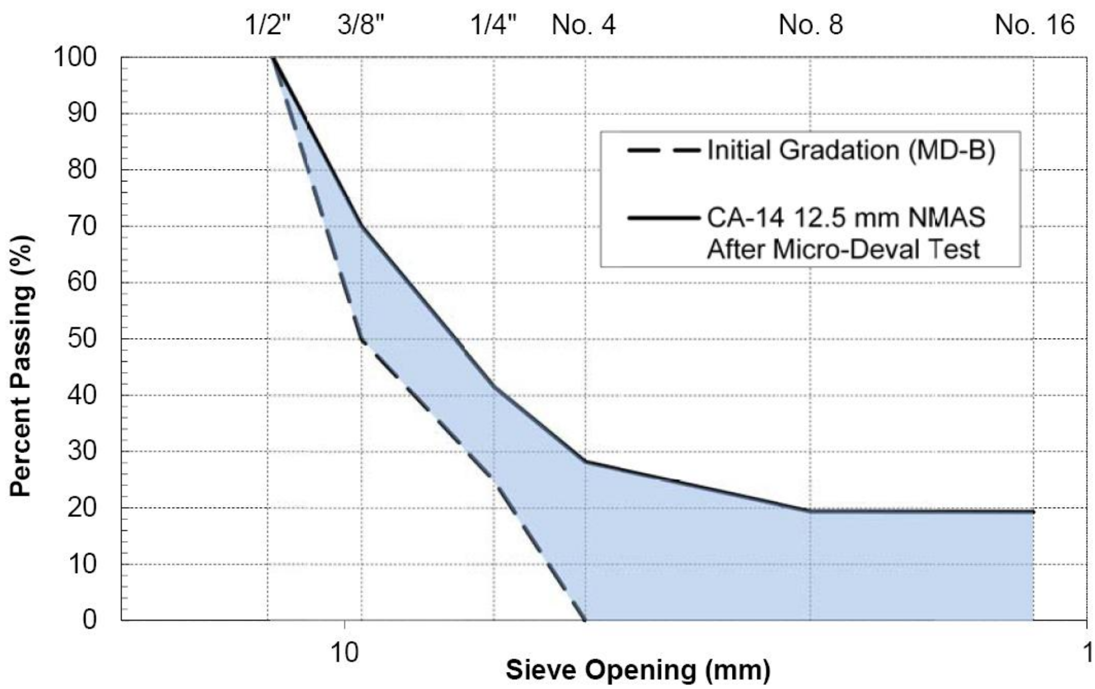
16 State House Station
Augusta, Maine 04333

MaineDOT

Transportation Research Division



Technical Report 12-06

DURABILITY ASSESSMENT OF COARSE AGGREGATES FOR HMA IN MAINE

December 2012

Technical Report Documentation Page

1. Report No. ME 12-06	2.	3. Recipient's Accession No.
4. Title and Subtitle DURABILITY ASSESSMENT OF COARSE AGGREGATES FOR HMA IN MAINE		5. Report Date December 2012
		6.
7. Author(s) Derek Nener-Plante		8. Performing Organization Report No.
9. Performing Organization Name and Address Maine Department of Transportation 16 State House Station Augusta, ME 04333-0016		10. Project/Task/Work Unit No.
		11. Contract © or Grant (G) No.
12. Sponsoring Organization Name and Address Maine DOT 16 State House Station Augusta, ME 04333-0016		13. Type of Report and Period Covered
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract (Limit 200 words)

In this study, Micro-Deval and L.A. Abrasion were used to evaluate the durability of 72 individual coarse aggregates used for HMA in Maine. Aggregates used in hot-mix asphalt (HMA) must be durable and resistant to abrasion and degradation. Material loss in HMA pavements has recently been observed by MDOT and aggregate degradation has been hypothesized as a possible contributor. The Micro-Deval results showed no correlation with results from the L.A. Abrasion and the range in values was quite large. Two alternative methods of analyzing Micro-Deval were employed to measure the change in gradation of aggregate samples. A relatively large portion of tested aggregate sources were found to degrade significantly in the Micro-Deval test while having acceptable AASHTO Micro-Deval loss values, this presumably due to fracturing instead of abrasion. The weighted average method and area between curves method proved to be effective in measuring the change in particle size distribution not captured with the Method 1 Micro-Deval loss value. In addition, a significant influence of initial grading size was found in all of the Micro-Deval data with finer initial gradations producing higher loss values. The alternative analysis methods for Micro-Deval are recommended for use in detecting degradation not captured by the traditional Micro-Deval value.

