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Use of the Micro-Deval Test for Assessing the Durability of Virginia Aggregates

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Supplementary Notes

Abstract

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The Micro-Deval and several known aggregate tests were compared. The Micro-Deval test showed a very high potential in evaluating aggregate durability with higher precision and accuracy than the conventional tests such as the magnesium sulfate and Los Angeles abrasion tests. The Micro-Deval test was able to differentiate between good and poor performing aggregates at least 70 percent of the time and was able to identify the quality difference between similar aggregate types with varying degrees of weathering.

Because of the study findings, the researchers recommend that the Micro-Deval test be used as a quality control tool for aggregate assessment to supplement the current measures of aggregate quality.

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ABSTRACT

Aggregate is one of the most widely used construction material, and the key aspect of aggregate quality is durability. In this study, the Micro-Deval test, a new test developed in France and modified by Canadians, was studied to evaluate its suitability in assessing the durability of coarse and fine aggregates from Virginia sources.

The Micro-Deval and several known aggregate tests were compared. The Micro-Deval test showed a very high potential in evaluating aggregate durability with higher precision and accuracy than the conventional tests such as the magnesium sulfate and Los Angeles abrasion tests. The Micro-Deval test was able to differentiate between good and poor performing aggregates at least 70 percent of the time and was able to identify the quality difference between similar aggregate types with varying degrees of weathering.

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INTRODUCTION

A key aspect of an aggregate's suitability for use in construction is its durability, or its ability to withstand the stresses to which it is subjected during production, transport, and placement and throughout its intended service life. Primary stressors during production, transport, and placement include impact and abrasion. During service, cycles of freezing and thawing are the primary stressor, but cycles of wetting and drying, cycles of heating and cooling, and traffic abrasion may also have an impact.

Two tests have long served as principal quality assessment tools in judging aggregate suitability for use in construction materials: (1) the Standard Method of Test for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine, AASHTO T 96-02 (known as the Los Angeles [LA] abrasion test),[1] and (2) the Standard Method of Test for Soundness of Aggregate by Use of Sodium Sulfate or Magnesium Sulfate, AASHTO T 104-99 (known as the sodium or magnesium sulfate soundness test).[1] The LA abrasion test subjects dry aggregate to impact and abrasion in a large ball mill with an internal shelf that lifts and drops a charge of aggregate and steel spheres on each rotation. The sulfate soundness test was developed prior to widespread use of refrigeration to simulate environmental stress, principally cycles of freezing-thawing through the swelling of salt crystals, but its protocol of alternate soaking and drying also incorporates cycles of wetting-drying and heating-cooling into its test cycle.

Although both tests have a long history of use by state departments of transportation (DOTs), including the Virginia Department of Transportation (VDOT), as indicators of aggregate quality, issues have long been raised about their relevance in predicting the actual performance of an aggregate in service. In the LA abrasion test, soft but resilient materials that break down in use may have a lower loss than hard, abrasion-resistant, yet brittle materials that suffer high losses because of the large impact stresses that do not reflect their behavior during production, transport, and placement. This creates a dilemma when establishing criterion for evaluating the results of the LA abrasion test. The sulfate soundness test is recognized as requiring a very tight control over particular test parameters to keep test variability at an acceptable level.[2]

As a consequence, researchers have tried to develop simpler tests to evaluate the durability of aggregate for use in pavements and other applications. French scientists developed the Micro-Deval test, in which aggregate samples are abraded in a small ball mill.[3] Research conducted by the Ministry of Transportation (MTO) in Ontario, Canada, found this test to be one of the better indicators of aggregate durability when used along with other tests.[3] In several National Cooperative Highway Research Program (NCHRP) studies,[4-7] the Micro-Deval test was also found to be a good indicator of aggregate durability, toughness, and abrasion resistance. Kandhal and Parker[4] found the Micro-Deval and sulfate soundness tests to be related to the performance of hot-mix asphalt (HMA) pavement in terms of raveling, popouts, or potholes and that the results of the two tests with a maximum loss of 18 percent could be used to distinguish "good-" or "fair-" from "poor-performing" aggregates. They recommended that these tests be used instead of the LA abrasion, sodium sulfate soundness, and unconfined freezing-thawing tests. In a subsequent study to validate the findings of Kandhal and Parker,[4] White et al.[7] recommended that the Micro-Deval and magnesium sulfate soundness tests be used to evaluate aggregates for HMA with maximum loss limits of 15 and 20 percent, respectively, for all climates and traffic loading conditions.

Saeed et al.[5] recommended that the Micro-Deval and magnesium sulfate soundness tests be used to evaluate aggregates for unbound pavement layers, with a range of limits related to the climate and traffic loading conditions. In a recent study at Texas Tech University,[8] a fair to good correlation was established between Micro-Deval and magnesium sulfate soundness test results for aggregates used in Texas.

The South Carolina DOT[9] evaluated the Micro-Deval test using 23 local sources of aggregate commonly used throughout the state. Although traditional tests such as the LA abrasion, magnesium sulfate soundness, and sodium sulfate soundness tests were not so successful, a loss of 17 percent as determined by the Micro-Deval test was able to differentiate all the good-performing coarse aggregates from fair or poor performers. The South Carolina DOT recommends the use of the Micro-Deval test to assess coarse aggregate quality in addition to existing tests in their specification.

Several sources of coarse aggregates with known performance and aggregates from several new sources were evaluated using the Micro-Deval, LA abrasion, and Nordic ball mill tests in a study conducted by the Oregon DOT.[10] The Micro-Deval test did not appear to be any more discriminating than the LA abrasion test in evaluating aggregate durability with respect to the damage caused by studded tires on flexible pavements. But the Nordic ball mill test showed some promise and was recommended for further investigation. The Nordic ball mill test is a wet abrasion test similar to the Micro-Deval test. The major difference is in the charge size, i.e., 15-mm-diameter balls compared to 10-mm balls in the Micro-Deval. The duration of the Nordic ball mill test is shorter, and the cylinder is longer than in the Micro-Deval test.

The Colorado DOT[11] recently implemented a specification requirement of 18 percent degradation by abrasion in the Micro-Deval test for the coarse aggregate used in HMA and stone mastic asphalt (SMA). This implementation was based on an in-house informal study using 19 sources of aggregate with known performance. A loss value of 15 percent was suggested as a specification requirement to eliminate poor-performing aggregate.

Tarefder et al.[12] studied the Micro Deval test for evaluating the durability and abrasion resistance of limestone and sandstone coarse aggregates commonly used by the Oklahoma DOT. A Micro-Deval loss value of 25 percent was proposed as a maximum for good-quality aggregate by comparing known field performance of 18 sources of bituminous aggregate. The performance ranking was better explained by the Micro-Deval results than by the LA abrasion test results. No significant correlation was found between other tests such as freeze-thaw soundness, aggregate durability index, specific gravity, water absorption, or aggregate type and the Micro-Deval test.

The Texas DOT[13] has been using the Micro-Deval test based upon the recommendation of a Texas Tech study[8] for quite some time as a screening test for bituminous aggregate to determine whether further investigation is needed. Although it is included in the specification as a job control test (production test), there is no limit set in the specification. The project engineer is to decide how to use the results.

In a study by Lang et al., the Micro-Deval test was recommended for use to evaluate coarse aggregate durability; but the researchers suggested that it not be used to reject any aggregate solely based on the test result.[14] Instead, the Micro-Deval test could best be used to identify a good-performing aggregate. Aggregates tested in this study were collected from all over the United States and some provinces of Canada. The following tests were performed on all sources of aggregates: mineralogical evaluation, Micro-Deval, LA abrasion, magnesium sulfate soundness, Canadian freeze-thaw soundness, aggregate crushing value, absorption, specific gravity, particle shape factor, and percent fractured. The Aggregate Imaging System was used to obtain additional information about aggregate particle shape, angularity and texture. Field performance data regarding these aggregates for specific uses such as HMA and portland cement concrete (PCC) were collected from state DOTs. The Micro-Deval test results had the best correlation with field performance, and some improvement in the relationship was observed when either Canadian freeze-thaw soundness, absorption, or specific gravity test results were included. Aggregate particle shape and texture did not influence the test results of any of the tests. The overall success rate of Micro-Deval alone for predicting field performance was 69 and 83 percent for HMA and PCC, respectively.

PURPOSE AND SCOPE

The propose of this study was to evaluate the Micro-Deval test as an alternative or supplement to the magnesium sulfate soundness or LA abrasion test to monitor the quality of Virginia coarse and fine aggregates for use in pavement construction.

METHODOLOGY

Overview

The Micro-Deval and several other known aggregate durability tests along with performance history were used in the laboratory to evaluate the durability of fine and coarse aggregates commonly used in Virginia.

Aggregate Selection

Aggregates were selected from the nine VDOT districts. The respective district materials engineer (DME) was asked to select three coarse aggregate sources with varying levels of performance. The reported performance levels varied from good to poor, with several fair or borderline. Although subjective, this information was based on the experience of those most familiar with the use and performance of the materials. The DMEs also selected fine aggregate sources with known or perceived performance for evaluation. Twenty coarse aggregate and 10 fine aggregate sources were evaluated. Selected sources represented all physiographic regions and predominant aggregate types available in Virginia.

