 was selected because it appeared that the loss of mixture strength was due to a possible loss of cohesion (i.e., binder problems) rather than due to asphalt-aggregate interactions. Therefore, it was expected that the net adsorption results should all be above 1.00 mg/g, although a decrease in values due to a decrease in aggregate surface area would also be apparent. Table 9 shows that both the fine and JMF gradations followed the expected trends. However, the net adsorption results for the coarse gradations were below the 1.00 mg/g limit. As with the District 6 mixtures, this appears to be due to a problem aggregate source.

Previous research has indicated that quartzite aggregates such as those comprising the 009 Hodgeman stockpile for District 7 (Table 3) can result in a true stripping mixture (4). When the percentage of this stockpile was approximately 40 percent, the net adsorption values were well below the 1.00 mg/g limit. As long as the percentage was less than 30 percent (either the fine or JMF gradation), the net adsorption results were acceptable. Since the percentage of this stockpile in the original Mn/DOT mixture testing was only 10 percent, it was not surprising that only limited visual stripping was reported.

District 8 was selected to represent a low initial mixture strength with little or no indications of true stripping or loss of cohesion. Therefore, it was anticipated that the net adsorption results should be acceptable for all aggregate gradations. Table 9 shows that this is the case. Since there were no known problem aggregate types in this mixture, changes in the proportions of aggregate sources had little influence on the results. The decrease in the net adsorption results appears to be only the result of the decrease in aggregate surface area.

Table 9. Net Adsorption Test Results

Test	Project								
	District 6 7904-36			District 7 3204-60			District 8 6407-27		
	Gradations								
	Fine	JMF	Coarse	Fine	JMF	Coarse	Fine	JMF	Coarse
Asphalt Adsorbed after 6 hr., (mg of AC)/(g agg.)	2.07	1.81	1.21	1.93	1.70	1.13	2.28	2.26	1.58
Asphalt Desorbed after 6 hr. (mg of AC)/(g agg.)	0.38	0.40	0.47	0.41	0.33	0.31	0.53	0.41	0.21
Net Adsorption (mg of AC)/(g agg.)	1.69	1.41	0.75	1.53	1.37	0.85	1.75	1.53	1.36
Visual Stripping, %	NA	30-40	NA	NA	<3	NA	NA	5-10	NA

Figure 4 summarizes the above discussion. The District 8 mixture shows the expected, generally linear, decrease in net adsorption with a decrease in aggregate surface area. When a critical percentage of a problem aggregate source was exceeded, then there was a significant drop in the net adsorption results. The scope of this testing program was not sufficient to estimate critical percentages of problem aggregates. However, both the net adsorption and Mn/DOT mixture data suggest that percentages of these types of aggregate sources above 30 percent could result in substantial moisture sensitivity problems.

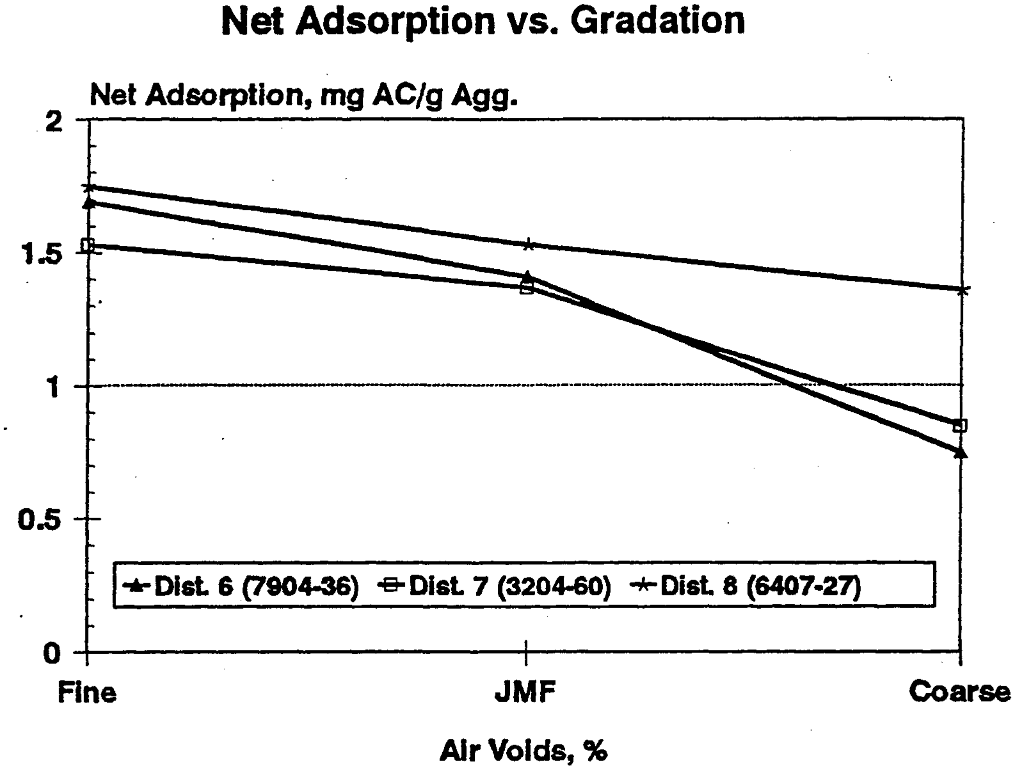


Figure 4. Influence of Aggregate Gradation on Net Adsorption Results.

Mixture Testing

Initial Between-Laboratory Comparison of Compacted Mixture Results: To insure that both the Mn/DOT and U of M laboratories were providing a similar assessment of the selected projects, the JMF mixtures were prepared at both laboratories. A reduced compactive effort was used in order to increase the air voids to a level similar to that of typical in-service pavements; both laboratories used the same reduced number of blows to compact these samples. The numbers of blows, air voids and tensile strengths after freeze/thaw conditioning obtained by both laboratories are shown in Table 10.

While the air voids were similar between laboratories, significantly different tensile strengths were obtained both before and after freeze/thaw conditioning. However, the before and after conditioning trends are the same, e.g., the order of the initial tensile strength does not change between the two laboratories, and the largest difference for before and after was seen for the District 7 mix. This could be due to differences in procedures for saturating, freezing, and thawing the samples. It also could be due to the differences in preparing the aggregate gradations; these differences were noted in the mix design section.

These results emphasize the need for an assessment of testing variability. Precision statements are needed in order to identify the differences between real material variability and testing variability.

Table 10. Comparison of Mn/DOT and U of M Test Results for JMF Samples. (JMF Gradation and Asphalt)

Project	Number of Blows[1]	Mn/DOT			U of M		
		Air Voids %	Tensile Strength Unconditioned kPa (psi)	Tensile Strength After Freeze/Thaw kPa (psi)	Air Voids %	Tensile Strength Unconditioned kPa (psi)	Tensile Strength After Freeze/Thaw kPa (psi)
District 6 7904-36	22	7.6	634 (92)	359 (52)	8.6	524 (76)	428 (62)
District 7 324-60	12	8.3	883 (128)	455 (66)	7.6	704 (102)	235 (34)
District 8 6407-27	13	8.6	421 (61)	421 (61)	6.8	317 (46)	331 (48)

1: Marshall compaction, bevel head, rotating base.

Film Thickness, Air Voids, and VMA Considerations: Table 11 shows that the air voids for the fine gradation ranged between 8.2 and 11.2 percent. This was due to the actual asphalt content being below the optimum for this gradation (Table 7). While the actual asphalt cement content was higher than the optimum for the coarse gradation, the air voids for these samples were within the desired range of 6 to 8 percent for a reduced compactive effort (Table 8). The differences in the air voids were also reflected in the VMA. In general, as the air voids increased, so did the VMA.

The asphalt cement content was held constant so that the effect of film thickness could be evaluated. Table 11 shows that the film thickness was dependent upon the aggregate gradation and decreased with the increasing fineness of the aggregate gradation. An estimate of the film thickness for each gradation for each project was obtained using an equation presented by Aljassar and Haas (5,6). Because of the limited material available for both aggregate tests and mixture preparation, an insufficient quantity of material below this fraction was available for a hydrometer analysis. Therefore, the surface area in this case was calculated for the 0.075 mm (No. 200) and above fractions. The results, shown in Table 11, were as expected: the finer the gradation, the greater the surface area. The asphalt film thickness was estimated for each mixture based on effective volume of asphalt cement (i.e., total volume minus absorbed volume), surface area of the aggregate, and weight of aggregate in the sample (6, pg. 151). As the coarseness of the gradation increased, so did the film thickness.

Table 11. Estimated Aggregate Surface Areas, Film Thicknesses, and Voids in Mixtures Information.

Test	Project								
	District 6 7904-36			District 7 3204-60			District 8 6407-27		
	Gradations								
	Fine	JMF	Coarse	Fine	JMF	Coarse	Fine	JMF	Coarse
Aggregate Surface Area (Without Minus 0.075 mm (No. 200), m^2/kg (ft^2/lb)	8.24 (40.05)	5.76 (28.02)	3.29 (15.99)	6.77 (32.91)	4.90 (23.82)	3.85 (18.73)	4.28 (20.83)	4.08 (19.85)	2.95 (14.33)
Estimated Asphalt Cement Film Thickness, μm	6.60	9.40	16.45	6.81	9.89	17.79	10.00	10.49	14.53
Void Information for Mixtures[1]									
Air Voids, %	8.2	4.6	6.8	10.7	6.4	5.7	11.2	8.6	7.0
Voids in Mineral Aggregate, %	20.0	16.3	19.2	20.0	17.9	16.1	24.7	22.4	17.9

1: The asphalt contents were 6.0, 5.5, and 5.0 for Districts 6, 7, and 8, respectively. No changes were made for different gradations.

Modified Lottman (ASTM D4867) Mixture Results: Table 12 shows the average test results for a set of three samples for each gradation for each district. The air voids for the fine aggregate gradation tended to be higher than either the JMF or coarse gradations. As discussed previously, the difference in air voids was most likely due to the less than optimum asphalt content in the fine aggregate gradations.

Concentrating on the tensile strength results, the original (dry) tensile strengths for a given district were fairly consistent. Dry tensile strengths ranged from:

- 545 to 593 kPa (79 to 86 psi) for District 6
- 379 to 407 kPa (55 to 59 psi) for District 7
- 351 to 485 kPa (51 to 63 psi) for District 8

While the moisture conditioned (wet) results appear to be somewhat dependent upon the air voids with higher air voids generally associated with lower strengths, there was also an apparent dependence on the film thickness. As the film thickness increased, the wet tensile strengths also increased (Figure 5), except for District 6.

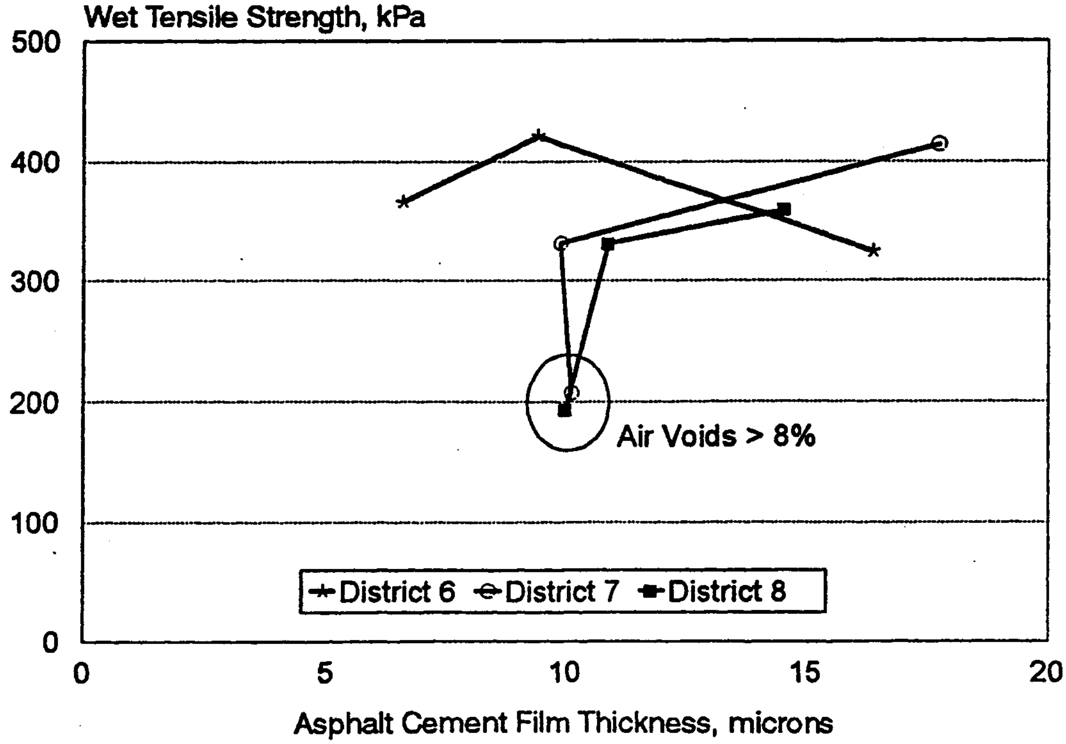


Figure 5. Influence of Film Thickness on Conditioned (Wet) Tensile Strengths.

Table 12. Moisture Sensitivity of Asphalt Mixtures Prepared with Koch 120/150 Pen Asphalt.