		18. Availability Statement	
19. Security Class (this report)	20. Security Class (this page)	21. No. of Pages 18	22. Price

DURABILITY ASSESSMENT OF COARSE AGGREGATES FOR HMA IN MAINE

Derek Nener-Plante, M.S., E.I.T. (corresponding author)
Assistant Engineer
Pavement Design/Quality
Maine Department of Transportation
derek.nener-plante@maine.gov
(207) 215-0849

ABSTRACT

In this study, Micro-Deval and L.A. Abrasion were used to evaluate the durability of 72 individual coarse aggregates used for HMA in Maine. Aggregates used in hot-mix asphalt (HMA) must be durable and resistant to abrasion and degradation. Material loss in HMA pavements has recently been observed by MDOT and aggregate degradation has been hypothesized as a possible contributor. The Micro-Deval results showed no correlation with results from the L.A. Abrasion and the range in values was quite large. Two alternative methods of analyzing Micro-Deval were employed to measure the change in gradation of aggregate samples. A relatively large portion of tested aggregate sources were found to degrade significantly in the Micro-Deval test while having acceptable AASHTO Micro-Deval loss values, this presumably due to fracturing instead of abrasion. The weighted average method and area between curves method proved to be effective in measuring the change in particle size distribution not captured with the Method 1 Micro-Deval loss value. In addition, a significant influence of initial grading size was found in all of the Micro-Deval data with finer initial gradations producing higher loss values. The alternative analysis methods for Micro-Deval are recommended for use in detecting degradation not captured by the traditional Micro-Deval value.

INTRODUCTION

Aggregates used in hot-mix asphalt (HMA) must be durable and resistant to abrasion and degradation. Aggregates must be able to withstand the stresses experienced during the production, placement, compaction, and service life of HMA. These actions can cause aggregate breakdown and degradation, which result in a change in gradation of the HMA material. It has been noted that if the gradation of HMA is altered by these stresses and actions, the pavement will no longer contain the properties it was designed for and could result in premature failure caused by numerous modes of distress.

Traditionally, the toughness of aggregates in the United States (U.S.) has been determined using the Los Angeles (L.A.) Abrasion test (AASHTO T 96). This test entails subjecting a dry aggregate sample of specified grading to impact and abrasion in a large ball mill. The ball mill contains an internal shelf that lifts and drops a charge of aggregate and steel spheres on each rotation. The L.A. Abrasion value is defined as the percent passing the No. 12 sieve in the residual sample. The maximum acceptable L.A. Abrasion loss value used by most transportation agencies in the U.S. ranges between 30% and 50% depending on the type of treatment and traffic levels. Many researchers have suggested that the L.A. Abrasion test does not provide a good indication of aggregate performance in the field (*1-3*). The reasoning given for the disparity is that the L.A. Abrasion test produces large impact stresses that do not closely mimic the abrasion generally experienced by aggregates during construction and service life in HMA.

Concerns about the shortcomings of the L.A. Abrasion test led researchers to try and develop a less complicated and more accurate test for durability of construction aggregates. The Micro-Deval test was developed in France in the early 1960s and has been extensively studied in Canada and more recently in the United States (*4-6*). The test entails saturating an aggregate sample and then abrading it in a small ball mill. The Micro-Deval value is defined as the percent passing the No. 16 sieve in the residual sample. In several NCHRP studies, the Micro-Deval was found to be a good indicator of aggregate durability, toughness, and abrasion resistance (*1, 5*). Multiple transportation agencies have evaluated Micro-Deval and set criteria for maximum loss values ranging from 6% to 18% to distinguish between good and poor performers (*1, 5, 7-8*). Most recently, the Micro-Deval test was used in Virginia by researchers to evaluate the durability of the coarse aggregate material used in HMA. The researchers found that the Micro-Deval test could distinguish between good and poor performers at least 70% of time when using a maximum loss of 15% as the criteria (*6*).

In recent years, the Maine Department of Transportation (MDOT) has observed premature failure of its HMA pavements due to loss of material in the wheelpaths. Researchers at MDOT have hypothesized that aggregate degradation is a contributor to the premature failure of the HMA material. The MDOT currently uses the Micro-Deval test (AASHTO T 327) to determine aggregate quality characteristics on the combined aggregate gradation for HMA, not on individual aggregate sources. HMA aggregate blends are required to have a maximum Micro-Deval loss value of 18% for use in MDOT mix designs. This study was conducted to evaluate the performance of individual aggregate stockpiles in durability testing to ascertain whether aggregate quality should be a concern for the MDOT. The durability measures were observed for individual aggregates to evaluate the range in loss values, as an indication of the level of blending for quality occurring in MDOT HMA mix designs. Individual coarse aggregate sources in Maine were tested using both the Micro-Deval and the L.A. Abrasion test procedures and the correlation between these tests was assessed. In addition, two modified Micro-Deval analysis methods, previously used by Hossain, Lane, & Schmidt (*9*) in analysis of fine aggregate, were used on the Micro-Deval data and compared with the AASHTO T 327 values. The two alternative analysis methods for Micro-Deval are utilized to measure the particle size distribution change of test samples in the Micro-Deval test. The two measures are used in order to quantify the degradation of the aggregate not reflected in the AASHTO Micro-Deval loss value. The influence of the test grading size on the results for Micro-Deval testing was also evaluated.