Laboratory Testing Program

Petrographic Description

Each aggregate was examined with the aid of a binocular microscope, and the predominant rock types or minerals along with weathering were identified for coarse and fine aggregates.

Specific Gravity and Absorption Test

The specific gravity and absorptive potentials of aggregates were determined in accordance with the following test methods: (1) the Standard Method of Test for Specific Gravity and Absorption of Fine Aggregate, AASHTO T-84-00,[1] and (2) the Standard Method of Test for Specific Gravity and Absorption of Coarse Aggregate, AASHTO T-85-00,[1] respectively.

The samples prepared for the Micro-Deval test were used for specific gravity and absorption determination. Coarse and fine aggregate samples were used for this test before the Micro-Deval test was conducted since the specific gravity and absorption tests are nondestructive tests. Three replicate samples were tested for each coarse and fine aggregate source.

Micro-Deval Test

The resistance to abrasion of the aggregates was determined with a Micro-Deval apparatus in accordance with Canadian and AASHTO standards for fine and coarse aggregate, respectively. The standards followed were:

- Ministry of Transportation, Ontario, Test Method LS-619[15]: *Method of Test for the Resistance of Fine Aggregate to Degradation by Abrasion in the Micro-Deval Apparatus*

- AASHTO T 327-05[1]: *Resistance of Coarse Aggregate to Degradation by Abrasion in the Micro-Deval Apparatus*.

Fine Aggregate Preparation

After washing over a 0.075-mm (No. 200) sieve and drying to constant mass, fine aggregate samples were prepared by sieving into individual size fractions. Test samples weighing 500 g were prepared to a fineness modulus of 2.8 using the gradation shown in Table 1. The initial mass of each sample was then recorded. Three samples were prepared for each source for a total of 30 samples.

Supplementary samples of select aggregate sources were prepared in a similar fashion except that separate 500-g test samples were composed of individual size factions. As many samples as possible were prepared based on the availability of the remaining raw aggregate.

Table 1. Fine Aggregate Gradation for Micro-Deval Test

Passing		**Retained**			
Sieve No.	**Opening (mm)**	**Sieve No.**	**Opening (mm)**	**Mass (g)**	**(%)**
4	4.75	8	2.360	50	10
8	2.36	16	1.180	125	25
16	1.18	30	0.600	125	25
30	0.60	50	0.300	100	20
50	0.30	100	0.150	75	15
100	0.15	200	0.075	25	5
Total mass of sample				500	
15 min test duration at 100 ± 5 revolutions per minute					

Coarse Aggregate Preparation

Coarse aggregate was washed clean of fine material, dried to constant mass, and separated into individual fractions. A 1500-g sample was prepared in accordance with Table 2 based on the maximum nominal particle size of the sample. The maximum nominal size for all sources was 19.0 mm since VDOT No. 57 aggregate was used for this study. The initial mass of each sample was then recorded. Three replicate samples were prepared for each source for a total of 60 samples.

Table 2. Coarse Aggregate Gradation for Micro-Deval Test

Maximum Nominal Size, mm	Sieve Size, mm (inch or no.)		Mass, g	Test Duration, min (at 100 ± 5 rpm)
	Passing	Retained		
19.0	19.0 (3/4 in)	16.0 (5/8 in)	375	120 ± 1
	16.0 (5/8 in)	12.5 (1/2 in)	375	
	12.5 (1/2 in)	9.5 (3/8 in)	750	
	Total sample mass		1500	
16.0	12.5 (1/2 in)	9.5 (3/8 in)	750	105 ± 1
	9.5 (3/8 in)	6.3 (1/4 in)	375	
	6.3 (1/4 in)	4.75 (No. 4)	375	
	Total sample mass		1500	
12.5	9.5 (3/8 in)	6.3 (1/4 in)	750	95 ± 1
	6.3 (1/4 in)	4.75 (No. 4)	750	
	Total sample mass		1500	

Fine Aggregate Testing Procedure

Each sample was processed in the Micro-Deval apparatus in accordance with the Ministry of Transportation, Ontario, Test Method LS-619. Samples were saturated with tap water at room temperature for 24 ± 4 hr prior to being processed in the Micro-Deval apparatus. After saturation, excess tap water was decanted off and each sample was placed into the stainless steel Micro-Deval jar with 750 mL of tap water and a 1250 ± 5 g charge of 9.5 ± 0.5 mm stainless steel balls. The jar was rotated at 100 ± 5 rpm for 15 min ± 10 sec. After running in the Micro-Deval apparatus, samples were washed out of the stainless steel jar over a 6.7-mm sieve to separate the steel balls and onto a 0.075-mm (No. 200) sieve. The sample was washed until the water ran clear and subsequently dried to constant mass. After drying, the final mass was recorded and the percent finer than a No. 200 sieve was reported as the loss value.

Following completion of the standard procedure, a sieve analysis of the +0.075-mm material for the individual size fraction samples and the graded samples was performed for comparison with the original test sample grading.

Coarse Aggregate Testing Procedure

Each sample was processed in the Micro-Deval apparatus in accordance with AASHTO T 327-05. Samples were placed in the stainless steel Micro-Deval jar with 2.0 ± 0.05 L of tap water and allowed to saturate for at least 1 hour prior to processing on the Micro-Deval apparatus. A 5000 ± 5 g charge of 9.5 ± 0.5-mm stainless steel balls was placed into the jar. The jar was then rotated at 100 ± 5 rpm for 2 hr for 19.0-mm sample gradation as reported in Table 2. After running in the Micro-Deval apparatus, samples were washed out of the stainless steel jar onto a 4.75-mm (No. 4) sieve over a 1.18-mm (No. 16) sieve. The steel balls were removed with a magnet, and samples washed until the water ran clear. The material retained on the two sieves was combined and dried to constant mass. After drying, the final mass was recorded and the percent passing the No. 16 sieve was reported as the loss value.

Magnesium Sulfate Soundness Test

The resistance of aggregates to disintegration by saturated magnesium sulfate solution was evaluated in accordance with AASHTO T 104-99 with modified solution storage and final aggregate washing procedures.

Fine Aggregate Preparation

After washing over a 0.075-mm (No. 200) sieve and drying to constant mass, fine aggregate samples were prepared by rough sieving the material into individual size fractions in accordance with Table 3. From the rough separation, 110-g samples were prepared, sieved to refusal, and weighed out into 100 g of individual sized samples for testing. The initial mass of each sample was then recorded. Three samples of each fraction were prepared for each source for a total of 120 fine aggregate specimens.

Table 3. Sample Size and Gradation for Magnesium Sulfate and/or Freeze-Thaw Soundness Test

Aggregate Samples	Sieve Size, mm (in or No.)		Mass, g	Loss Calculation Sieve, mm
	Passing	Retained		
Coarse	19.0 (3/4 in)	12.5 (1/2 in)	670 ± 10	8.0 (5/16 in)
	12.5 (1/2 in)	9.5 (3/8 in)	330 ± 5	
	Total mass of sample		1000 ± 10	
Coarse	9.5 (3/8 in)	4.75 (No. 4)	300 ± 5	4.0 (No. 5)
Fine	4.75 (No. 4)	2.36 (No. 8)	100	2.36 (No. 8)
Fine	2.36 (No. 8)	1.18 (No. 16)	100	1.18 (No. 16)
Fine	1.18 (No. 16)	0.60 (No. 30)	100	0.60 (No. 30)
Fine	0.60 (No. 30)	0.30 (No. 50)	100	0.30 (No. 50)

Coarse Aggregate Preparation

Coarse aggregate was washed clean of fine material, dried to constant mass, and separated into fractions and sample sizes in accordance with Table 3. Each sample had its initial mass recorded. Three samples of each fraction were prepared for each source for a total of 180 coarse aggregate specimens.

Fine Aggregate Testing Procedure

Magnesium sulfate solutions were prepared to a specific gravity of 1.300 and monitored throughout testing such that specific gravities remained between 1.297 and 1.306. Discolored solutions were filtered through a No. 200 sieve to remove insoluble particles and discarded when subjectively determined to be excessively discolored. During testing, the sulfate solutions were prepared at a temperature of 70 +/- 2^{o}F, placed in insulated boxes, and stored in a concrete curing chamber designed to maintain a constant temperature range of 70.4 to 76.4^{o}F. Temperatures were observed to vary between approximately 68 and 73^{o}F; the temperature of solution in each insulated box was monitored daily during testing. Samples were contained in the solution on the sieves on which they were prepared. Each cycle of testing consisted of immersion in solution for 16 to 18 hr, removal from solution, draining for 15 ± 5 min, drying to constant mass, and cooling before re-immersion. Each sample was subjected to five cycles of immersion and drying. After the completion of the final drying cycle, samples were submerged in clean tap water to dislodge particles and salt cake from the sieves on which they were tested. Samples were then washed by repeated decanting, refilling, and gentle hand stirring over a period of approximately 2 days. The prescribed method of circulation of water through samples from the bottom and being allowed to overflow was found to be unmanageable because the flow rate could not be adjusted low enough to prevent fine particles in the sample from flowing out of the sieve. After washing, samples were dried to constant mass. After final drying, samples were sieved over the original sieves on which they were prepared and final mass determined. The loss values were calculated as percent finer than original sieve.