Temperature	Resilient Modulus at Various Temperatures, MPa (ksi)								
	Project								
	District 6 7904-36			District 7 3204-60			District 8 6407-27		
	Gradations								
	Fine	JMF	Coarse	Fine	JMF	Coarse	Fine	JMF	Coarse
Air Voids, %	8.5	4.2	6.3	8.5	5.8	7.2	11.1	6.5	7.6
VMA, %	20.3	17.1	14.8	20.3	18.6	17.3	20.4	22.1	18.0
Degree of Saturation, %	55	65	49	55	77	60	67	87	56
Resilient Modulus, Dry 25°C (77°F), MPa (ksi)	1,151 (167)	1,483 (215)	2,110 (306)	1248 (181)	1,020 (148)	1,166 (169)	1,393 (202)	1,497 (217)	1,675 (243)
Resilient Modulus, Wet 25°C (77°F), MPa (ksi)	697 (101)	945 (137)	1,104 (160)	620 (90)	1,055 (53)	1,166 (169)	593 (86)	993 (144)	1,400 (203)
Resilient Modulus Ratio, %	61	64	52	61	104	100	50	67	84
Tensile Strength, Dry 25°C (77°F), kPa (psi)	593 (86)	524 (76)	552 (80)	379 (55)	386 (56)	407 (59)	351 (51)	315 (46)	435 (63)
Tensile Strength, Wet 25°C (77°F), kPa (psi)	366 (53)	421 (61)	324 (47)	207 (30)	331 (48)	414 (60)	193 (28)	331 (48)	359 (52)
Tensile Strength Ratio, %	62	80	59	62	86	102	55	104	82

NA:Data not available

While the net adsorption results for the coarse District 6 mixtures suggested an increase in percentage of high absorption limestone should increase the mixture moisture sensitivity, the mixture results suggest that an increased film thickness from around 9 μm for the JMF to about 16 μm for the coarse gradation offset the potential problems from the increased percentage of the high absorptive limestone stockpile. Even when the film thickness was decreased below 9 μm and the air voids increased, as was seen for the fine aggregate gradation, but the percentage of the high absorption limestone was minimized, the wet tensile strengths were similar to those for the coarse gradation. This suggests that there is a trade-off of low film thickness and/or high air voids with good aggregates and an increased film thickness with moderate air voids and a potential problem aggregate source.

Similar results were noted for the District 7 mixtures, except that for these mixtures there was a significant reduction in wet strengths with a reduction in film thickness and higher air voids (fine gradation). Using the coarse aggregate gradation for this mixture significantly improved the wet strengths. Again, this suggests that mix design changes which would increase the film thickness and/or decrease the air voids may offset problems with marginal aggregate sources.

Even though the District 8 aggregate sources were considered to be good sources from an asphalt-aggregate interaction view point, the wet strengths of this mixture were significantly reduced by decreasing the film thickness and/or increasing the air voids. This suggests that without a sufficient film thickness and proper density control, even good materials could have marginal performance.

Mixture Tensile Strength Requirements: In order to suggest absolute tensile strength values and percent retained strength limits, expressed as the tensile strength ratio (TSR) for identifying potentially moisture sensitive mixtures, the work completed at the Mn/DOT laboratory and included as Appendix A was analyzed. Figures 6 and 7 show both of these values for projects separated first by maximum size aggregate and then by type of gradation for each maximum size. For the 12.5 mm (1/2 in) minus gradation (Figure 6) the type 2331 tensile strengths ranged from 365 to 448 kPa (53 to 65 psi), and 324 to 551 kPa (47 to 80 psi) for the type 2341. No specific trends were evident in this figure. However, for the 19 mm (3/4 in) minus gradation, it appears that the inclusion of recycled asphalt pavement (RAP) in the mixture increased the tensile strength of the Type 2342 and 2332 mixtures (Figure 7). All of the RAP mixtures also had tensile strength ratios above 70 percent and tensile strengths of at least 414 kPa (60 psi).

While there was insufficient data for any given type of mixture, a general estimate of acceptable tensile strength limits was obtained by combining all variables for each of the type 2331 and 2341 mixtures. The mean and standard deviation for any type 2331 or 2332 mixture for either top size aggregate, were 512 kPa (74.3 psi) and 98 kPa (14.2 psi), respectively. Using one standard deviation as an acceptable lower limit below the mean, then any type 2331 or 2332 mixture should have a minimum dry tensile strength value of 414 kPa (60 psi). The mean and standard deviation for any of the type 2341 or 2342 mixtures were 678 kPa (98.4 psi) and 114 kPa (16.6 psi), respectively. Based on the above approach, the lowest acceptable dry tensile strength for any type 2341 or 2342 mixture would be 552 kPa (80 psi).

An examination of Figures 6 and 7 show that in most cases, Minnesota mixtures can exhibit TSR values over 70 percent. However, three out of a total of 15 projects had values between 50 and 70 percent retained. This range of TSRs may indicate mixtures in need of remedial action such as a reduction in aggregate surface area (i.e., a coarser aggregate gradation), a thicker film thickness, and/or lower air voids. TSRs in this range may also indicate a true stripping problem; the mineralogy and percent of mix of each aggregate stockpile should be evaluated in an effort to identify any potentially marginal aggregate sources.

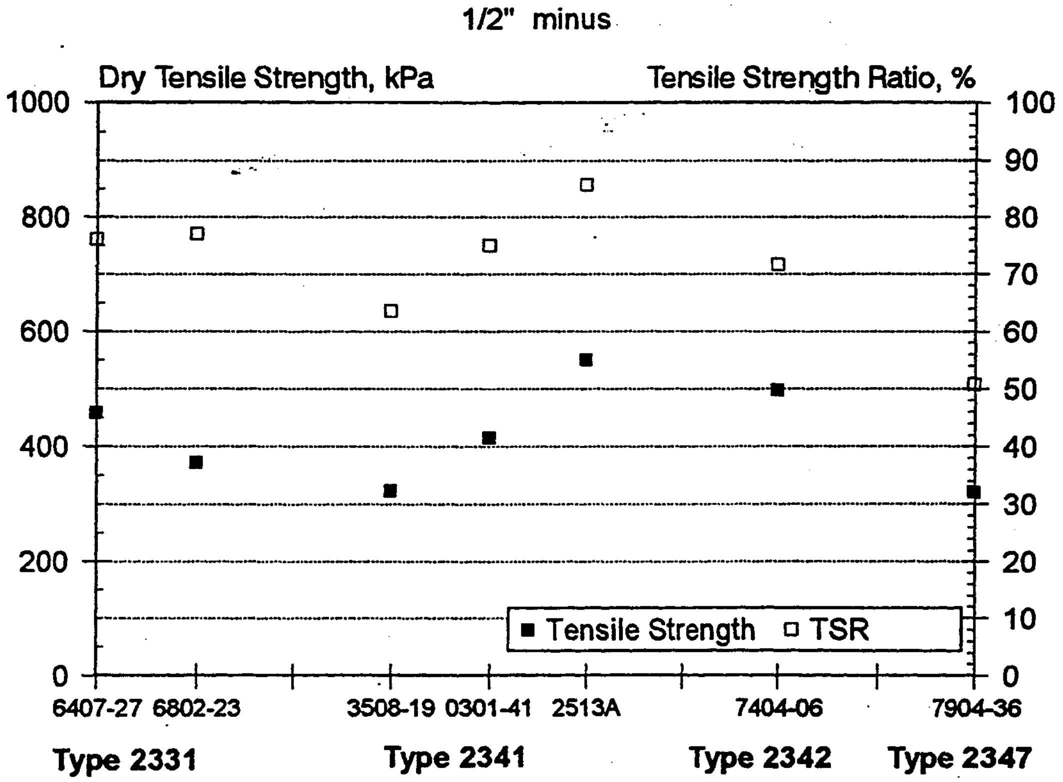


Figure 6. Relationship Between Type of Mix, and Tensile Strengths and Ratios (12.5 mm (1/2 in) minus Gradation)

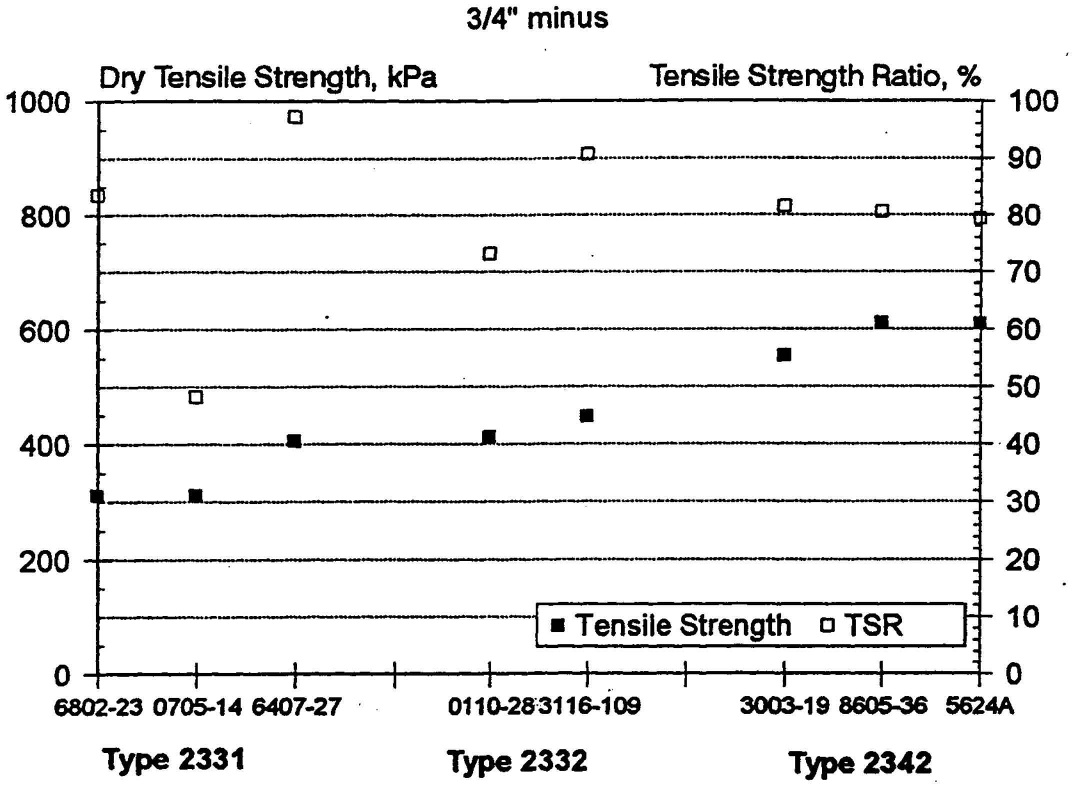


Figure 7. Relationship Between Type of Mix, and Tensile Strengths and Ratios (19 mm (3/4 in) minus Gradation)

CONCLUSIONS

The following conclusions can be drawn from this study:

1. Pavement distresses in Minnesota which have been attributed to moisture can actually represent one of three mechanisms: 1) true stripping (debonding of the asphalt from the aggregate), 2) loss of cohesion in the binder, or 3) low initial mixture strength. Suggested approaches to identify these mechanisms are as follows:

   True stripping can be identified by a combination of low retained strengths of the compacted mixture after moisture conditioning and an obvious percentage of bare aggregate after a boiling water test (greater than about 30 percent).

   Loss of cohesion in the binder can be identified as a substantial loss in retained strength (TSR of about 60 percent or less) with little or no visual stripping.

   Low mixture strength can be identified by values of unconditioned tensile strength values of less than about 483 kPa (70 psi).

   These definitions were based on a limited number of laboratory tests and should be confirmed through comparisons with field performance and further laboratory testing.

2. The properties of a true stripping mixture can be marginally improved by either an increased film thickness, lower voids, or using a decreased percentage of a marginal aggregate source.

3. Mixtures with a low initial strength may be improved somewhat by using a coarser aggregate gradation. While it is also possible to increase the initial mixture strength with a stiffer grade of asphalt, care needs to be taken so that other problems such as thermal cracking are not generated as a result of improving the strength by using a stiffer binder.

4. Aggregate characteristics that appear to promote moisture damage problems includes high absorptive (> 2 percent water absorption capacity) dolomitic limestone and quartzite.

5. The finer aggregate gradation appeared to minimize any differences in temperature susceptibility due to changes in aggregate source or properties at or below 25°C (77°F).

RECOMMENDATIONS

Before a quality control and quality assurance testing program can be formalized, the following needs to be completed:

1. Both within- and between-laboratory testing variability needs to be established for the tensile strength test so that statistically reasonable limits for material compliance can be developed. Statistics should be developed so that any potential influence of mixture type, maximum aggregate size, or sample size can be evaluated. Statistics should also be developed for unconditioned (dry) and conditioned (wet) results.

2. Test method choices as currently written may be needed to minimize the testing variability. An example of one such possible change would be to specify a vacuum pressure and time designed to produce approximately 100 percent saturation in all samples. This would eliminate variability due to the range of saturation levels currently allowed in the test method, but it may also excessively damage material.

3. Limits need to be established for both a minimum unconditioned tensile strength and a minimum percent retained strength after conditioning. The need for different limits for different mixtures (i.e., type 2131, 2141, etc.) should be identified. If possible, results should also be sorted by grade of asphalt cement.

4. Testing should include the use of conventionally prepared and sized samples (i.e., 100 mm (4 in) diameter by 60 mm (2.5 in) high cylinders prepared with a bevel head, rotating base Marshall hammer), and the SHRP-recommended 150 mm (6 in) diameter, gyratory compacted samples. It is anticipated that this change in sample preparation will change limits for absolute tensile strength values. It is also possible that the retained strength limits will be dependent upon sample size and method of preparation.

5. Once a precision statement has been developed for moisture sensitivity testing, this test (ASTM D4867) should be included in mix design testing. If true stripping is suspected as a potential problem, the boiling water test should also be conducted as a subjective way to confirm this as a source of potential problems.

6. Previous work has attempted to develop a precision statement for the boiling water test but it was indicated that the results were too subjective. This test should be used only as an indicator and not in any form as a quality control or acceptance test.