METHODOLOGY

Scope and Experimental Program

A total of 72 aggregate stockpiles from 26 different sources were selected for this study. All aggregates used in this study were used in MDOT HMA mix placed in 2011. Sixty of the 72 aggregates (83.3%) tested as part of this study are classified as crushed ledge material with the remaining 12 aggregates classified as gravel. Each of the aggregates were tested to determine percent loss observed in both the Micro-Deval and the L.A. Abrasion tests. In addition, a sieve analysis of the aggregate material was performed after the Micro-Deval test in order to further analyze the degradation of the material.

Micro-Deval

The durability of coarse aggregate sources against abrasion was evaluated using a Micro-Deval apparatus and in accordance with the AASHTO T 327-08 standard. The aggregate samples were prepared by first washing the bulk aggregate and then drying it to a constant mass. The material is subsequently sieved according to AASHTO T-27 and reduced into individual fractions. The grading (A, B, or C) of the sample is dependent on the nominal maximum aggregate size (NMAS) of the coarse aggregate, and the breakdown of each grading is shown below in TABLE 1.

TABLE 1 Gradings of Coarse Micro-Deval Test Samples

Passing		Retained		Mass of Indicated Sizes, g		
Sieve No.	Opening (mm)	Sieve No.	Opening (mm)	MD-A (19.0 mm NMAS)	MD-B (12.5 mm NMAS)	MD-C (9.5 mm NMAS)
3/4 in.	19.0	5/8 in.	16	375	-	-
5/8 in.	16.0	1/2 in.	12.5	375	-	-
1/2 in.	12.5	3/8 in.	9.5	750	750	-
3/8 in.	9.5	1/4 in.	6.3	-	375	750
1/4 in.	6.3	No. 4	4.75	-	375	750
		Total Mass of Sample (g) =		1500	1500	1500

Each sample was saturated with tap water at room temperature for no less than one hour. After the saturation period, excess tap water was decanted off, and the sample was placed into the Micro-Deval apparatus with 2.0 L of tap water and a 5,000 ± 5 g charge of 9.5 ± 0.5 mm stainless steel balls. The jar was rotated at 100 ± 5 rpm for a length of time dependent on the particle size. The sample was then washed and dried to a constant mass. The final mass of each sample was recorded, and the percentage of aggregate finer than a 1.18-mm (No. 16) sieve was reported as the Method 1 Micro-Deval loss value. After completion of the standard AASHTO T 327-08 procedure, a sieve analysis of the materials retained on the No. 16 sieve was performed for evaluation of further aggregate degradation. The three different Micro-Deval loss values were calculated using the gradation of the sample after testing in the following ways:

- Method 1: Percent passing the No. 16 sieve (AASHTO T 327).
- Method 2: The weighted average based upon the test gradation using the percent degradation values on the respective individual size sieves. The degradation values (defined as the post-test percent passing subtracted by the initial percent passing on a particular sieve) were multiplied by weight factors based upon the initial gradation breakdown of the test sample. An example of the calculation for the 12.5 mm coarse aggregate CA-14 is shown below in TABLE 2 in Columns 5 -7. The initial sample is comprised of material retained on the 3/8 in., 1/4 in., and No. 4 sieve. The degradation values on those sieves are averaged according to their respective weight in the initial sample.
- Method 3: Amount of degradation expressed as the change in area under the gradation curve between the before and after Micro-Deval test. The area values were calculated by treating the region between gradation curves and two successive sieve sizes as a trapezoidal area. The individual area values between successive sieve sizes are subsequently summed.