Coarse Aggregate Testing Procedure

Coarse aggregate samples were tested in a similar manner to the fine aggregate procedure with the same number of cycles (five). After the final drying phase, the samples were washed of the sulfate salts by introducing warm water through the base of the sample and allowing water to flow over the edge of the sieve on which it was tested. After washing, samples were dried to constant mass and sieved to refusal over sieves in accordance with Table 3, after which a final mass was recorded. The loss values were calculated as percent finer than the respective sieves in Table 3.

Los Angeles Abrasion Test

The resistance of aggregates to degradation by the LA degradation device was evaluated in accordance with AASHTO T-96.

Coarse Aggregate Preparation

Coarse aggregate was washed clean of fine material, dried to constant mass, and separated into fractions in accordance with Table 4. At least one 5000-g sample for each source was prepared to conform to the requirements of AASHTO T-96, Grading B and/or C. These sample gradations are presented in Table 4. An initial mass of each sample was then recorded.

Table 4. Coarse Aggregate Gradation for Los Angeles Abrasion Test

Gradation	Sieve Size, mm (inch or No.)		Mass, g	Loss Calculation Sieve, mm
	Passing	Retained		
B	19.0 (3/4 in)	12.5 (1/2 in)	2500	1.70 (No. 12)
	12.5 (1/2 in)	9.5 (3/8 in)	2500	
	Total sample mass		5000	
C	9.5 (3/8 in)	6.3 (1/4 in)	2500	1.70 (No. 12)
	6.3 (1/4 in)	4.75 (No. 4)	2500	
	Total sample mass		5000	

Coarse Aggregate Testing Procedure

Each sample was placed into the steel testing drum along with 11 or 8 steel spheres weighing approximately 420 g for Grading B and C, respectively. The drum was rotated for 500 revolutions. The sample was then removed from the drum, the steel spheres were removed, and the sample was then sieved dry over a No. 12 sieve. The final mass retained on the No. 12 sieve was recorded, and the LA abrasion loss determined as percent finer than the No. 12 sieve.

Freeze-Thaw Soundness Test

The resistance to disintegration by freezing and thawing of aggregates was tested in accordance with the Standard Method of Test for Soundness of Aggregate by Freezing and Thawing, AASHTO T103-91,[1] as required by the VDOT specification.[16]

Fine Aggregate Preparation

After washing over a 0.075-mm (No. 200) sieve and drying to constant mass, fine aggregate samples were prepared by rough separation of the sample into individual size fractions in accordance with Table 3, similar to the magnesium sulfate soundness test. From the rough separation, 110-g samples were prepared, sieved to refusal, and weighed out into 100-g individual sized samples for testing. The initial mass of each sample was recorded, and each sample was stored in a plastic bag and rigid plastic container for testing. Three samples of each fraction were prepared for each source for a total of 120 fine aggregate specimens.

Coarse Aggregate Preparation

Coarse aggregate was washed clean of fine material, dried to constant mass, and separated into fractions and sample sizes in accordance with Table 3. The initial mass of each sample was recorded, and each sample was stored in a plastic bag and rigid plastic container for testing. Three samples of each fraction were prepared for each source for a total of 180 coarse aggregate specimens.

Testing Procedure

Freezing and thawing cycling was performed in accordance with AASHTO T103-91, Procedure A (total immersion). Each bagged sample was filled with water 24 hr before the start of the first freezing cycle and placed in an environmental chamber. The chamber was configured to cycle between 73 and –15^{o}F as quickly as possible and set to remain at each temperature for 6.5 and 7.5 hr, respectively. A temperature history of a typical cycle is shown in Figure 1. During the first 10 cycles, the soak time at each temperature was adjusted slightly to ensure all samples were completely thawed and completely frozen during each cycle. Thermocouples were place at eight points in the environmental chamber to monitor temperature to ensure proper freezing and/or thawing of all samples. The average high and low temperatures in the environmental chamber for the duration of the test are summarized in Figure 2. Samples were subjected to 100 continuous cycles as required by the VDOT specification[16] over 58 days.

Examination

After completion of the final freezing cycle, the machine was turned off and the samples were allowed to thaw. Because of the insulating properties of the chamber, some samples remained frozen for an extended (but unmeasured) period of time before being removed from the chamber and exposed to room temperature conditions. After each sample was thawed, it was carefully washed out of its plastic bag and container and washed over sieves in accordance with Table 3 for coarse aggregate and over the original retaining sieve for fine aggregate. After

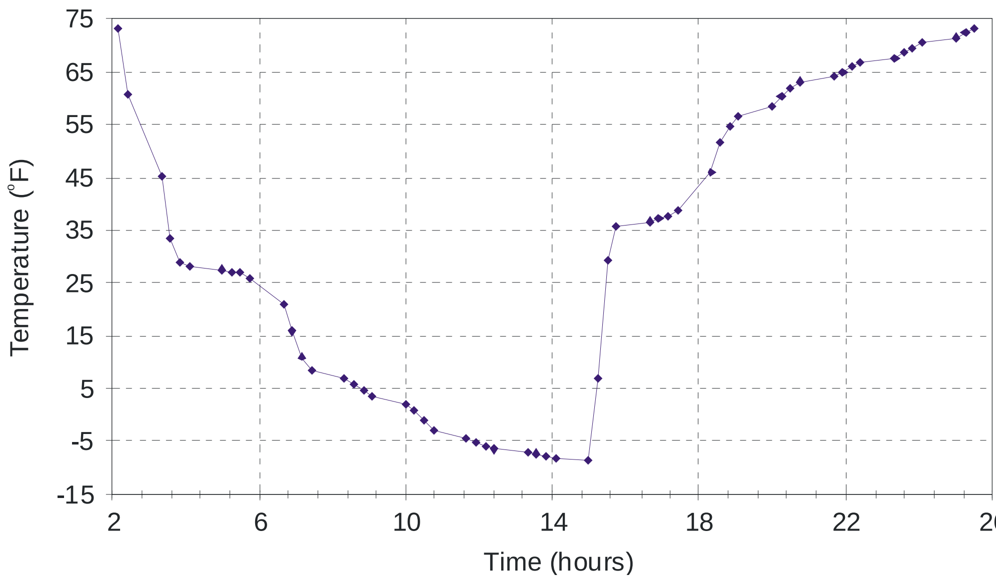

Figure 1. Typical Cycle Temperature History for Freeze-Thaw Test

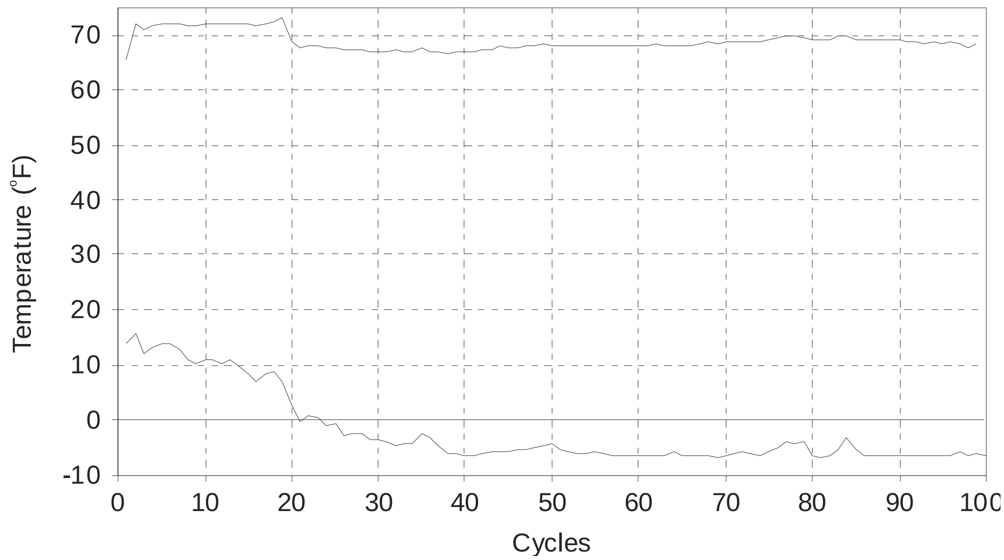

Figure 2. High and Low Chamber Temperatures in Freeze-Thaw Test Cycles

washing, each sample was dried to constant mass. After drying to constant mass, samples were again hand sieved to refusal over sieves in accordance with Table 3 for coarse aggregate and over the original retaining sieve for fine aggregate, after which the final mass was recorded. Freeze-thaw testing losses were determined in a manner similar to that for the sulfate soundness and LA abrasion tests.

Performance Evaluation

The initial performance evaluation of selected materials was primarily based on the experience of the respective VDOT district. DMEs were contacted for their subjective but experienced-based evaluation of the general quality and performance of the material. Their evaluations provided valuable insight into the expected performance of each aggregate relative to the test results. Each district ranked their aggregate based on their experience using qualitative descriptions such as "best," "better," "good," "fair," "borderline," and "poor." Hence the relative ranking among the sources for a particular district is more valuable than the absolute performance rating considering all the aggregates together. It is important to note that most of the ratings were not directly related to the actual field performance. In some cases, they were related to not satisfying the current VDOT specifications[16] as shown in Table 5.