7. Because the inclusion of RAP in the mixture appears to improve both the tensile strength of the mixtures as well as the retained strengths, a separate study should be designed to investigate RAP mixtures more thoroughly. Topics of investigation should include control of RAP variables such as binder content and aggregate gradation, optimum percentage added to the mixture, and influence of mixture type on results.

8. Links between laboratory-determined values and field performance should be established.

9. Further research testing (i.e., the net adsorption) should be continued as a means of identifying aggregate mineralogy with a tendency for producing moisture sensitive mixtures.

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APPENDIX A

ASPHALT MIXTURE DURABILITY STUDY 9PRS 1016
Prepared by Dan Wegman, P.E. for Mn/DOT
June, 1995

ASPHALT MIXTURE DURABILITY STUDY 9PRS 1016

DAN WEGMAN P.E.

Abstract: The use of hot mix asphalt pavements represents a major investment in highways by the people of Minnesota each year. The performance of these pavements is a function of the design and construction of each project. Minnesota's Quality Management Program has been a key factor in significant improvements in the performance of asphalt pavements in Minnesota, especially in the elimination of rutting. However, a few projects still experience problems associated with long term durability such as premature cracking, stripping and in some cases ravelling of the pavement. Moisture sensitivity, density and absorptive aggregates were suspected as primary factors contributing to these conditions. In order to qualify these suspicions a study was initiated to look at asphalt mixes statewide on a mix design and production basis. This study emphasizes moisture sensitivity (stripping), absorption and voids in the mineral aggregate (VMA). In addition, in-place pavement voids were determined and will be tracked over time to provide correlations to actual pavement performance.

Premature failure or poor performance of asphalt pavements may be attributed to many factors relating to mixture design, production and placement. Factors in each of these areas or combinations thereof may significantly contribute to long term pavement performance. Factors specific to each area may create detrimental conditions which can adversely impact another area thus magnifying the chance for premature failure. For instance, a dry mixture with inadequate VMA is more difficult to compact thus increasing the potential for high in-place voids. With this in mind, this study was initiated with a major objective of determining how quality mixture production can be obtained for all extremes of materials used to produce asphalt mixtures throughout the state. The main areas of concentration being moisture sensitivity, absorption and VMA.

Dick Root of Chicago Testing Laboratory, Inc. was hired as a consultant to provide his expertise, establish a sampling/ testing plan and assure valid laboratory testing.

SAMPLING AND TESTING PLAN

A copy of the sampling and testing plan is provided at the end of this appendix. Sample sites were set up so each outstate District would have 2 or 3 (1993) projects included in the study. Criteria for project selection was to include projects supplied from marginal performing aggregate sources if possible. However, the construction program was small, so projects for the most part were selected on a basis of what was being constructed at the time the study was initiated. The study includes virgin and recycle mixes used for level, binder and wearing courses. Course designations are distinguished by two numbers (mix type) followed by three letters (first letter denotes max. agg. size; A=1/2 minus, B=3/4 minus and last two letters denote course; WE= Wear, BI= Binder, LV= Level. Three mix types were used in the study: Type 31 is a low volume, low crush mixture; Type 41 is a medium volume and crush mixture and Type 47 is a high volume and crush mixture. Type 32, 42 and 48 are the same classification but have recycled asphalt pavement (RAP) material in them. Aggregate samples were taken from the aggregate feed belts wherever possible otherwise samples were taken from the contractors stockpiles. Asphalt samples were taken from the contractors storage tank and Hot Mix Asphalt (HMA) samples were taken from behind the paver. All samples were transported to the Mn/DOT central laboratory for testing.

LABORATORY AND FIELD TESTING

It was decided to perform all laboratory testing within the Mn/DOT central laboratory so inter-laboratory testing discrepancies would not be introduced. Testing performed included the Modified Lottman (ASTM D4867), aggregate specific gravities (AASHTO T84, T85) and asphalt absorption (determined by the rice method). VMA values were also calculated for all mixtures.

Volumetric field testing was conducted on each project in accordance with Mn/DOT's quality assurance specification. contractor quality control tests include voids and gradations run on a one per thousand ton basis with minimum asphalt content assured at start up and maintained during production by plant settings. State quality assurance tests are run at an approximate rate of one per four contractor tests. Contractors tests are used for acceptance provided they are verified by State test results.

Results from the laboratory test are shown in Table 1. Both the contractor and Mn/DOT test results are shown in Figures A-1 through A-18.

STUDY OBJECTIVES

One objective of this study is to evaluate Mn/DOT's Quality Assurance Specification in terms of its ability to assure good mixture durability in relation to moisture sensitivity, asphalt absorption and VMA. These parameters have been identified as crucial to mix durability in the Superpave System developed by SHRP. Another objective is to determine the need for measuring these parameters during mixture production in addition to the determinations made in the standard mix design process. The primary objective is to evaluate existing conditions to determine future needs for the transition to the Superpave System.

MOISTURE SENSITIVITY

In the past, Mn/DOT used a cold water abrasion test to screen mixes for potential moisture sensitivity. In 1985 this test was discontinued on trial mixes due to its insensitivity to mixture performance. Mn/DOT currently does not have a specification related to moisture damage and identification of moisture sensitive mixtures is not part of the existing mix design procedure. For this study the modified Lottman test method (ASTM D4867) was chosen to measure the loss of mixture strength due to cohesive and/or adhesive problems.

Many states using this test method in their specifications require a minimum tensile strength ratio (TSR - a measure of the retained tensile strength after conditioning) of 70 percent. In this study, of the 18 mixtures tested, 13 exceeded this requirement after wet conditioning and 10 mixtures exceeded the requirement after freeze/thaw conditioning. Mixtures failing 70 percent TSR were predominantly located in the southern part of the state (Districts 6, 7 and 8) where marginal quality aggregates (in terms of absorption, durability and soundness) are frequently encountered.

Dry strengths exhibited a very wide range from 54 to 149 psi with the values showing a correlation to the amount of crushing in the mixtures (Figure A-19).

ASPHALT ABSORPTION

Asphalt absorption was suspected as a contributor to mix durability problems and thus was included as a research parameter. Work done by Kandhal and Khatri showed that asphalt absorption is time dependent (Fig. A-20) and can be a factor which leads to premature failure of asphalt paving mixtures.

Mn/DOT's standard procedure for laboratory mixed material is to cure (age) the mixture in the oven at 143°C (290°F) for 45 minutes. Kandhal's recommendation is to age the mixture for 4 hours in order to more accurately account for asphalt absorption. For this study cure times of 3/4, 2, and 4 hours were performed to determine asphalt absorption over time and assess its significance to mix durability. Results were somewhat surprising in that asphalt absorption over time did not appear to be as big a factor as anticipated. In comparing the difference in asphalt absorption between the 3/4 and 4 hour cure times most mixtures were under 0.2 percent with the largest difference being 0.35 percent absorption. A greater concern is that absorptions based on 4 hour aging ranged from 0.28 to 1.94 percent. This wide range questions whether VMA is being adequately accounted for on a project and program basis in Minnesota.

VOIDS IN THE MINERAL AGGREGATE (VMA)

Many factors can have an effect on the VMA content of a mix. Aggregate gradation, shape and surface texture are all important properties. In addition, the properties of the fine aggregate generally have a greater effect on the VMA content of a mix than do the properties of the coarse aggregate. Virtually all asphalt mixtures placed in Minnesota are on the fine side of the maximum density line when plotted on the .45 power chart (Figures A-21 and A-22). Mn/DOT also assures adequate VMA by specifying a minimum asphalt content for all mixtures. This approach is based on the assumption that the specific gravity of aggregates are relatively uniform throughout the state and that broad band gradation requirements coupled with minimum asphalt contents will provide adequate VMA (Figure A-23).

For economical purposes contractors typically design mixtures as close to the maximum density line as possible with minimum asphalt content and gradations in compliance. During production a "VMA collapse" is often encountered forcing the contractor to make adjustments to his gradations to raise voids. VMA cannot easily be checked after these adjustments because aggregate specific gravities are not usually determined in the mix design process. In submitting his mix designs, the contractor is given the option of determining his aggregate specific gravities (AASHTO T84 and T85) or using an assumed 1 percent asphalt absorption to calculate the bulk specific gravity of the aggregate. In virtually all cases the contractor elects to use the 1 percent absorption option. Mixtures with aggregates having an excess of 1 percent absorption and designed at or near minimum asphalt levels can have inadequate VMA in conjunction with insufficient asphalt film thickness on the aggregate thus creating potential durability problems. Mixtures with aggregates having less than 1 percent adsorption and designed at or near minimum asphalt levels may require gradation adjustments upon start up to maintain the required 3-5 percent mixture air voids. The degree of aggregate absorption divergence from the assumed 1 percent and the changes in aggregate shape upon going through the plant are both potential factors in the mixture having inadequate VMA.

Asphalt absorption over time can also present a challenge when trying to duplicate mixture design properties in the field. The most obvious case being when an asphalt mixture is insufficiently aged in the mix design to account for a substantial portion of the absorption that ultimately takes place in the field. This situation creates the potential for poor mixture durability due to inadequate effective asphalt in the mix.

For the projects in this study, the mix design data shows in most cases the VMA calculated using the 1 percent absorption assumption is higher than the VMA calculated using aggregate specific gravities determined via AASHTO T84 and T85. In many cases the VMA calculated via T84 and T85 does not meet Asphalt Institute or Mn/DOT criteria. It is also interesting to note that the lowest VMA calculated by T84 and T85 corresponds to a very low TSR even though the asphalt absorptions for this mixture are very low (see SP 4705-34).

The design process is not complete until the mixture is produced through the mixing facility and the design parameters are verified in the field. In light of the "VMA collapse" typically encountered with plant produced material this study went ahead and tracked VMA along with voids on a production basis. Voids were calculated on mix samples taken behind the paver as required on all Mn/DOT quality assurance projects. VMA was recalculated from the T84 & T85 aggregate specific gravity values whenever a change in the mixture took place. The charts with this plotted data also show a line denoting minimum VMA values based on the Asphalt Institute and Mn/DOT criteria. In most cases VMA criteria is not maintained throughout the project and in some cases never met at all.

CONCLUSIONS

1. Moisture sensitivity, absorption and inadequate VMA can all be factors in poor pavement durability. It appears that moisture sensitivity on a regional level and inadequate VMA on a statewide level are the most prominent factors in Minnesota.

2. Factors not included in this study may also play a prominent role in circumstances of poor pavement durability. Pavement density (in place voids) and Fines to Asphalt (F/A) ratio are two factors that warrant particular attention.

3. The freeze/thaw (iced) conditioning performed in the modified Lottman testing does not appear to be necessary in detecting moisture sensitive mixtures based on this data. However, this observation is contradicted in research performed by others. (See reference 4.)

4. The subjective visual stripping observations conducted by Mn/DOT's Senior Central Lab

Technician did not correlate well with measured TSR values.

5. The rate of change of asphalt absorption between 3/4 and 4 hour aging was not as big a factor as anticipated. However, most of the mixtures tested had asphalt absorptions greater than the 1 percent assumed absorption used in determining VMA in current mix design procedures.

6. VMA calculations using AASHTO T84 & T85 for aggregate specific gravity determinations were usually lower than VMA calculations using current Mn/DOT procedures.

7. Mixture changes made during production in the field to maintain proper air voids can cause VMA to fall below recommended levels. Therefore, the broad band gradations and minimum asphalt contents of Mn/DOT's Quality Assurance program do not assure adequate VMA in all asphalt mixtures.

RECOMMENDATIONS

1. Continued research in this area should include evaluation of fines to asphalt (F/A) ratios and in-place voids as contributors to inadequate pavement durability.

2. A specification for moisture sensitivity should be developed and implemented in those regions which show through data and experience to have aggregate sources prone to moisture sensitivity. Presently the specification should be implemented in Districts 6, 7 and 8.

3. Changing the mix design oven aging time from 45 minutes to 2 hours would be beneficial to better duplicate actual absorptions encountered in the field.

4. A better means of assuring adequate VMA in both mix design and during production is essential. This should be developed and implemented as soon as possible.

5. All mix durability factors identified in this study are addressed in the Level One Superpave System being promoted by the FHWA. Implementation of the Level One Superpave System once the equipment and expertise is obtained is recommended.

REFERENCES

1. "Evaluation of Asphalt Absorption by Mineral Aggregates," Prithvi S. Kandhal and Maqbool A. Khatri, National Center for Asphalt Technology, Auburn, Alabama 1991.

2. "Hot-Mix Asphalt Paving Handbook," AASHTO/NAPA, James A. Scherocman (Consultant), July, 1991.

3. "The Effects of Testing and Production Procedures on Mix Design Results," National Asphalt Pavement Association, Richard E. Root (Consultant), IS 112, 1991

4. "Changes in Asphalt Concrete Durability Resulting from Exposure to Multiple Cycles of Freezing and Thawing," ASTM, Gilmore, Darland, Girdler, Wilson and Scherocman; 1985.

Table 1. Test Results from Various Methods of Moisture and Freeze/Thaw Conditioning.