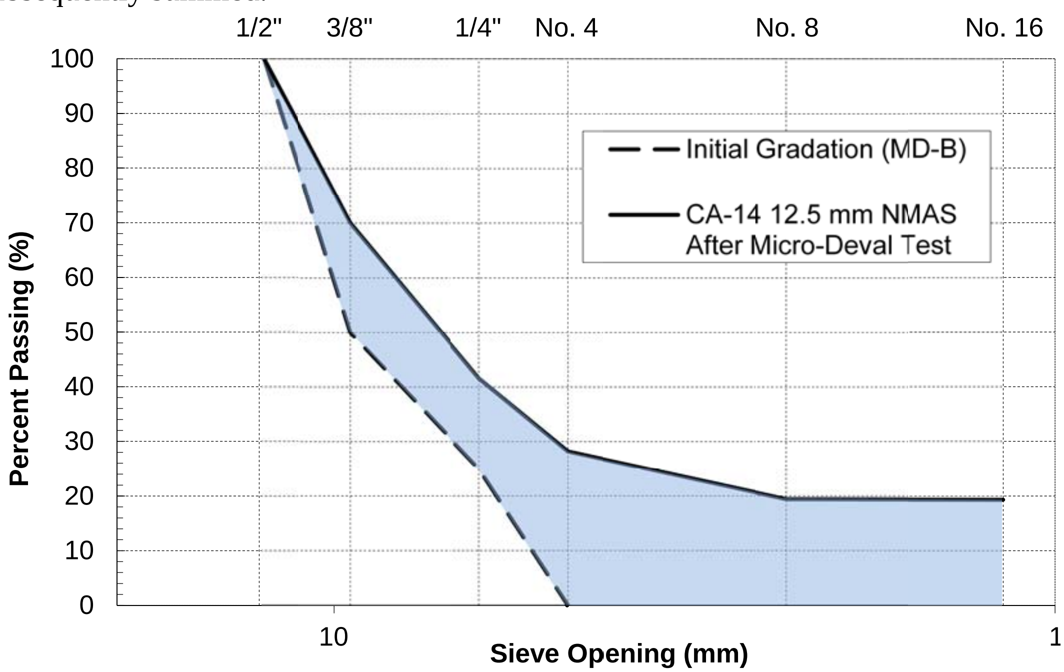


FIGURE **1** graphically displays the area used for calculation of this measure for the 12.5 mm aggregate from source CA-14. The details for the area calculation are shown in Columns 8 and 9 of TABLE 2. The area values are normalized against the maximum area value (determined using a post-test gradation of 100% passing each sieve, value is parenthesis) for the respective Micro-Deval grading, as shown in Equation (1) below.

(1)

Where A_{Max} for grading A = 1225.8 %·mm
A_{Max} for grading B = 767.6 %·mm
A_{Max} for grading C = 553.3 %·mm

TABLE 2 Micro-Deval Loss Value Calculations for CA-14 HMA Ledge-12.5mm

Percent Passing					Weighted Value		Area Between the Curves	
Sieve No.	Opening (mm)	Original Gradation	After Test Gradation	Percent Degradation	Weight Factor	Value	Trapezoidal Area	Value
1/2 in.	12.50	100.0	100.0	0.0	0.00	0.00	N/A	N/A
3/8 in.	9.50	50.0	70.0	20.0	0.50	10.00	0.5*(0+20)*(12.5-9.5)	30.00
1/4 in.	6.30	25.0	41.6	16.6	0.25	4.15	0.5*(20+16.6)*(9.5-6.3)	58.56
4	4.75	0.0	28.2	28.2	0.25	7.05	0.5*(16.6+28.2)*(6.3-4.75)	34.72
8	2.36	0.0	19.4	19.4	0.00	0.00	0.5*(28.2+19.4)*(4.75-2.36)	56.88
16	1.18	0.0	19.3	19.3	0.00	0.00	0.5*(19.4+19.3)*(2.36-1.18)	22.83
Method 1: passing no. 16 sieve (%)				19.3				
Method 2: weighted average Micro-Deval loss (%)						21.20		
Method 3: area between gradation curves (% mm)								202.99 (26.44%)