In a few instances, as noted by the DMEs in the aggregate performance evaluation, aggregate breakdown is reported during production, such as HMA production, but a subsequent adjustment in asphalt content during production prevented any undesirable field performance. The responses grouped according to the respective district are summarized in Tables 6 and 7 for coarse and fine aggregates, respectively.

Table 5. VDOT Requirements for Aggregate

Application	Magnesium Sulfate Soundness Loss (%), maximum		Freeze-Thawing Loss (%), maximum		LA Abrasion Loss (%), maximum (500 revolutions)
	Coarse	Fine[a]	Coarse	Fine[a]	Coarse[b]
Hydraulic cement concrete (HCC)	12	18	5	8	40 (Grade A)
Asphalt surface layer (ASL)	15	25	6	15	40 (Grade A) or 45 (Grade B)
Asphalt concrete base	20	30	7	15	40 (Grade A) or 45 (Grade B)
Aggregate base	20	-	7	-	40 (Grade A) or 45 (Grade B)
Subbase and select material	30	-	12	-	50 (Grade C)

[a]Fine aggregate crushed from Grade A stone or natural sources.
[b]Coarse aggregate grading based on LA abrasion loss.

Table 6. Coarse Aggregate Performance Evaluation by VDOT Districts

Aggregate	Performance	Remarks
CA-11	Good	
CA-12	Borderline	Failed LA abrasion and soundness requirement; some indication of breakdown in surface HMA
CA-13	Poor	Failed LA abrasion and soundness requirement; some indication of breakdown in surface HMA
CA-31	Best	
CA-32	Good	Minor breakdown during production, stockpiling, transportation, and compaction of HMA
CA-33	Poor	This aggregate is used in limited applications.
CA-41	Good	Based on specification requirement
CA-42	Fair	Based on specification requirement
CA-43	Poor	Failing LA abrasion requirements
CA-51	Good	
CA-52	Fair to Poor	Breakdown of 21 As in handling and pug-milling operation (performance in cement-treated aggregate
CA-61	Good	
CA-62	Fair to Poor	High mica content; need more washing.(performance in 21B)
CA-71	Best	
CA-72	Better	High mica content
CA-73	Good	Flat & elongated particles
CA-81	Good	Used in HCC and HMA
CA-82	Fair	Breakdown during compaction in HMA
CA-83	Questionable	Possible particle breakdown: stripping problem in HMA in the past; poor magnesium sulfate soundness results compared to other limestone sources in area
CA-90	Poor	Breakdown in HMA

Table 7. Fine Aggregate Performance Evaluation by VDOT Districts

Aggregate	Performance
FA-11	Good
FA-12	Borderline
FA-13	Borderline
FA-14	Poor
FA-2P	Poor
FA-3G	Good
FA-4P	Poor
FA-8G-1	Good
FA-8G-2	Good
FA-8Q	Good

Testing Quality Control

The accuracy and precision of the tests were evaluated regularly. For established tests, precision and bias statements were used. For the Micro-Deval test, a standard material was tested periodically to check that the results were falling within established bounds. Micro-Deval tests were run periodically on reference (Brechin Quarry No. 2) aggregate supplied by the Ministry of Transportation, Ontario.

After approximately every 10 samples, a sample of the control aggregate was tested to ensure the quality of the results. For coarse aggregate, the expected mean loss is 19.1 percent, with a range of 17.5 to 20.7 percent. On the other hand, the expected mean Micro-Deval loss for fine aggregates is 18.9 percent, with a range of 16.8 to 21.0 percent. The results of quality control procedures for the Micro-Deval test are presented in Table 8. The loss value for both fine and coarse aggregate was approximately 20 percent. Although these values are on the upper end, they are well within the specified limit.

Table 8. Micro-Deval Apparatus Quality Control Test Results

Coarse Aggregate (Brechin, Canada)		Fine Aggregate (Brechin, Canada)	
Sample	**Percent Loss**	**Sample**	**Percent Loss**
1	20.68	1	21.28
2	20.23	2	20.24
3	19.93	3	20.07
4	20.26	4	20.00
5	20.70	5	20.14
Average	20.36	Average	20.35
Coefficient of variation	1.62%	Coefficient of variation	2.61%

RESULTS AND DISCUSSION

The petrographic description and the specific gravity and absorption, magnesium sulfate soundness, freeze-thaw, LA abrasion, and Micro-Deval test results are summarized in Tables 9 through 18. The coefficient of variation is included for the magnesium sulfate soundness, freeze-thaw, and Micro-Deval tests to show the variability among the replicate measurements.

Table 9. Coarse Aggregate Petrography

Aggregate	Petrography	Remarks
CA-11	Gneiss (granitic)	
CA-12	Ultramafic (altered)	Probably serpentine and talc
CA-13	Amphibolite: 54%; Gneiss/Schist: 46%	
CA-31	Granite	
CA-32	Granite: 53%; Aplite: 47%	
CA-33	Marble	Flat & elongated: 70%; Only elongated: 30%
CA-41	Metarhyolite (felsic: 23%; mafic: 77%)	
CA-42	Gneiss (amphibolite, biotite: 80%; granitic: 20%)	
CA-43	Gneiss (granitic: 85%; amphibolite, biotite: 13%; pegmatite:2%)	Biotite flakes easily
CA-51	Granite	
CA-52	Granite	
CA-61	Diorite/Amphibolite: harder 77% and softer 23% (more rounded)	
CA-62	Granite	
CA-71	Diabase (Traprock)	
CA-72	Gneiss (coarse grained): 85%; Schist (fine grained): 15%	
CA-73	Siltstone: hard and dense.	About 25% flat, tabular particles
CA-81	Limestone (micrite: 87%; sparry calcite: 13%)	
CA-82	Arkose (relatively unweathered: 36%; weathered: 64%)	
CA-83	Arkose and Quartzite (somewhat weathered: 53%; weathered: 47%)	Another sample evaluated: Quartzite: 30%; Arkose (slight weathered): 30%; Arkose (quite weathered): 40%
CA-90	Gneiss (granitic)	

Table 10. Fine Aggregate Petrography

Aggregate	Petrography	Remarks
FA-11	Gneiss (granitic)	Medium grained, crushed
FA-12	Ultramafic (altered)	Probably serpentine, crushed
FA-13	Quartzite: 47%; Rock fragments: 33%; Feldspar: 12%; Quartz: 7%	Natural; Rock fragments: fine-med grained, somewhat weathered, rounded
FA-14	Amphibolite: 67%; Gneiss: 18%; Schist: 15%	Amphibolite friable; Schist weathered
FA-2P	Amphibolite gneiss	Crushed friable
FA-3G	Aplite	Crushed
FA-4P	Feldspar: 81%; Quartz: 19%	Natural
FA-8G-1	Limestone	Crushed
FA-8G-1	Limestone	Crushed
FA-8Q	Rock fragments: 60%; Arkose: 40%	Natural, rock fragments fine-grained

Table 11. Aggregate Specific Gravity and Absorption Data Summary

Aggregate	Bulk Specific Gravity	Bulk Specific Gravity (SSD)	Apparent Specific Gravity	Absorption (%)
Coarse Aggregate				
CA-11	2.693	2.706	2.727	0.46
CA-12	2.759	2.779	2.816	0.73
CA-13	2.956	2.972	3.005	0.54
CA-31	2.762	2.778	2.806	0.57
CA-32	2.806	2.818	2.840	0.43
CA-33	2.792	2.804	2.825	0.42
CA-41	2.644	2.661	2.690	0.65
CA-42	2.741	2.758	2.788	0.62
CA-43	2.686	2.701	2.725	0.54
CA-51	2.655	2.663	2.675	0.27
CA-52	2.615	2.616	2.646	0.68
CA-61	2.929	2.944	2.974	0.51
CA-62	2.749	2.763	2.787	0.49
CA-71	3.032	3.046	3.075	0.45
CA-72	2.819	2.832	2.856	0.46
CA-73	2.731	2.751	2.786	0.72
CA-81	2.707	2.716	2.731	0.32
CA-82	2.444	2.501	2.593	2.35
CA-83	2.489	2.540	2.621	2.01
CA-90	2.649	2.661	2.683	0.49
Fine Aggregate				
FA-11	2.710	2.720	2.738	0.38
FA-12	3.020	3.030	3.049	0.32
FA-13	2.563	2.604	2.672	1.58
FA-14	2.709	2.73	2.766	0.75
FA-2P	3.035	3.052	3.088	0.57
FA-3G	2.774	2.787	2.812	0.49
FA-4P	2.552	2.586	2.641	1.32
FA-8G-1	2.701	2.714	2.737	0.49
FA-8G-2	2.692	2.708	2.738	0.62
FA-8Q	2.613	2.652	2.718	1.48