27-Sep-95				DRY		WET						ICED						ASPHALT ABSORPTION				VMA	VMA
DIST	S.P.	COURSE	BLOWS	% AIR VOIDS	STRENGTH	%AIR VOIDS	% SAT INT	% SAT FIN	STRENGTH	TSR	VISUAL STRIPPING	%AIR VOIDS	% SAT INT	% SAT FIN	STRENGTH	TSR	VISUAL STRIPPING	3/4 HOUR	2 HOUR	4 HOUR	3/4-4		Calculated assuming 1
1	0110-28	32BWE	13	8.4	81.8	8.4	71.5	88.5	59.9	73.2%	5-10	8.4	72.7	97.2	56.4	68.9%	5-10	1.26	1.30	1.35	0.09	14.73	15.20
1	3116-109	32BWE	12	7.4	72.0	7.4	66.4	90.7	65.2	90.6%	5-10	7.4	69.1	89.5	62.3	86.5%	<5	0.86	0.66	0.86	0.00	14.77	15.40
2	3508-19	41AWE	15	8.7	73.6	8.7	65.7	94.5	47.0	63.8%	15-20	8.8	62.8	86.6	47.7	64.8%	15-20	0.85	0.92	0.94	0.09	16.09	17.60
2	6802-23	31BWE	13	7.7	54.2	7.7	62.8	83.3	45.3	83.6%	<5	7.7	63.4	79.6	46.7	86.2%	<5	0.35	0.50	0.55	0.20	16.38	15.08
2	6802-23	31ALV	13	7.3	70.1	7.3	62.1	86.8	54.1	77.2%	20-30	7.3	65.4	87.5	54.4	77.6%	10-20	1.08	1.10	1.24	0.16	14.54	14.33
3	3003-19	42BWE	12	7.0	98.7	7.0	64.8	90.9	80.5	81.6%	3-5	7.0	65.7	86.6	83.6	84.7%	<1	1.25	1.27	1.43	0.17	14.56	15.00
3	3003-19	42BBI	12	6.8	110.1	6.7	61.8	83.7	88.8	80.6%	<3	6.8	63.9	78.7	91.8	83.4%	~5	0.24	0.31	0.33	0.09	14.53	14.30
3	8605-36	42BBI	11	6.8	111.2	7.0	66.2	88.4	88.4	79.5%	~5	7.0	65.4	85.1	86.7	78.0%	<1	1.08	1.37	1.42	0.34	13.45	14.18
4	0301-41	41AWE	18	7.6	80.4	7.7	67.1	100.0	60.4	75.2%	20-30	7.7	64.2	95.6	52.6	65.4%	<1	0.84	0.88	0.88	0.04	15.49	15.70
4	5624A	42BWE	13	8.7	90.2	8.6	60.5	82.3	71.4	79.2%	<3	8.7	61.2	79.5	72.8	80.7%	<3	1.11	1.16	1.25	0.14	14.92	14.80
6	2513A	41AWE	20	8.1	93.0	8.1	62.0	85.6	79.9	85.9%	5-10	8.1	62.0	82.7	75.3	81.0%	<1	1.55	1.67	1.53	-0.02	14.11	15.60
6	7404-06	42AWE	12	8.1	100.9	8.1	67.2	101.5	72.4	71.8%	10-15	8.0	67.1	98.4	70.9	70.3%	<3	1.00	1.20	1.35	0.35	15.31	15.52
6	7904-36	47AWE	22	7.6	91.7	7.6	57.0	85.6	46.6	50.8%	40-50	7.7	52.9	75.1	51.5	56.2%	30-40	1.03	1.10	1.27	0.24	15.21	16.03
7	0705-14	31BLV	12	9.7	93.8	9.6	69.0	113.6	45.3	48.3%	15-20	9.0	68.0	111.3	45.9	48.9%	10-15	1.46	1.82	1.82	0.36	13.04	15.50
7	3204-60	41BLV	12	8.3	128.7	8.3	64.9	95.4	65.5	50.9%	10-15	8.2	65.4	91.0	65.9	51.2%	<3	1.47	1.58	1.61	0.14	13.34	14.40
8	4705-34	48BBI	19	8.4	149.8	8.3	74.2	109.0	85.4	57.0%	10-15	8.4	73.8	105.7	87.1	58.1%	5-10	-0.11	0.11	0.28	0.39	12.91	14.30
8	6407-27	31BLV	13	8.6	60.8	8.6	65.5	93.3	59.1	97.2%	5-10	8.5	66.4	94.1	61.3	100.8%	5-10	1.32	1.39	1.50	0.18	13.15	14.30
8	6407-27	31AWE	20	8.9	87.4	8.9	67.5	95.8	66.6	76.2%	15-20	8.8	67.3	93.0	57.2	65.4%	10-15	1.81	1.83	1.94	0.13	12.45	15.50

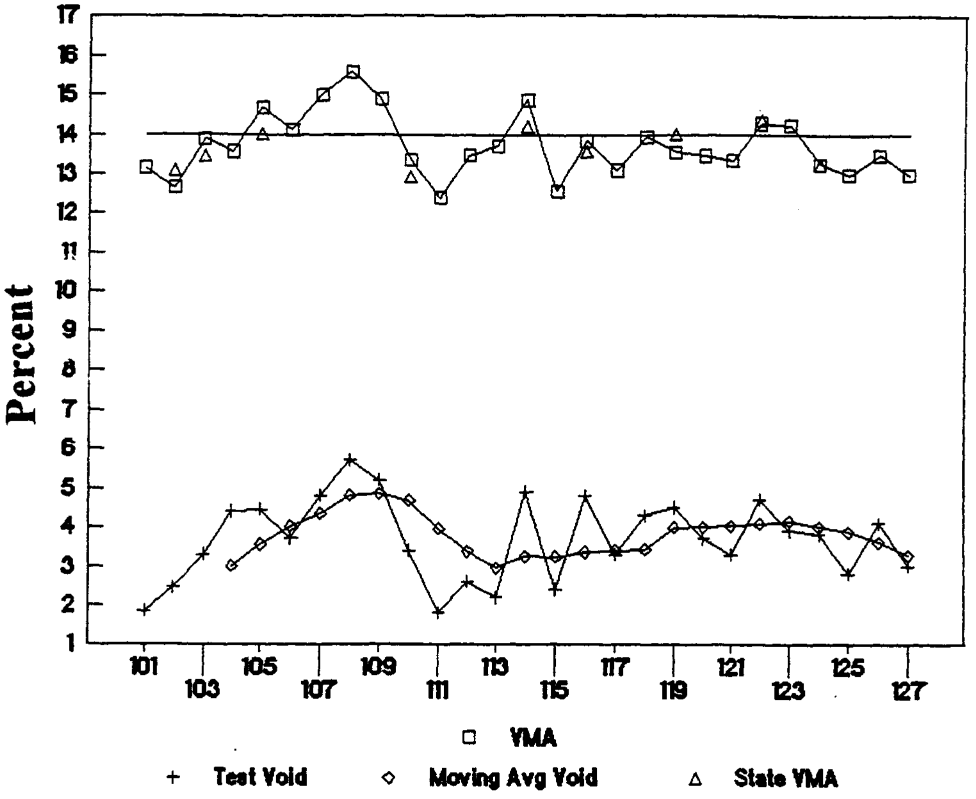


Figure A-1. District 1, Project 0110-28, 32B Wear.

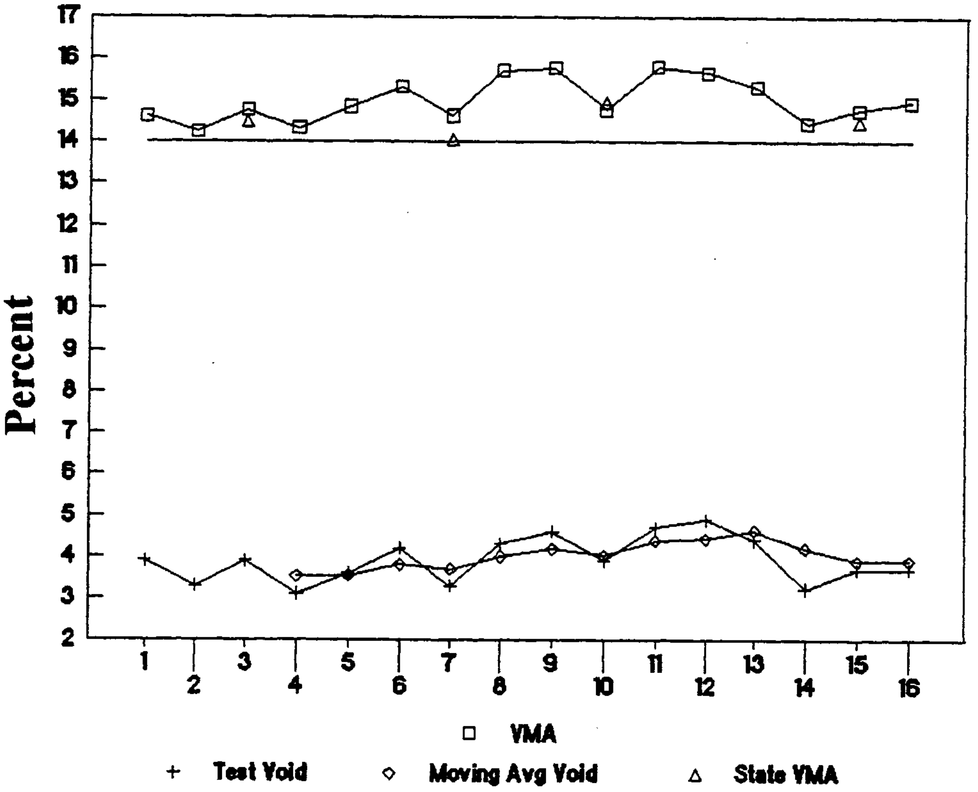


Figure A-2. District 1, Project 3116-109, 32B Wear.

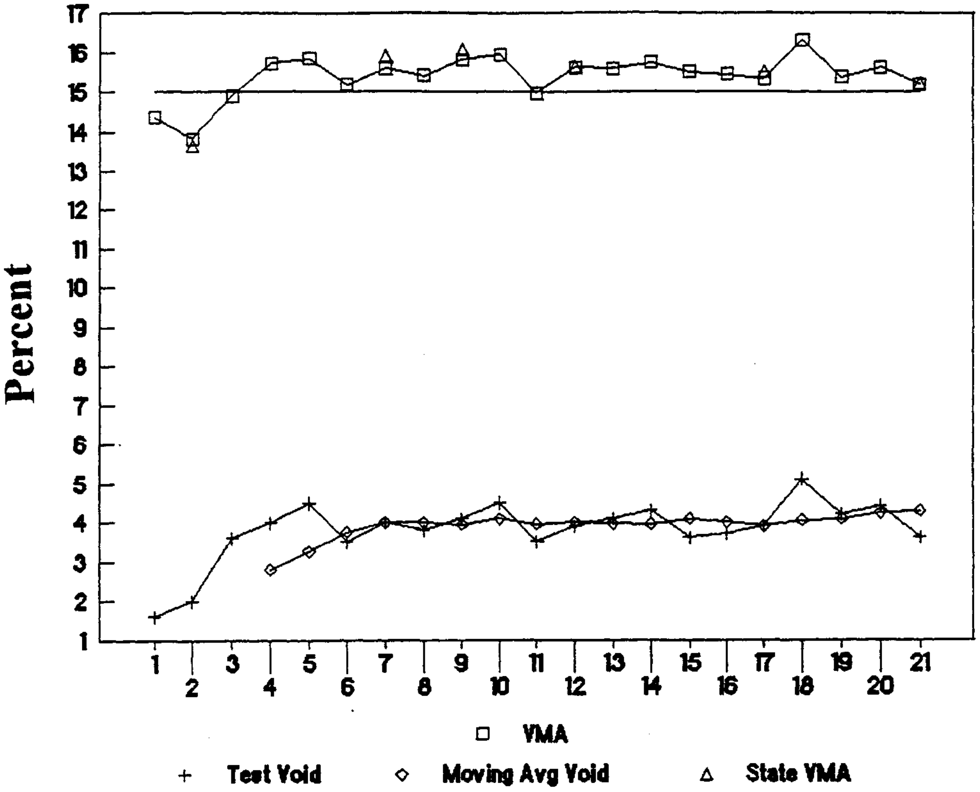


Figure A-3. District 2, Project 3508-19, 41A Wear.

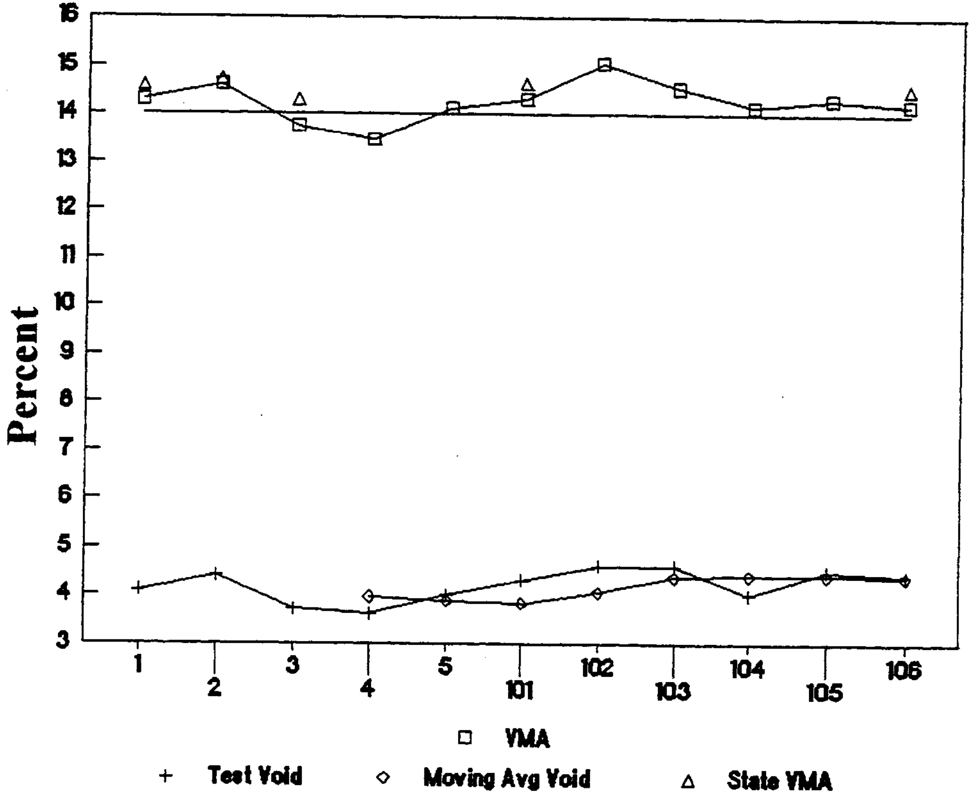


Figure A-4. District 2, Project 6802-23, 31B Wear.

No Data Available

Figure A-5. District 2, Project 6802-23, 31A Leveling.

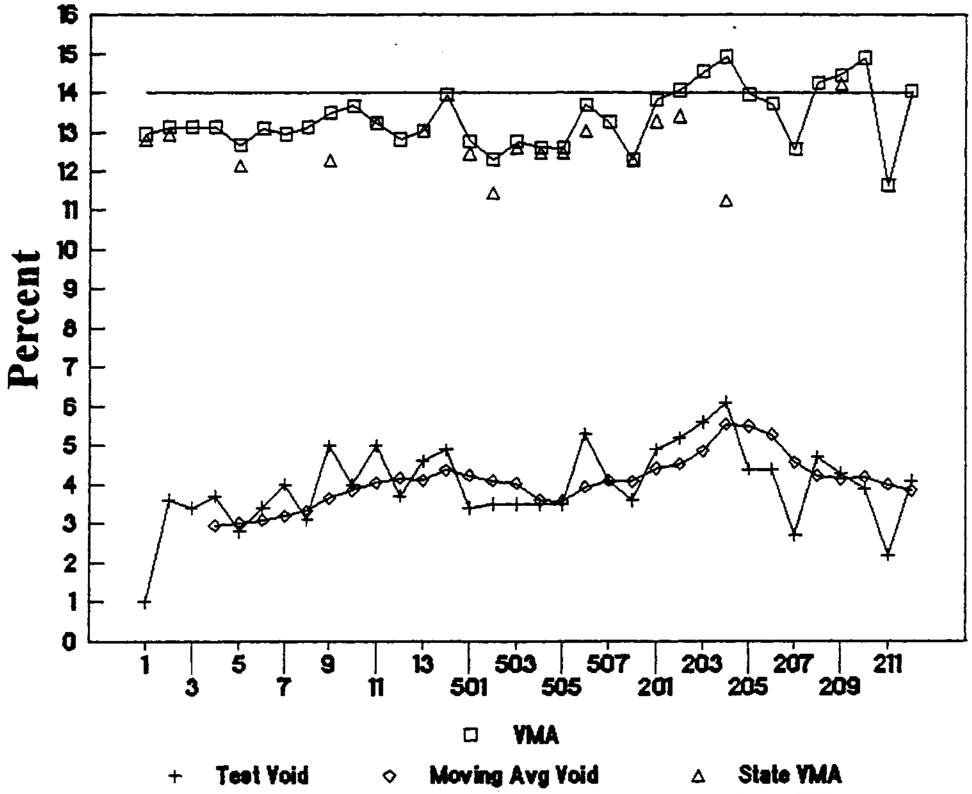


Figure A-6. District 3, Project 3003-19, 42B Wear.

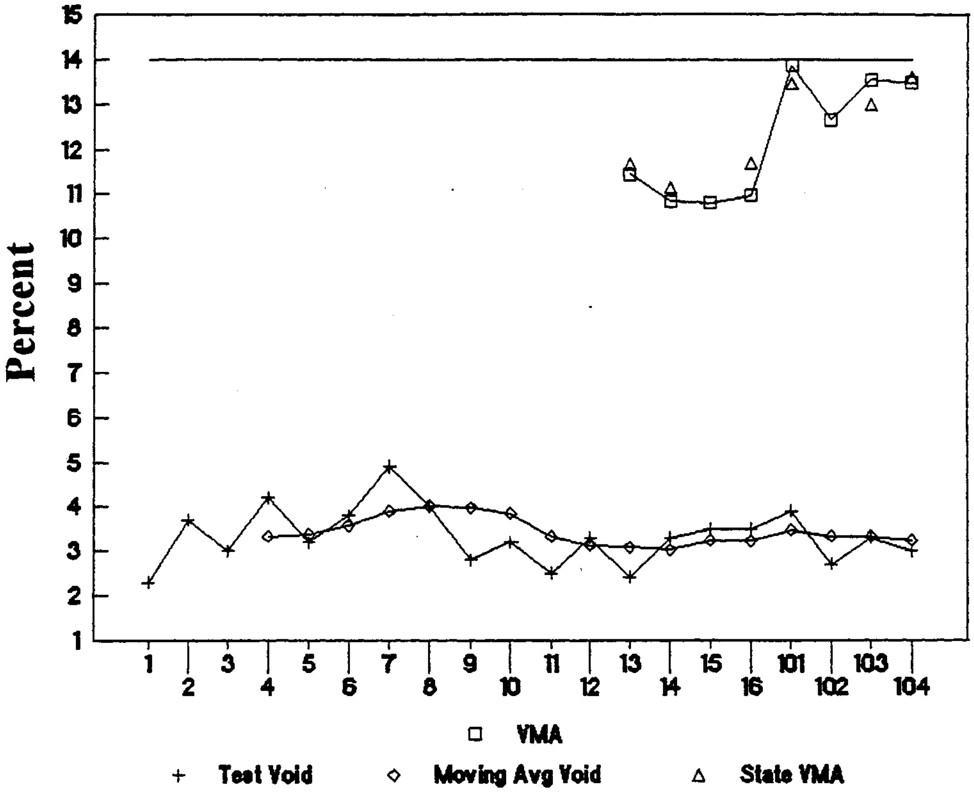


Figure A-7. District 3, Project 3003-19, 42B, Binder.

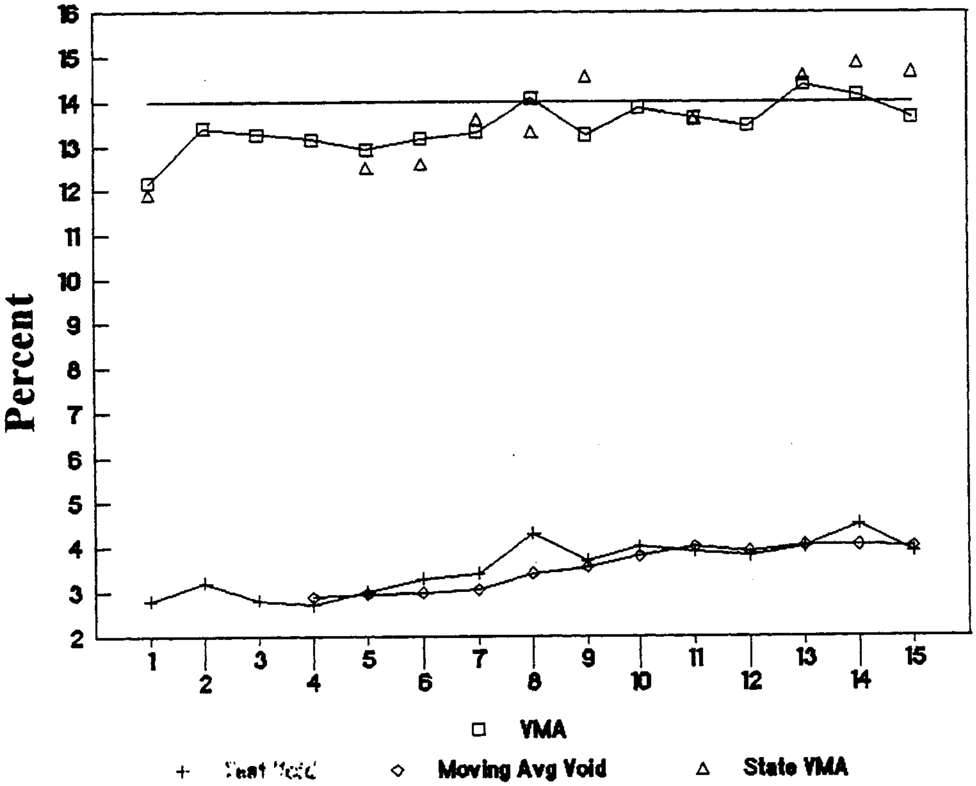


Figure A-8. District 3, Project 8605-36, 42B, Binder.

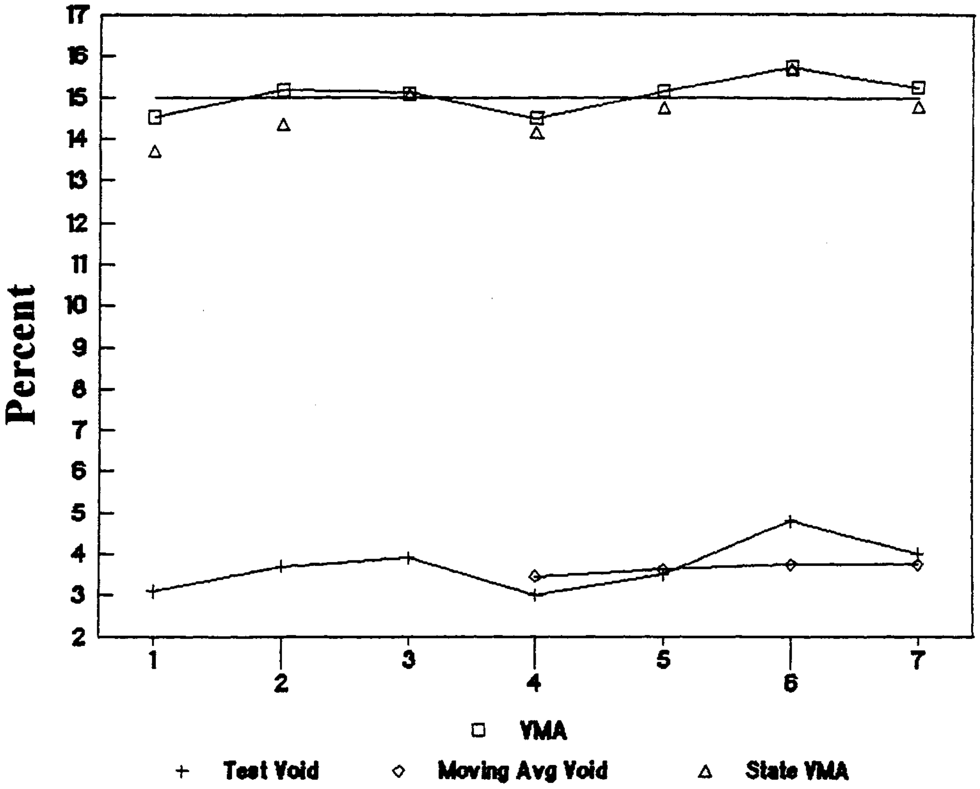


Figure A-9. District 4, Project 0301-41, 41A Wear.

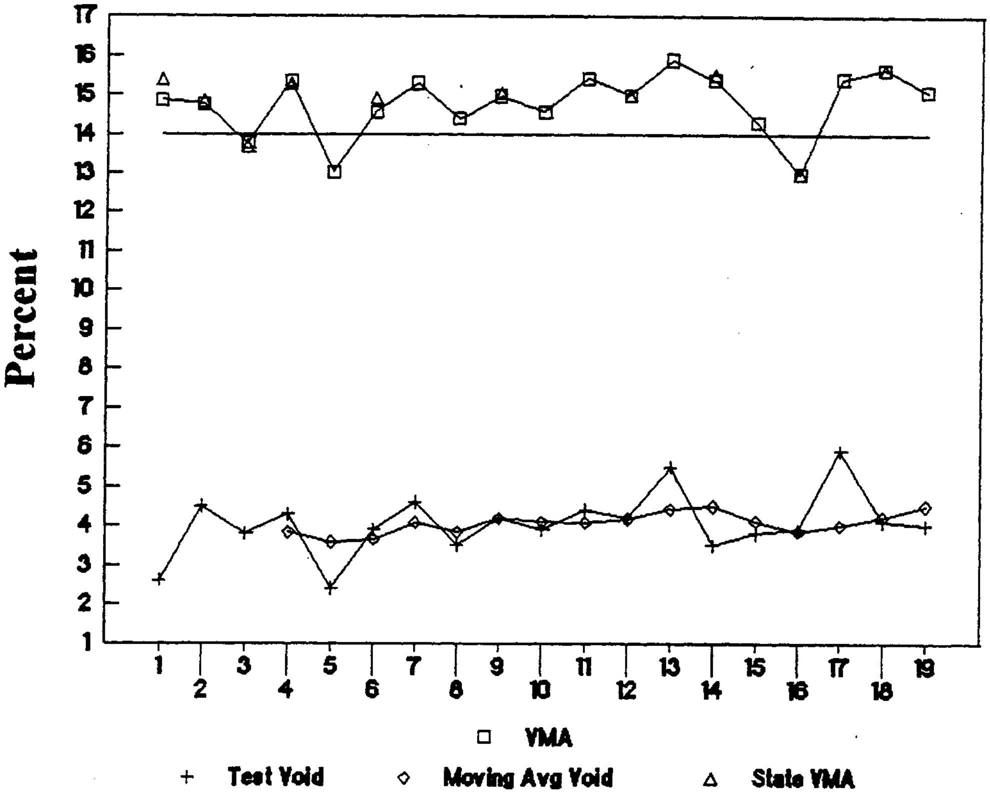


Figure A-10. District 4, Project 5625A, 42B Wear.