Table 12. Coarse Aggregate Magnesium Sulfate Soundness Data Summary

Aggregate	Magnesium Sulfate Soundness Loss (%)			
	3/4 to 3/8 in		3/8 in to No. 4	
	Mean	COV	Mean	COV
CA-11	0.56	0.56	1.69	0.19
CA-12	0.63	16.22	1.99	52.21
CA-13	3.46	26.07	17.52	28.86
CA-31	2.25	28.28	10.65	16.56
CA-32	0.49	10.83	1.98	18.73
CA-33	1.52	7.55	4.14	28.07
CA-41	3.80	27.93	8.90	24.36
CA-42	3.20	15.17	8.64	34.78
CA-43	1.81	45.79	5.42	25.72
CA-51	1.24	78.06	0.62	50.85
CA-52	6.50	11.57	9.94	13.37
CA-61	2.42	8.67	4.37	8.55
CA-62	2.54	22.80	8.80	19.49
CA-71	0.55	38.17	2.48	17.42
CA-72	0.67	15.21	2.16	23.00
CA-73	1.75	89.15	2.18	13.11
CA-81	1.34	69.87	0.93	9.40
CA-82	12.06	7.56	28.70	10.86
CA-83	2.47	26.48	17.49	11.40
CA-90	1.49	29.75	4.16	22.73

Table 13. Fine Aggregate Magnesium Sulfate Soundness Data Summary

Aggregate	Grain Size	Percent Loss	COV (%) 3 replicate samples
FA-11	8	6.43	28.08
	16	7.88	26.22
	30	9.89	15.92
	50	12.41	35.76
FA-12	8	10.59	2.25
	16	14.96	13.78
	30	22.46	1.40
	50	32.17	9.00
FA-13	8	56.11	8.81
	16	50.12	9.37
	30	27.47	5.12
	50	14.87	10.44
FA-14	8	37.08	42.35
	16	39.57	25.62
	30	45.35	31.51
	50	38.19	26.34
FA-2P	8	19.77	9.77
	16	22.44	12.30
	30	21.42	4.99
	50	26.29	8.61
FA-3G	8	3.46	38.02
	16	5.54	11.70
	30	7.28	18.41
	50	12.02	16.69
FA-4P	8	53.13	16.19
	16	44.63	10.11
	30	29.27	9.22
	50	21.95	22.21
FA-8G-1	8	7.39	24.71
	16	6.18	46.28
	30	8.97	7.75
	50	11.05	39.76
FA-8G-2	8	9.40	5.18
	16	11.70	18.56
	30	18.30	9.65
	50	26.00	5.91
FA-8Q	8	32.74	6.99
	16	29.43	15.68
	30	21.17	10.76
	50	11.08	15.53

Table 14. Coarse Aggregate Freeze Thaw Soundness Data Summary

Aggregate	Freeze-Thaw Soundness Loss (%)			
	3/4 to 3/8 in		3/8 in to No. 4	
	Mean	COV	Mean	COV
CA-11	0.64	1.76	0.62	21.70
CA-12	0.74	50.50	4.47	83.73
CA-13	1.04	22.55	1.73	10.42
CA-31	0.94	8.72	2.27	10.98
CA-32	0.36	10.08	0.72	17.44
CA-33	1.20	22.89	0.98	15.34
CA-41	1.48	15.59	2.05	14.61
CA-42	1.42	57.69	2.41	23.31
CA-43	0.71	14.24	1.85	31.46
CA-51	0.14	8.19	0.30	11.72
CA-52	4.18	4.09	4.35	23.90
CA-61	1.19	3.91	1.88	27.30
CA-62	0.79	14.27	1.11	20.28
CA-71	0.27	15.72	0.60	3.49
CA-72	0.33	12.37	0.43	12.26
CA-73	0.44	75.69	0.84	18.60
CA-81	1.28	23.94	0.97	41.76
CA-82	3.19	17.22	4.96	8.14
CA-83	0.50	39.47	0.99	14.38
CA-90	0.56	31.62	0.75	6.90

Table 15. Fine Aggregate Freeze-Thaw Durability Data Summary

Aggregate	Grain Size	Percent Loss	COV (%) 3 replicate samples
FA-11	8	1.04	6.94
	16	0.91	23.66
	30	0.63	65.68
	50	1.14	26.30
FA-12	8	2.98	18.00
	16	3.09	13.27
	30	0.93	22.49
	50	1.78	30.50
FA-13	8	6.56	22.37
	16	4.30	8.41
	30	1.54	28.62
	50	1.93	28.76
FA-14	8	3.50	32.90
	16	1.77	57.50
	30	0.88	55.01
	50	1.45	11.19
FA-2P	8	1.41	39.30
	16	1.19	33.07
	30	0.45	10.10
	50	0.63	29.65
FA-3G	8	1.15	35.38
	16	0.80	43.78
	30	0.61	46.56
	50	0.96	41.90
FA-4P	8	7.75	6.54
	16	2.91	32.49
	30	1.54	24.87
	50	1.51	18.58
FA-8G-1	8	0.65	42.85
	16	0.57	31.02
	30	0.33	65.63
	50	0.31	-
FA-8G-2	8	1.70	10.46
	16	1.54	26.87
	30	0.86	13.83
	50	1.64	27.71
FA-8Q	8	0.72	3.22
	16	0.78	30.15
	30	0.49	5.40
	50	0.09	47.14

Table 16. Coarse Aggregate LA Abrasion Data Summary

Aggregate	LA Abrasion Loss (%)	
	Gradation B	Gradation C
CA-11	-	25
CA-12	-	19
CA-13	-	-
CA-31	19	25
CA-32	17	20.5
CA-33	37	33.5
CA-41	20	22
CA-42	38	43
CA-43	40	45
CA-51	16	21
CA-52	28	30
CA-61	18	18
CA-62	37	39
CA-71	24	29
CA-72	24	26
CA-73	13	14
CA-81	21	20
CA-82	44	50
CA-83	31	32.5
CA-90	32	31.5

Table 17. Coarse Aggregate Micro-Deval Loss Values

Aggregate	Micro-Deval Loss (%)	
	Mean	COV
CA-11	6.14	3.23
CA-12	24.46	0.88
CA-13	17.16	1.24
CA-31	7.05	1.35
CA-32	5.94	27.13
CA-33	19.60	1.59
CA-41	10.55	2.05
CA-42	15.67	4.56
CA-43	10.15	9.17
CA-51	3.32	4.00
CA-52	8.25	3.86
CA-61	12.48	2.75
CA-62	13.91	5.60
CA-71	6.79	3.30
CA-72	10.51	0.59
CA-73	5.12	4.17
CA-81	10.46	2.74
CA-82	18.67	1.77
CA-83	6.53	7.68
CA-90	8.05	7.48

Table 18. Fine Aggregate Micro-Deval Loss Values

Aggregate	Micro Deval Loss (%)	
	Mean	COV
FA-11	12.83	2.41
FA-12	13.55	3.39
FA-13	14.42	1.16
FA-14	24.17	0.99
FA-2P	29.16	1.06
FA-3G	12.07	0.75
FA-4P	15.14	0.82
FA-8G-1	14.90	7.23
FA-8G-2	17.32	3.62
FA-8Q	12.66	1.95

Coarse Aggregate

Twenty sources of coarse aggregate from across Virginia were tested for Micro-Deval abrasion loss along with other conventional tests currently required by the VDOT specifications.[16] The field performance data gathered for these aggregates are presented in Table 6. These are subjective ratings, and there was no reference to relate these ratings among the VDOT districts. Moreover, they do not necessarily reflect the field performance as influenced by the aggregate quality alone but may also be influenced by other factors that affect the performance of composite materials. The basis for these ratings was primarily the experience of the district personnel. Some ratings are solely related to the specification requirement such as LA abrasion loss instead of any actual field use or performance record. The district experience was related, but not limited, to the use in asphalt concrete, HCC, and base aggregate. Therefore, it seemed reasonable to combine the poor/fair rated aggregates into a category labeled “questionable quality/performance.” On the other hand, good-performing aggregates had relatively fewer problems associated with their use.

Mean Micro-Deval test results for each coarse aggregate are plotted in a bar chart in Figure 3 where they are grouped as “good performer” and “questionable.” Values ranged from a low of 3.3 percent to a high of 24.5 percent. Ten aggregates were rated as good performers, and the remaining 50 percent had an associated negative comment based on field use over the years.

The four aggregates with the highest mean Micro-Deval loss values can be seen from the performance rankings and results from the LA abrasion, magnesium sulfate, freeze-thaw, and absorption tests (shown in Figure 4 using the same sequence as in Figure 3) to have multiple issues associated with a poor rating. These values exceeded 17 percent Micro-Deval loss, a value that would trigger usage restrictions by some agencies.[9] On this basis, one could say that the Micro-Deval test result correctly identified the relative performance of 14 of the 20, or 70 percent, of the aggregates included in the study, with the results for 6 somewhat ambiguous.