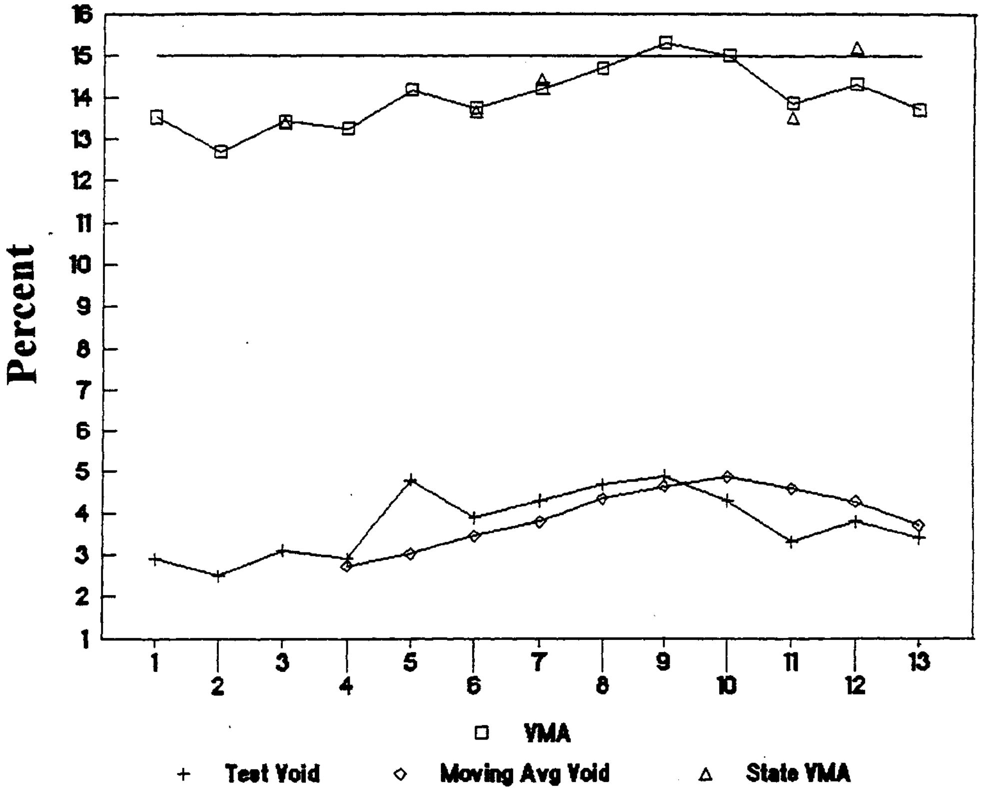


Figure A-11. District 6, Project 2513A, 41A Wear.

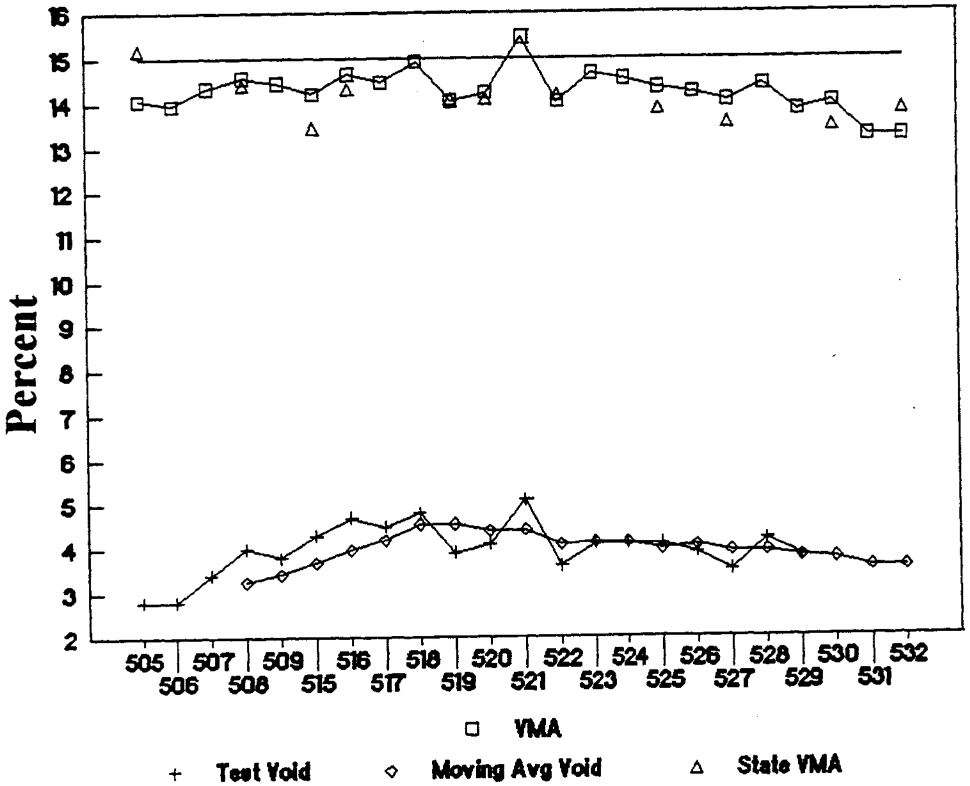


Figure A-12. District 6, Project 7404-06, 42A Wear.

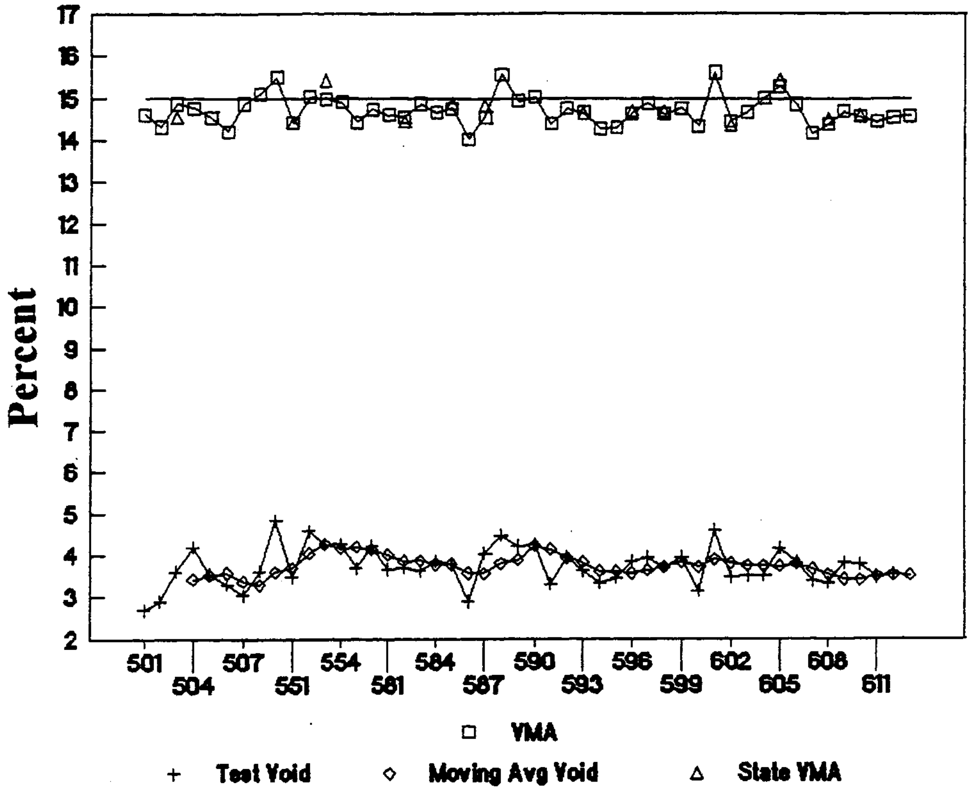


Figure A-13. District 6, Project 7904-36, 47A Wear.

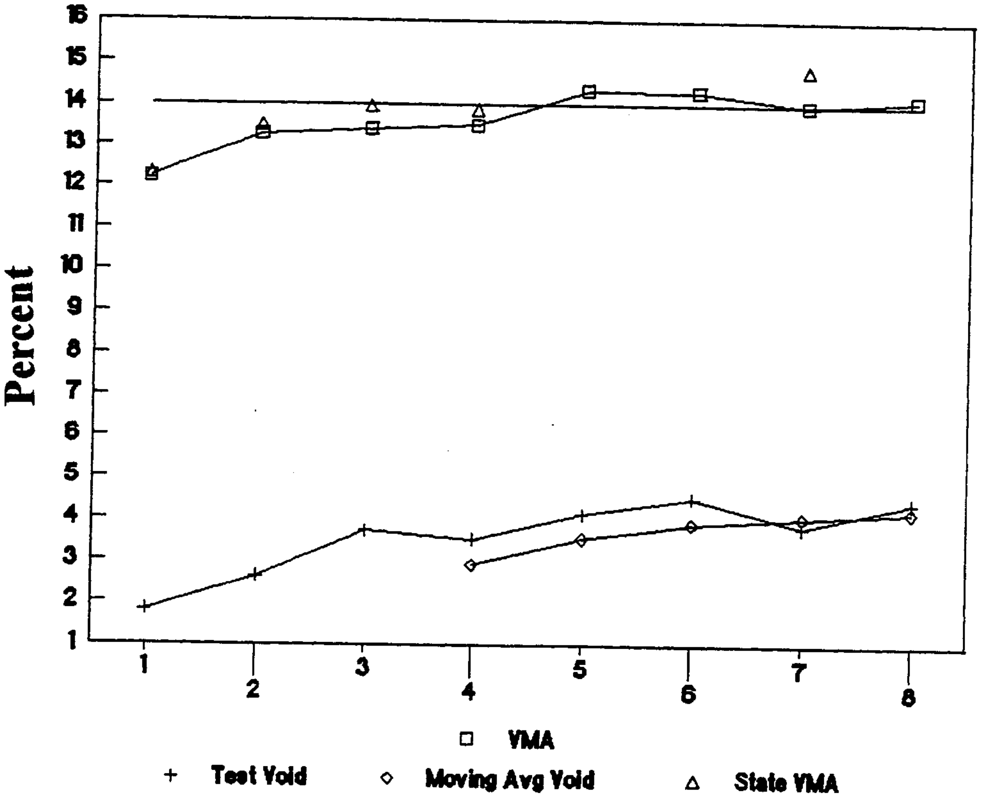


Figure A-14. District 7, Project 0705-14, 31B Leveling.

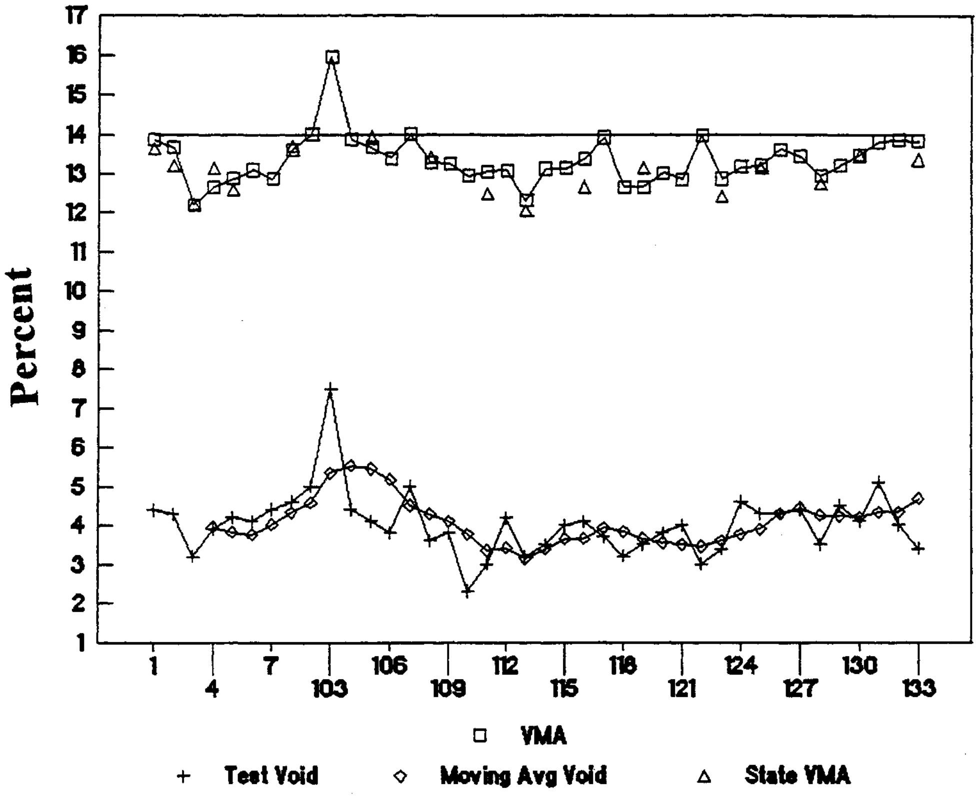


Figure A-15. District 7, Project 3204-60, 41B, Leveling.