The highest mean Micro-Deval loss result for an aggregate in the good category was 12.5 percent, which was higher than the mean values for four aggregates in the questionable category whose results ranged from 6.5 to 10.2 percent. Three of these aggregates, CA-43, CA-52, and

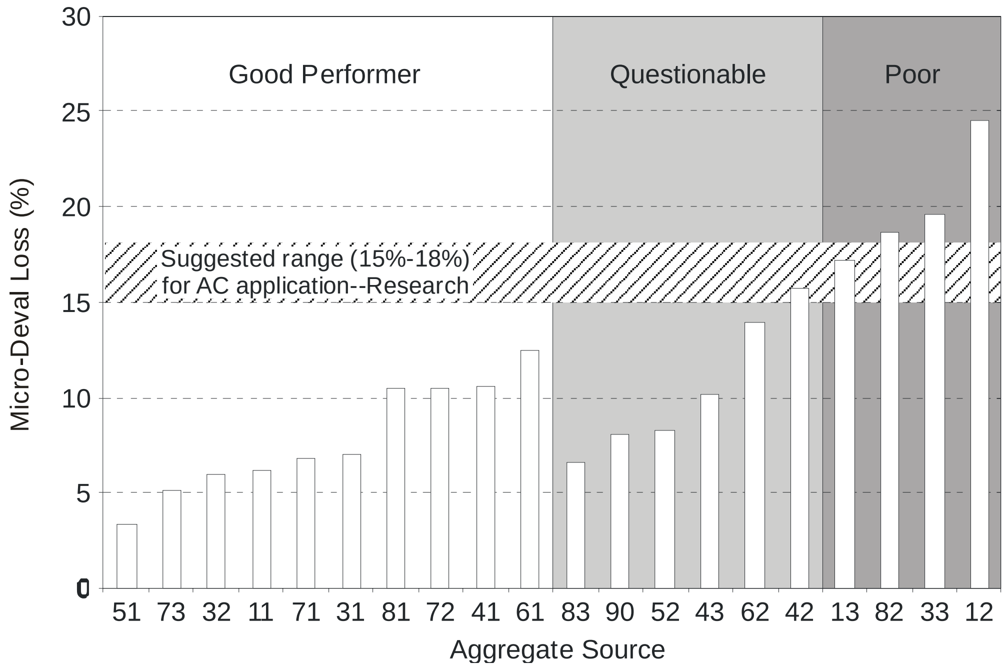

Figure 3. Coarse Aggregate Micro-Deval Test Results. AC = asphalt concrete.

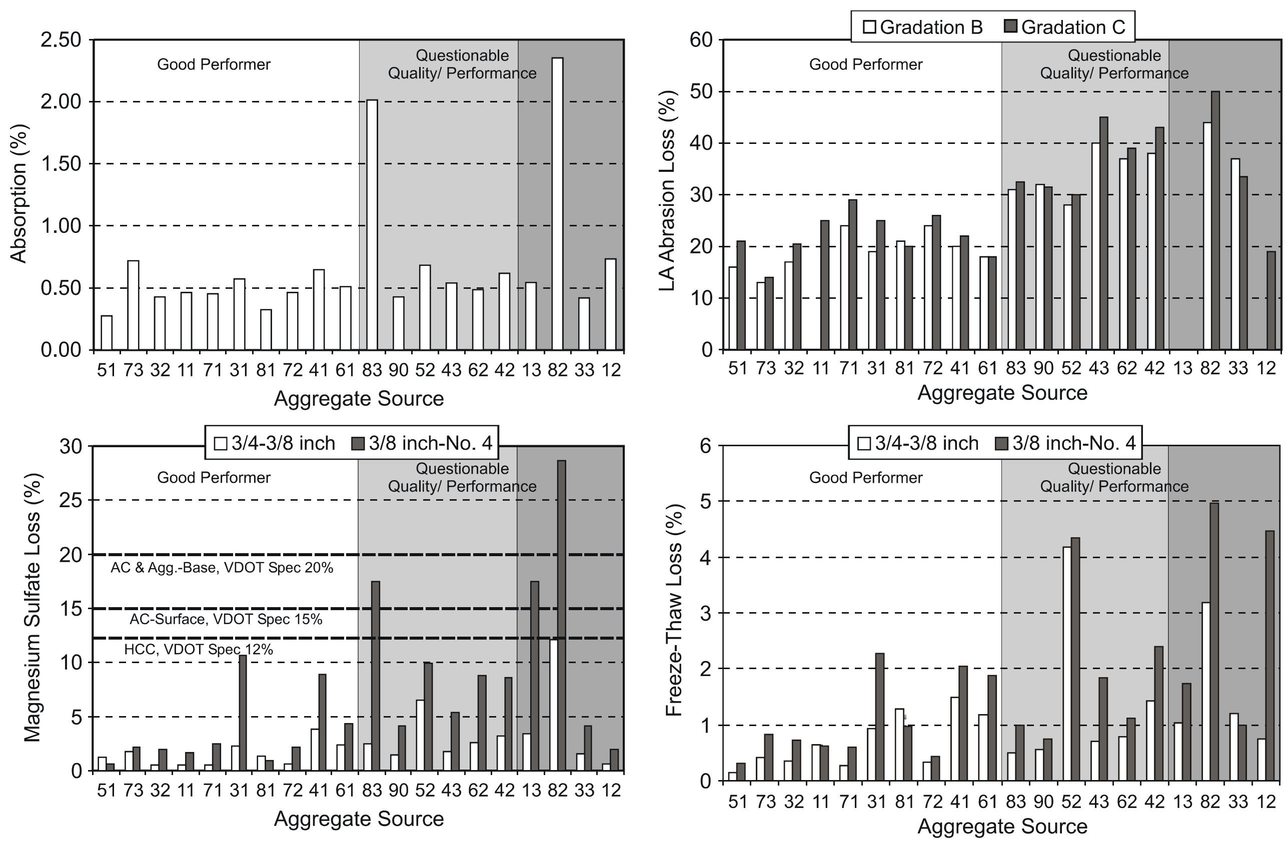

Figure 4. Conventional Test Results for Coarse Aggregate. AC = asphalt concrete, Agg. = aggregate, HCC = hydraulic cement concrete.

CA-90, were granites or granitic gneisses, and the fourth, CA 83, was an arkose (feldaspathic sandstone). The predominant mineral components of these aggregates, quartz and feldspar, are relatively hard, explaining the relatively low Micro-Deval abrasion losses. The reported questionable performance of the three granitic aggregates was associated in one case (CA-43) with a relatively high LA impact and abrasion loss and in the other two with a propensity for mica to flake off, generating an increase in fines content during processing and production that is usually compensated for in the mixture. Petrographically, the characteristics of these aggregates are similar to CA-41, CA-61, and CA-72, and given the subjective nature of the performance ranking, it seems unlikely that there are significant differences in actual performance between these aggregates. The performance issue with the arkose (CA-83) was a breakdown of asphalt concrete related to loss of binder adhesion probably associated with its high absorption. The Micro-Deval loss for CA-83 (6.5%) can be contrasted with that for CA-82 (18.7%), which is produced from a similar source rock. CA-82 is significantly more weathered, which results in breakdown of the feldspar to softer minerals and consequent weakening of the particles. The relatively weakened state of CA-82 is further illustrated by its high losses in the LA impact and abrasion, sulfate soundness, and freeze-thaw tests. From the foregoing, it might reasonably be inferred that CA-43, CA-52, CA-90, and CA-83 grouped with the good-performing aggregates.

In the NCHRP study,[7] validating performance-related tests for HMA, it was recommended that a maximum Micro-Deval loss value of 15 percent be imposed to ensure good performance in asphalt concrete. The mean values for two aggregates, CA-42 and CA-62, fell slightly above and below 15 percent loss, respectively. Both aggregates are of granitic composition with a relatively high LA impact and abrasion loss and thus are similar to CA-43, CA-53, and CA-90.

In general, questionable aggregates showed an LA abrasion loss of approximately 30 percent or more, and the values are consistently higher than those for good-performing aggregates. The VDOT specification[16] uses maximum LA impact and abrasion loss to classify the aggregate into three grades, A (40%), B (45%), and C (50%), that govern their use. The band of 40 to 50 percent is plotted in Figure 4. Of the six questionable aggregates, two exceeded the VDOT specification requirement for unrestricted use and a third was only slightly below 40 percent loss. One questionable aggregate, CA-12, had a relatively low LA abrasion loss (19%) that stands in sharp contrast to its high loss in the Micro-Deval test. This aggregate is an altered ultramafic rock, composed of relatively soft silicate minerals that provide for anomalous behavior in the LA abrasion test because of high resiliency.

The soundness loss did not follow any particular trend, but three sources in the questionable group, CA-13, CA-82, and CA-83, had magnesium sulfate soundness losses in one size fraction that exceeded the VDOT specification requirements for unrestricted use. Two of these, CA-82 and CA-83, had high absorptions that can prove problematic in the sulfate soundness test; however, their contrasting results in the Micro-Deval, LA abrasion, and freeze-thaw tests reflect differences in particle strength, as discussed previously. CA-13 is an amphibolite with some gneiss and schist in which the amphibolite particles are friable. This is reflected by its high Micro-Deval loss and a high LA impact and abrasion loss (48.3%) reported on the VDOT Materials Division List No. 5, March 2000.[17] Although none of the freeze-thaw test results was high enough to trigger restriction, the three aggregates with the highest losses were in the questionable group.

The six sources of questionable aggregates with Micro-Deval loss less than 17 percent have varied mineralogy and Micro-Deval loss values as low as 6.5 percent. None of these sources had any consistent record of poor performance. The performance of some of the aggregate sources was based on non-conformance with the VDOT specification requirement for other conventional aggregate tests. It is important to note that some of the aggregates have a significant percentage of weathered rock.

Fine Aggregate

Ten sources of fine aggregates from across the state were used to evaluate the Micro-Deval test. As with the coarse aggregate, other conventional tests such as magnesium sulfate and freeze-thaw soundness tests were conducted for comparison purposes. A graded sample was used for the Micro-Deval test, whereas individual size fractions were used in the magnesium sulfate and freeze-thaw tests. Micro-Deval loss values were calculated in the following three ways, including the Canadian standard method[15] (Method 1):

1. Method 1: Percent passing No. 200 sieve.

2. Method 2: The weighted average based on the test gradation using the loss values on respective individual size sieves.