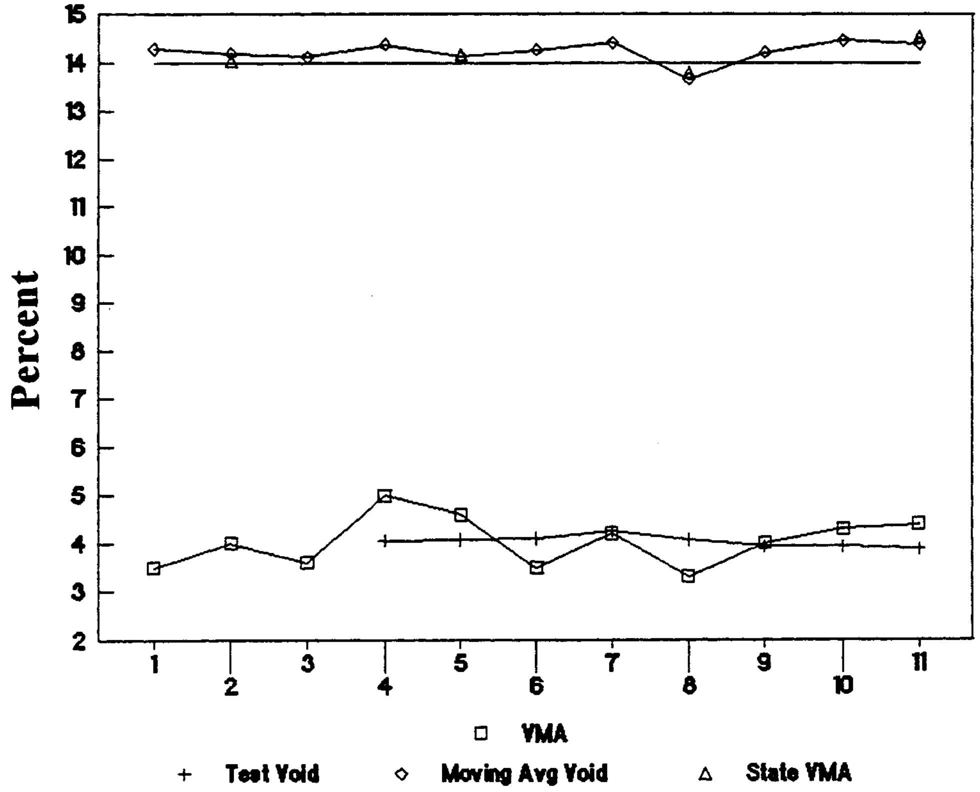


Figure A-16. District 8, Project 4705-34, 48B, Binder.

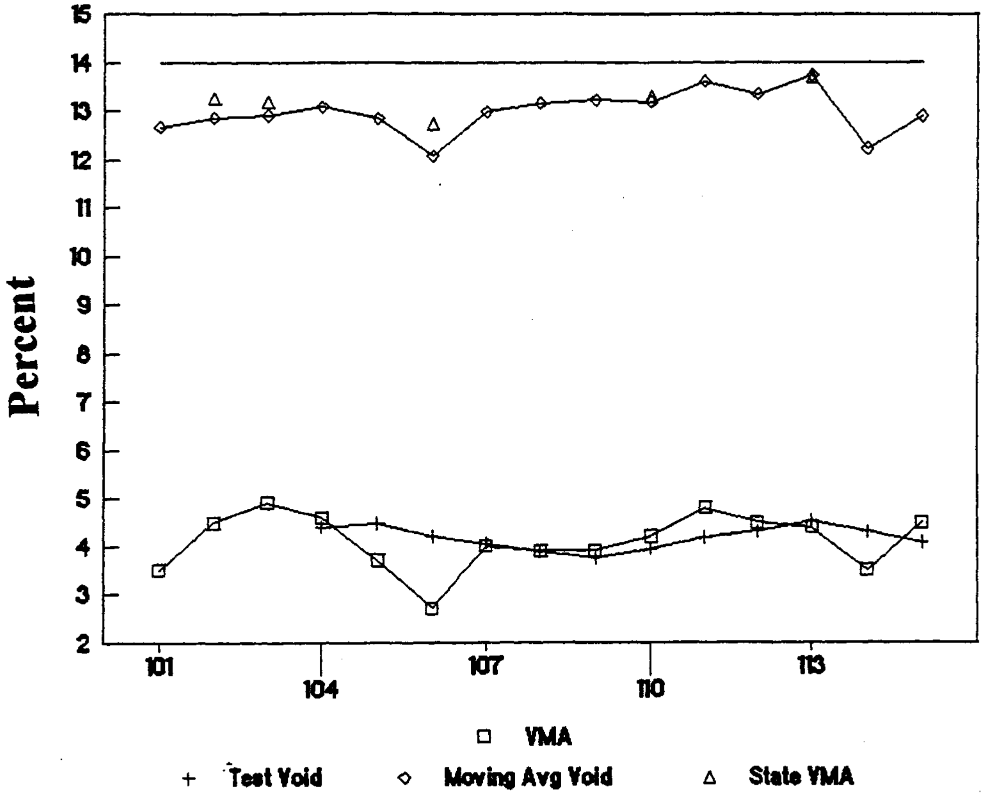


Figure A-17. District 8, Project 6407-27, 31B, Leveling.

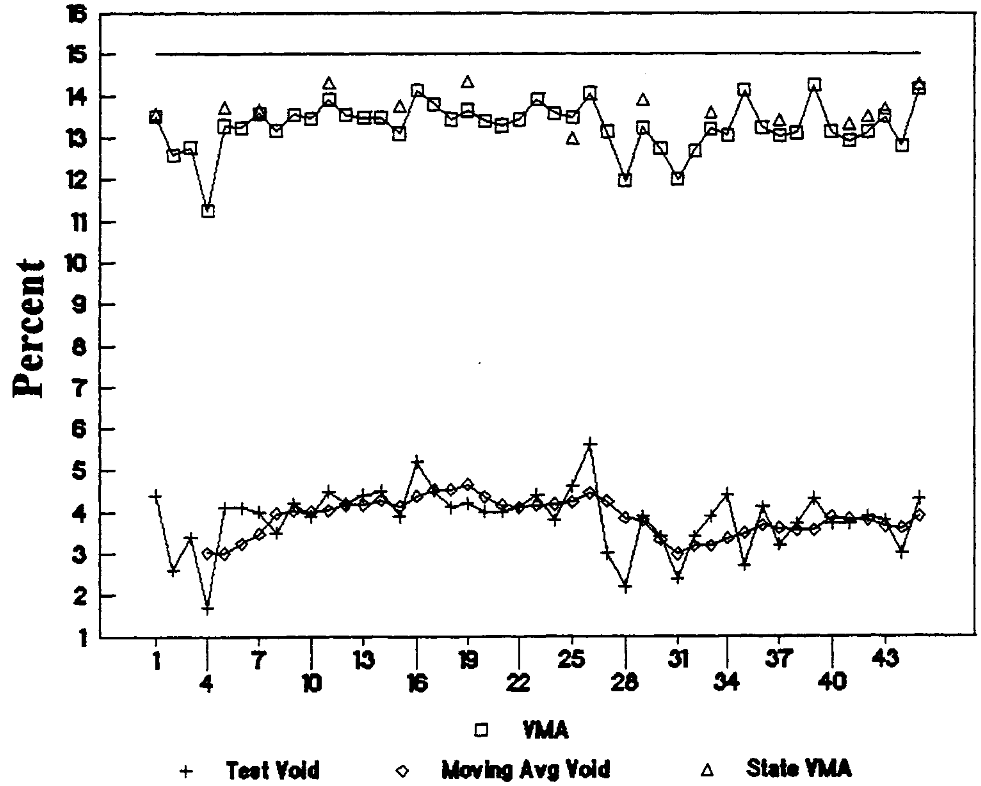


Figure A-18. District 8, Project 6407-27, 31A, Wear.

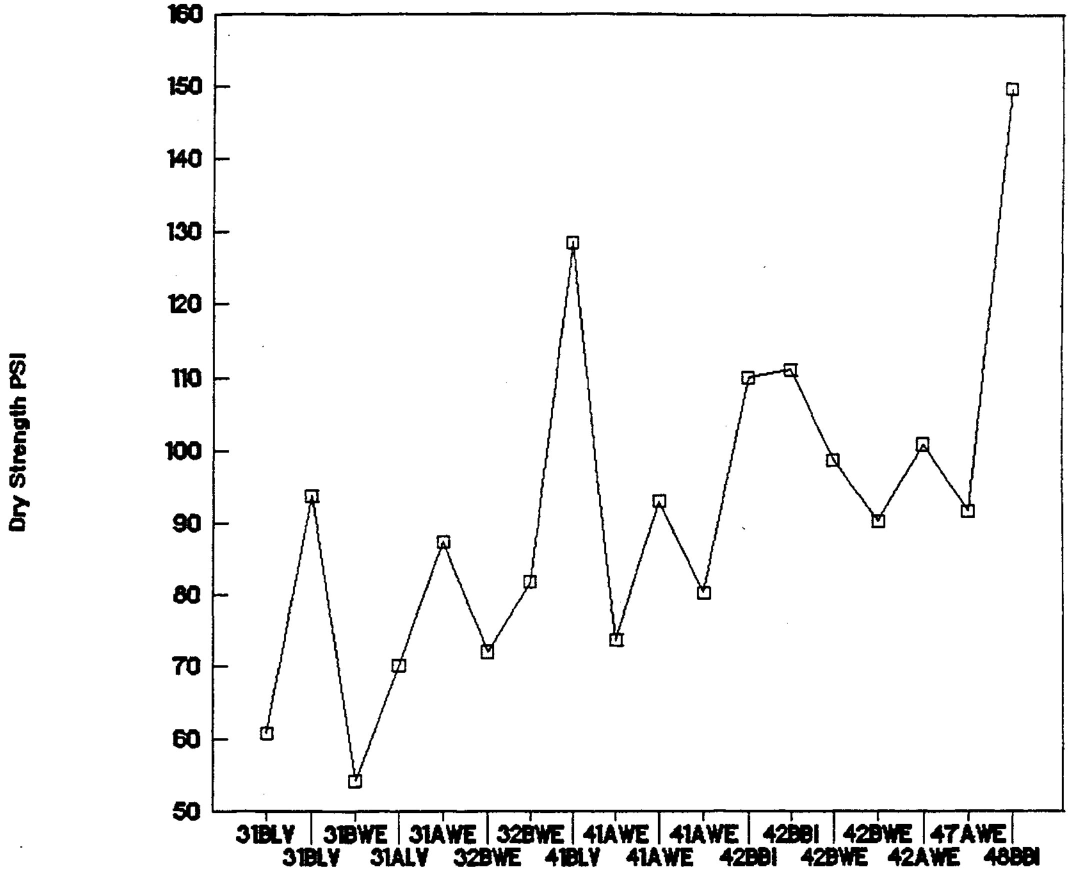
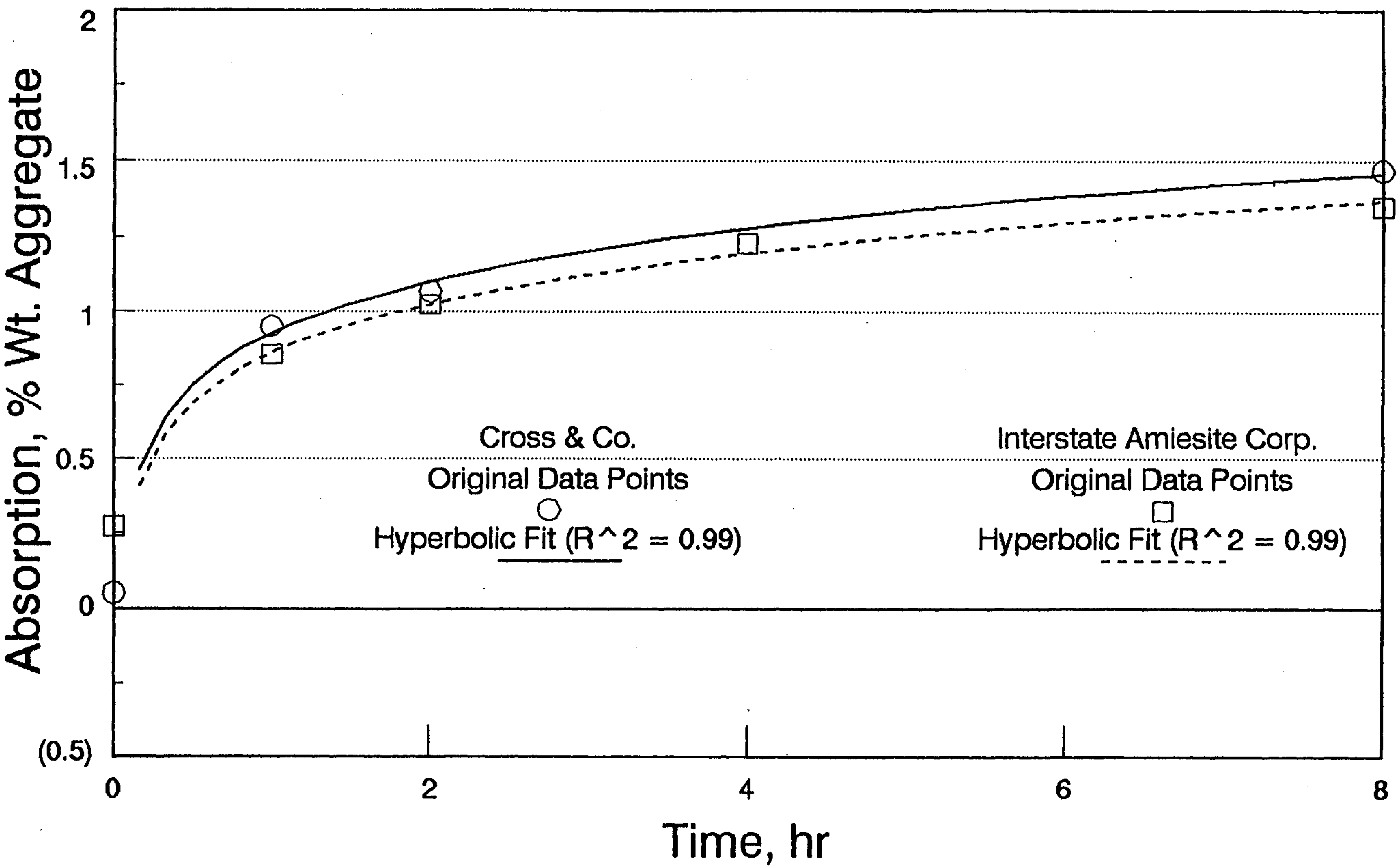