3. Method 3: Amount of degradation as the change in area under the gradation curve between initial and after tests as shown in Figure 5 and Table 19.

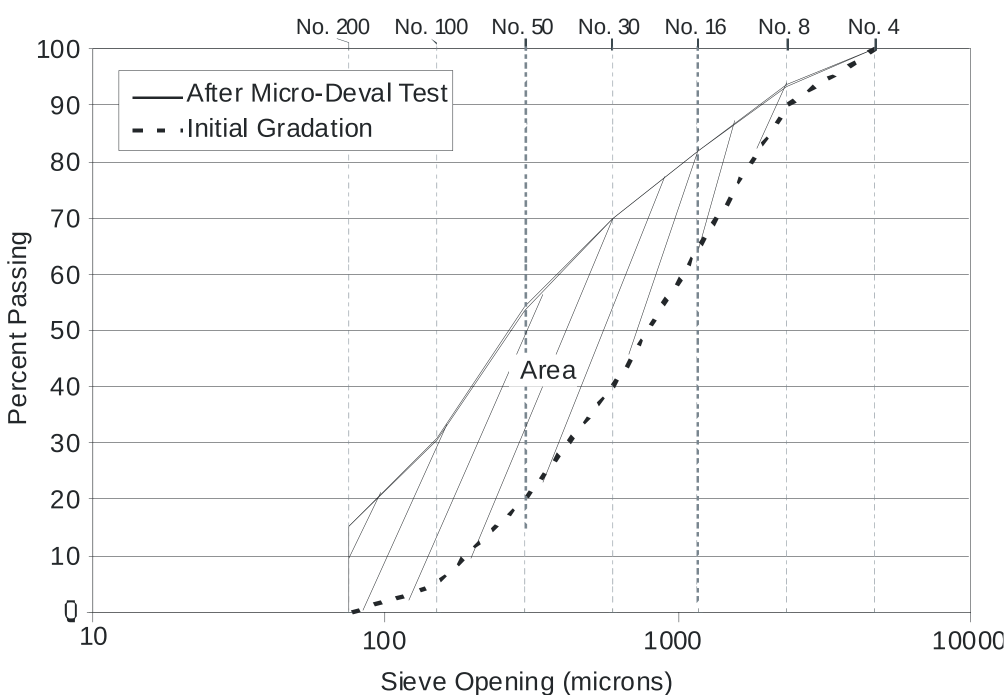

Figure 5. Grain Size Distribution: Initial vs. After Micro-Deval Test for Source FA-4P

Table 19. Micro-Deval Loss Value Calculations for Fine Aggregate

Percent Passing					Weighted Value		Area Between the Curves (Figure 5)	
Sieve No.	Opening (mm)	Original Gradation	After Test Gradation (FA-4P)	% Loss	Weight Factor	Value	Multiplier	Value
4	4.75	100	100	0	0	0		
8	2.36	90	93.4	3.4	0.1	0.34	0.5*(0+3.4)*(4.75-2.36)	4.06
16	1.18	65	82.0	17.0	0.25	4.25	0.5*(3.4+17.0)*(2.36-1.18)	12.04
30	0.60	40	69.8	29.8	0.25	7.45	0.5*(17.0+29.8)*(1.18-0.60)	13.57
50	0.30	20	53.8	33.8	0.20	6.76	0.5*(29.8+33.8)*(0.60-0.30)	9.54
100	0.15	5	30.7	25.7	0.15	3.86	0.5*(33.8+30.7)*(0.30-0.15)	4.84
200	0.075	0	15.1	15.1	0.05	0.76	0.5*(30.7+15.1)*(0.15-0.075)	1.72
Method 1: Micro-Deval Loss (%)				15.1				
Method 2: Weighted Average Micro-Deval Loss (%)					23.41			
Method 3: Area Between Gradation Curves (%-mm)							45.77	

These Micro-Deval loss values are plotted in Figure 6 with aggregates grouped according to good, questionable, and poor performance. The groups with good- and poor-performing aggregates had four sources each. The remaining two sources were in the questionable category. There was no particular trend observed from the Method 1 calculation, but two poor performers had more than 20 percent loss values with Method 1. On the other hand, the loss values calculated using Method 3 clearly separated good- from poor-performing aggregates. For good-performing aggregates, loss values were less than 20 (%-mm) compared to more than 30 (%-mm) for poor-performing aggregates. The weighted average calculated by Method 2 also showed a difference in performance at 20 percent loss values. No trend could be seen with the questionable aggregates with any of the three methods. Therefore, it is reasonable to conclude that the Micro-Deval test was able to differentiate between good- and poor-performing

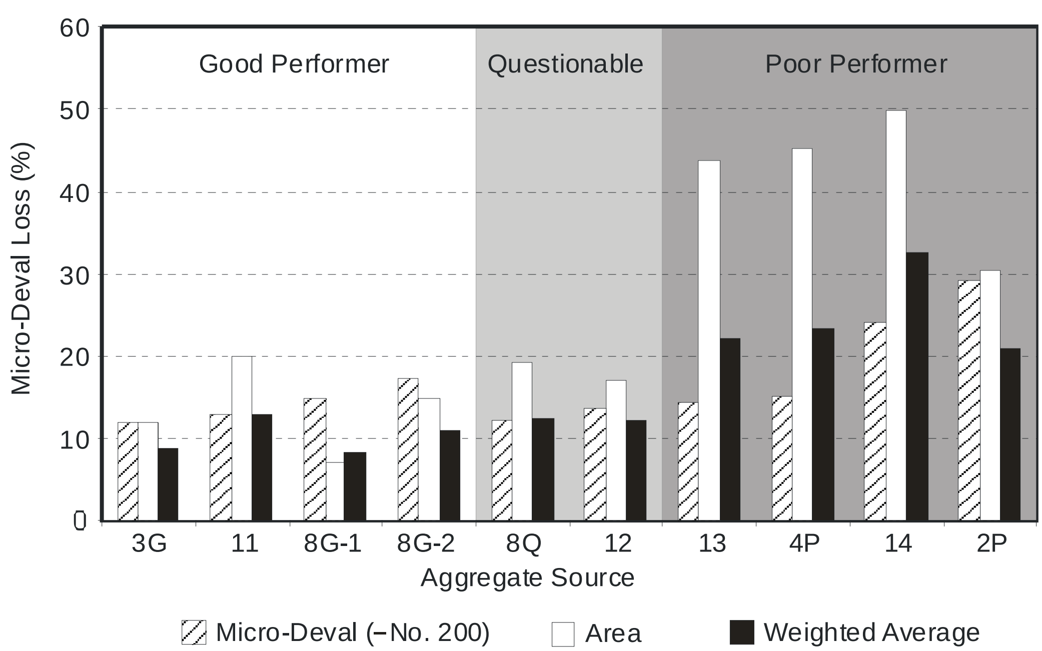

Figure 6. Micro-Deval Test Results for Fine Aggregate

aggregates at least 80 percent of the time (8 of 10). It is important to reiterate that these performance ratings are not always based on actual field experience; rather, some of them are based on non-conformance with VDOT specifications[16] for other aggregate tests such as magnesium sulfate loss.

The magnesium sulfate and freeze-thaw soundness loss values are calculated as a weighted average in accordance with the Micro-Deval gradation shown in Table 1. Since aggregates passing the No. 50 sieve were not tested, the percent loss for the No. 50 size was used for all other finer sizes in the weighted average calculation. These loss values are shown in Figure 7 along with the VDOT specification[16] requirements for magnesium sulfate soundness