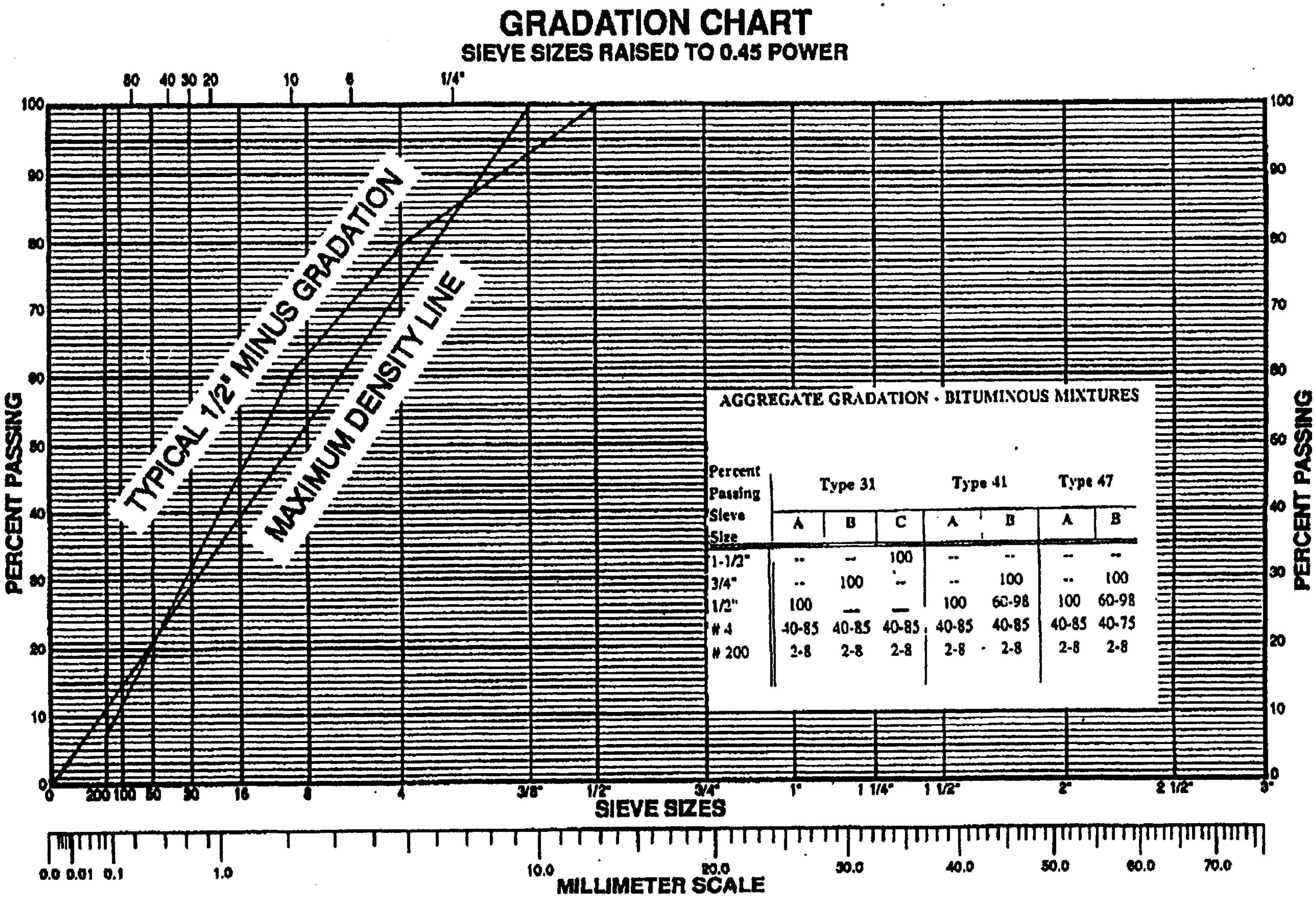
Figure A-19. Dry Tensile Strengths with Increasing Crushing
(Increasing % Crushing with Increasing Number)



Asphalt Absorption vs. Aging Time (Pennsylvania Data)

Taken From: "Evaluation of Asphalt Absorption
by Mineral Aggregates"
Kandahl and Khatri

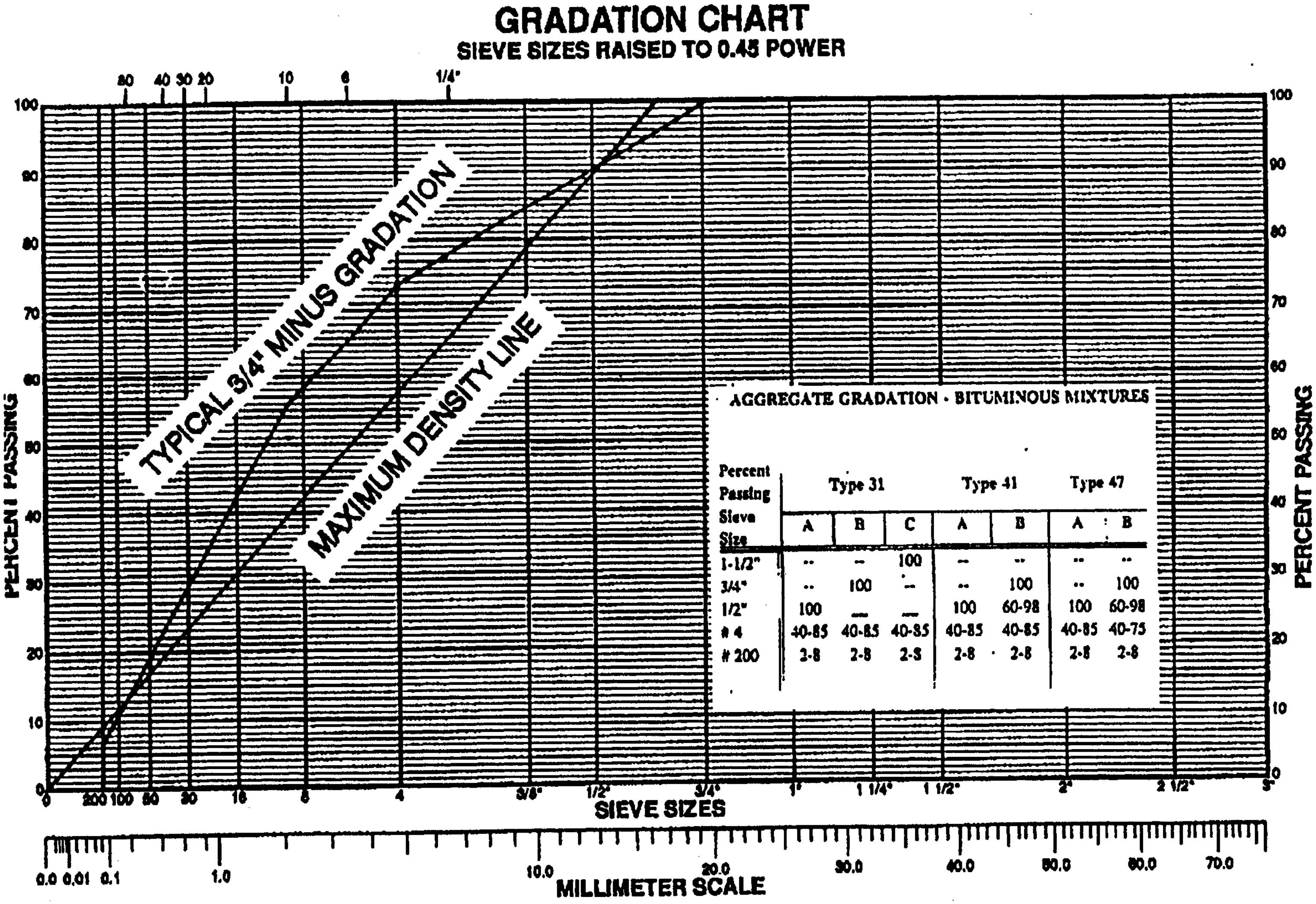
Figure A-20. Asphalt Absorption with Time (Kandhal and Khatri).



AGGREGATE GRADATION - BITUMINOUS MIXTURES

Percent Passing	Type 31			Type 41		Type 47	
Sieve Size	A	B	C	A	B	A	B
1-1/2"	--	--	100	--	--	--	--
3/4"	--	100	--	--	100	--	100
1/2"	100	—	—	100	60-98	100	60-98
# 4	40-85	40-85	40-85	40-85	40-85	40-85	40-75
# 200	2-8	2-8	2-8	2-8	2-8	2-8	2-8

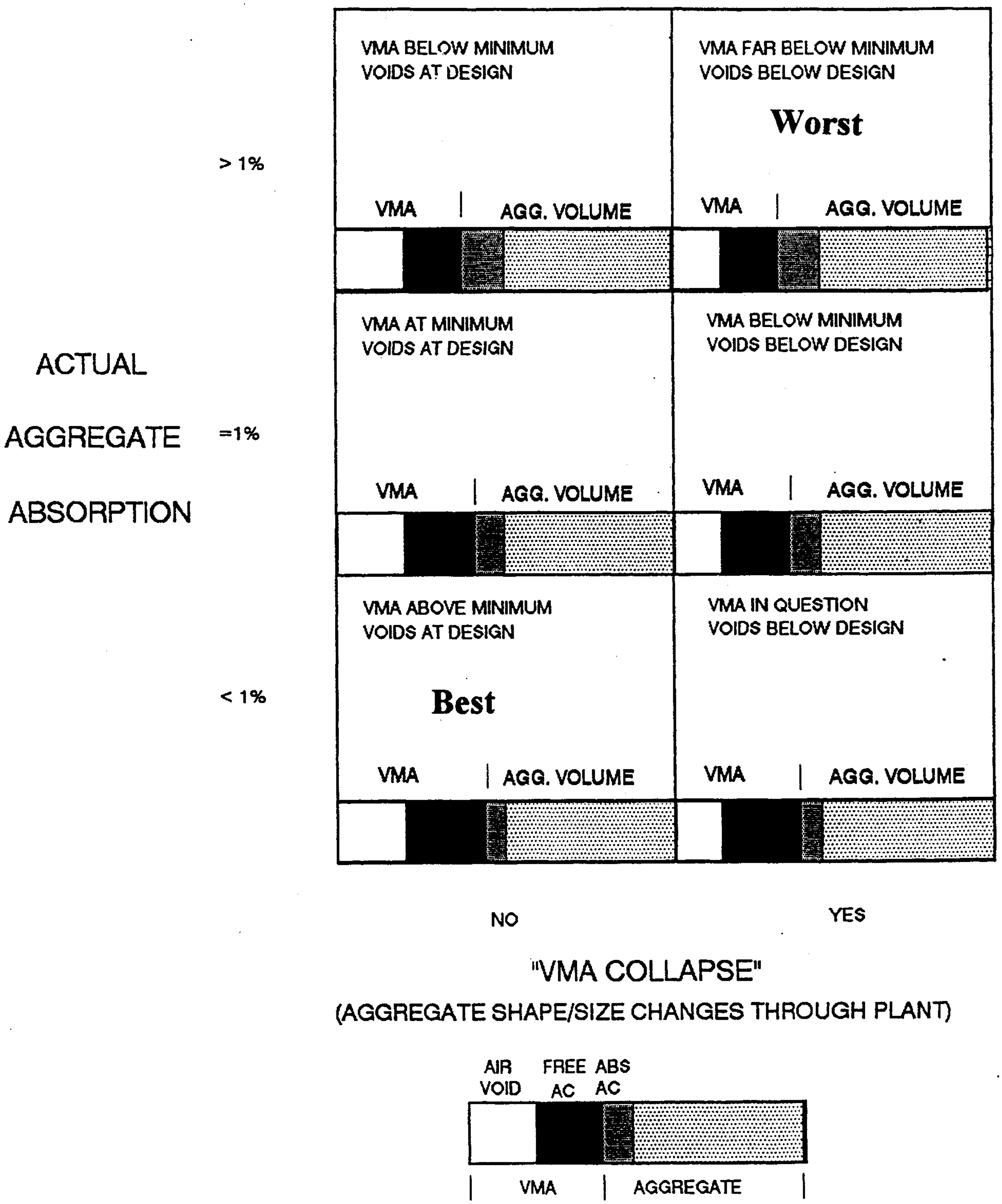
Figure A-21. Typical 12.5 mm (1/2 in) Aggregate Gradation.



AGGREGATE GRADATION - BITUMINOUS MIXTURES

Percent Passing	Type 31			Type 41		Type 47	
Sieve Size	A	B	C	A	B	A	B
1-1/2"	--	--	100	--	--	--	--
3/4"	--	100	--	--	100	--	100
1/2"	100	—	—	100	60-98	100	60-98
# 4	40-85	40-85	40-85	40-85	40-85	40-85	40-75
# 200	2-8	2-8	2-8	2-8	2-8	2-8	2-8

Figure A-22. Typical 19 mm (3/4 in) Aggregate Gradation.


ACTUAL
AGGREGATE
ABSORPTION
> 1%
=1%
< 1%
VMA BELOW MINIMUM
VOIDS AT DESIGN
VMA FAR BELOW MINIMUM
VOIDS BELOW DESIGN
Worst
VMA AT MINIMUM
VOIDS AT DESIGN
VMA BELOW MINIMUM
VOIDS BELOW DESIGN
VMA ABOVE MINIMUM
VOIDS AT DESIGN
Best
VMA IN QUESTION
VOIDS BELOW DESIGN
VMA
AGG. VOLUME
NO
YES
"VMA COLLAPSE"
(AGGREGATE SHAPE/SIZE CHANGES THROUGH PLANT)
AIR VOID
FREE AC
ABS AC
VMA
AGGREGATE