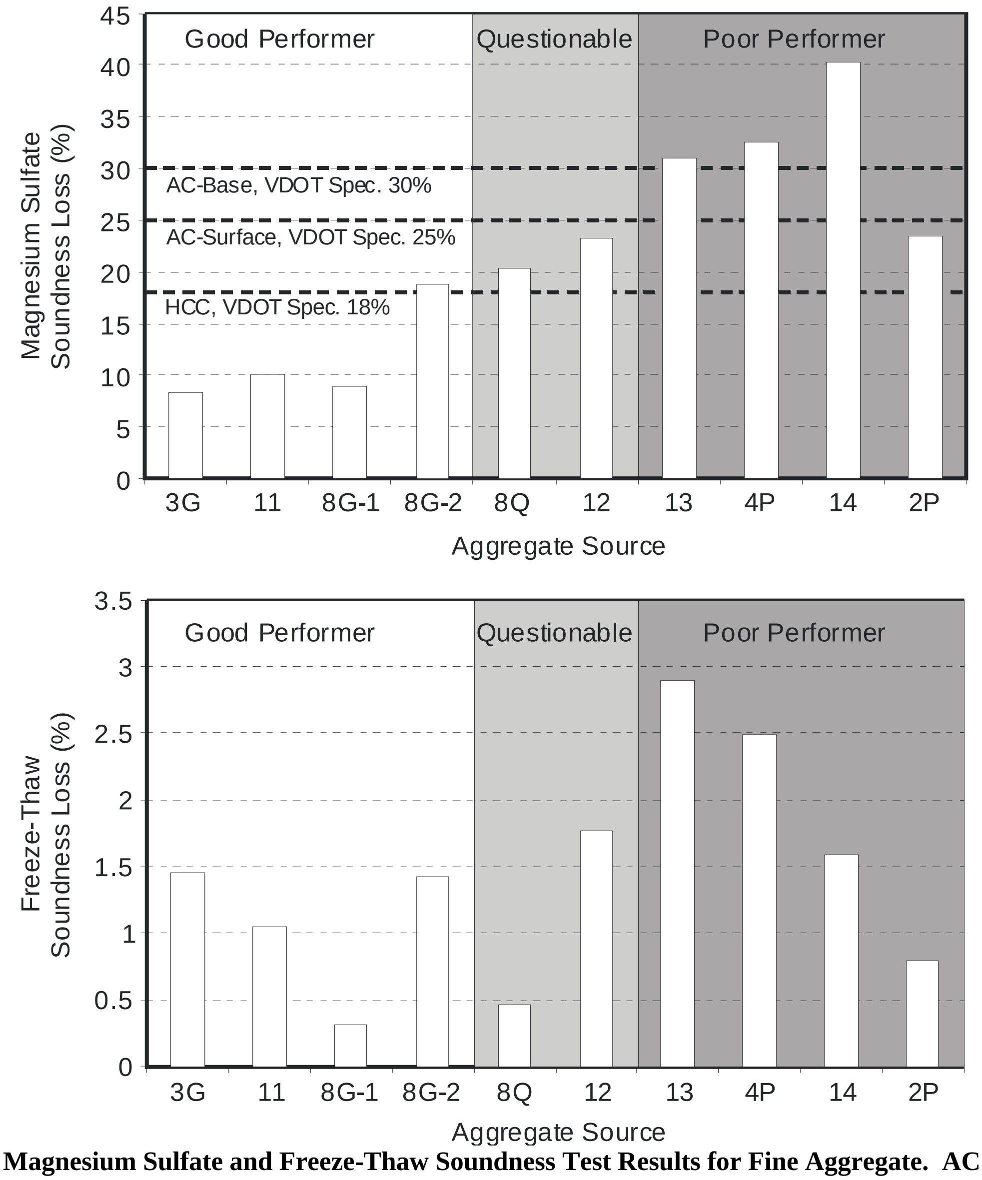

Figure 7. Magnesium Sulfate and Freeze-Thaw Soundness Test Results for Fine Aggregate. AC = asphalt concrete, HCC = hydraulic cement concrete.

loss. Those aggregates in the questionable and poor-performing categories and one included in the good-performing category did not meet VDOT magnesium sulfate loss requirements for unrestricted use. In a general sense, the performance of the aggregates in the freeze-thaw test mirrored the trend of the magnesium sulfate soundness results; however none of the aggregates approached the VDOT limit of 5 percent loss for unrestricted use.

Two of the aggregates in the poor category (FA-21 and FA-14) were manufactured fine aggregate crushed from amphibolite gneiss. They both tended to be friable and splintery. FA-14 was from the same source as CA-13, which also had high losses. The other two were natural sands (FA-13 and FA-41) in which some feldspar grains were weathered, weakening the particles. In these aggregates, the weathered particles may tend to degrade to smaller particles readily, although not to the point of passing the No. 200 sieve. Since the standard Micro-Deval loss calculation is based on the materials passing the No. 200 sieve, aggregates undergoing such degradation may not be identified. Such aggregates would be identified using Method 2 or 3 calculations that consider loss in each individual size fraction, which would be better approaches than simply calculating the minus No. 200 as in Method 1.

One of the aggregates in the questionable category (FA-12) was a manufactured fine aggregate crushed from the same source material as CA-12. When tested as fine aggregate, the losses were much lower than those obtained with the coarse aggregate. A likely explanation is that the rock is composed of two relatively soft minerals that differ in hardness and that the softer mineral does not survive the processing involved in producing the manufactured sand. The other questionable fine aggregate was a natural sand composed of fine-grained rock fragments and arkose with the rock fragments somewhat weathered and relatively soft compared to the arkose. The four aggregates in the good category were crushed: two from limestone sources and the other two from a granitic gneiss and an aplite (FA-3G).

Test Variability

Most testing during this study was conducted on three replicate samples (some two) from each source. Therefore, it was possible to calculate the within-laboratory coefficient of variation (COV) from the measurements. The COV is a standard way of measuring variability. The COVs for all sources were pooled (arithmetic average) across all sources and are summarized in Table 20. The COVs available in the respective standards (if available) are also included in the table for comparison purposes. The average COV for the coarse aggregate in the Micro-Deval test was about 4.76 percent, compared to 20 to 30 percent for all other conventional tests. Similarly, the average COV for the fine aggregate in the Micro-Deval test was 2.42 percent, compared to 15 to 30 percent for other tests.

The Micro-Deval test is less variable than other conventional aggregate tests. A similar observation was reported by other researchers.[8] Therefore, the difference between two Micro-Deval measurements (both within-lab and between-lab) would be less compared to the same for other tests. The consistent results and short testing duration make the Micro-Deval test an attractive alternative to the conventional aggregate tests.

Table 20. Aggregate Test Variability (Coefficient of Variability)

Aggregate Test/Type		Within-laboratory Coefficient of Variation (%) Pooled	Range	Remarks
Micro-Deval	Coarse	4.76	0.6-27.13	15 sources: Less than 5%; 4 sources: 5%-10%; 1 source: 27.13%; AASHTO T-327: Multi-laboratory COV: 5.3%-10%
	Fine	2.42	0.75-7.32	COV for all sources are below 4% except one 7.32%
Magnesium sulfate soundness	Coarse (3/4 to 3/8)	30.65	0.56-89.15	AASHTO T-104: COV 11%-25%
	Coarse (3/8 to No. 4)	21.48	0.19-52.21	AASHTO T-104: COV 11%-25%
	Fine	16.92	1.4-42.35	AASHTO T-104: COV 11%-25%
Freeze-thaw soundness	Coarse (3/4 to 3/8)	22.53	1.76-75.69	No reference available in AASHTO T-103
	Coarse (3/8 to No. 4)	20.89	3.49-83.73	No reference available in AASHTO T-103
	Fine	28.67	3.22-65.63	No reference available in AASHTO T-103

CONCLUSIONS

- *The Micro-Deval test can differentiate between good- and poor-performing aggregates at least 70 and 80 percent of the time for coarse and fine aggregate, respectively.*

- *The Canadian standard for fine aggregate in the Micro-Deval test is adequate but modifying the percent loss value calculation to a weighted average or the area under the degradation curve improves the ability to identify certain poor-performing aggregates.*

- *The Micro-Deval test is less variable than conventional quality tests and thus more repeatable and reproducible. Moreover, it is a short-duration test that does not require as much care and attention to detail to conduct.*

- *Coarse aggregate with a good performance rating had loss values of less than 15 percent and should be suitable for use in all applications.*

- *Poor-performing fine aggregates had weighted average loss values of more than 20 percent and/or an area of 30 (%-mm) between the initial and post-test gradation curves. Thus, aggregates with less than 20 percent weighted average loss or an area between the gradation curves of less than 30 %-mm should provide good performance.*

- *The Micro-Deval test can identify the quality difference between similar aggregate types with varying degrees of weathering, and thus regular testing of a given source should provide a good indicator of when changes occur in material quality that might affect performance.*

- *Instead of replacing the results from other conventional aggregate tests to evaluate aggregate quality, the Micro-Deval test supplements them in different but important aspects of quality. It will be necessary to gather years of experience with the Micro-Deval test before it can be recommended to replace some of the other aggregate tests.*

RECOMMENDATIONS

1. *VDOT's district materials sections should use the Micro-Deval test along with other tests and build their experience base relating the results to performance. Testing, particularly of sources with known or questionable quality variation, should be performed on a regular (e.g., monthly or quarterly) basis to track the consistency of the material being supplied by the source.*

2. *VDOT's Materials Division should collect Micro-Deval test results with respective performance history.*

3. *The Virginia Transportation Research Council and VDOT's Materials Division should review and evaluate the Micro-Deval test results in the near future to refine the acceptable limits for Micro-Deval test results.*

4. *For a critical or demanding application, a maximum Micro-Deval loss of 15 percent for coarse aggregate should be considered.*

5. *A weighted average loss of less than 20 percent or an area of less than 30 (%-mm) between the initial and post-test gradation curves should be considered for high-quality fine aggregates.*

6. *The Virginia Transportation Research Council should develop a standard test method for a fine aggregate test incorporating the suggested modification based on this research.*

COSTS AND BENEFITS ASSESSMENT

The benefits of implementing the recommendations provided are as follows:

- The Micro-Deval test has improved repeatability and reproducibility when compared to the current tests, which will improve the certainty with which decisions based on results are made and reduce the amount of testing needed to reach a decision about the suitability of a given material.

- The test provides additional information not provided by current tests about the quality of aggregate materials that will enhance VDOT's ability to judge and identify the suitability of aggregate materials for use in construction.

The nature of the work does not lend itself to a quantitative determination of cost, but it is not believed that incorporating the use of the Micro-Deval test into VDOT's aggregate quality assessment program will result in significant changes in cost to VDOT.

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