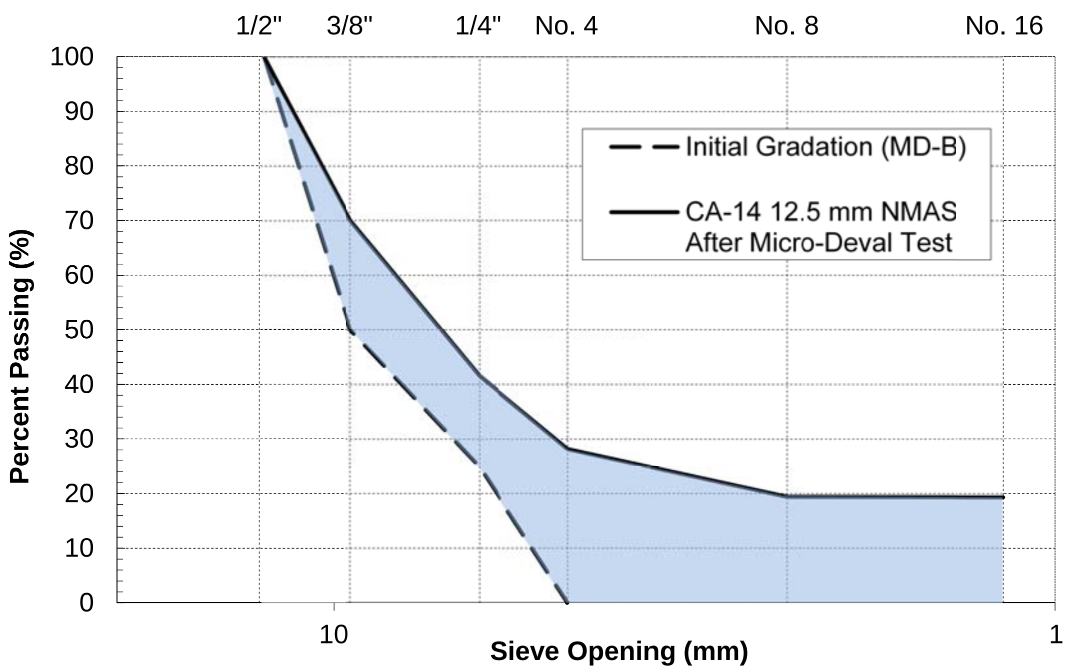


FIGURE 1 Grain size distribution: initial vs. after Micro-Deval test for CA-14 12.5 mm aggregate stockpile

Los Angeles Abrasion Test

The durability of coarse aggregate sources against abrasion was evaluated using the Los Angeles (L.A.) testing machine and in accordance with the AASHTO T 97 standard. The aggregate samples were prepared by washing the bulk aggregate and then drying it to a constant mass. The material is subsequently sieved according to AASHTO T-27 and reduced into individual fractions. The individual aggregate fractions were then recombined to the grading of TABLE 3 most nearly corresponding to the range of sizes in the aggregate as furnished for HMA (only gradings LA-B and LA-C were used in this study).

TABLE 3 Gradings of L.A. Abrasion Test Samples

Passing		Retained		Mass of Indicated Sizes, g	
Sieve No.	Opening (mm)	Sieve No.	Opening (mm)	LA-B (12.5/19.0 mm NMAS)	LA-C (9.5 mm NMAS)
3/4 in.	19.0	1/2 in.	12.5	2500	-
1/2 in.	12.5	3/8 in.	9.5	2500	-
3/8 in.	9.5	1/4 in.	6.3	-	2500
1/4 in.	6.3	No. 4	4.75	-	2500
		Total Mass of Sample (g) =		5000	5000

The sample was placed into the Los Angeles apparatus with a 3330g – 4584g charge (dependent on the grading) of 46.8 mm stainless steel balls. The machine was then rotated at a speed of 30 to 33 rev/min for 500 revolutions. The sample was washed over a 1.70 mm sieve and dried to a constant mass. The final mass of each sample was recorded, and the percentage of aggregate finer than a 1.70 mm (No. 12) sieve was reported as the loss value.

RESULTS

FIGURE 2 displays the comparison between the Method 1 Micro-Deval loss values and the L.A. Abrasion loss values. The figure includes the 18% maximum loss value for Micro-Deval as recommended by NCHRP 4-19 (*1*) and used by the MDOT for combined aggregate gradation for HMA. The figure also includes the commonly used maximum L.A. Abrasion loss value for durable aggregates of 40%. The Micro-Deval values significantly predicted the L.A. Abrasion values at $\alpha = 0.05$ using an exponential regression model ($p = 0.033$). However, the correlation between the two test values is very low (R = 0.25, $R^2 = 0.06$), indicating that other factors contribute more significantly to explaining the relationship. The lack of a strong correlation between the two testing methods is expected as previous researchers have found each test measures different properties of the aggregates (*2, 4, 7*). The L.A. Abrasion test measures the resistance of the aggregates to impact loadings of the steel charges in the drum where the Micro-Deval measures abrasion of the aggregate caused by the steel charges. The plot shows that nine of the 72 aggregates tested had Micro-Deval values greater than the criteria of 18% and ten aggregates had L.A. Abrasion values over the criteria of 40%. The plot also shows that 73.6% of the aggregates tested had passing values for both tests and only two aggregates had failing values for both tests. In the Micro-Deval test, the ten aggregates failing to meet the 18% maximum allowable loss value are from five different sources. All three aggregates from source CA-1 failed to meet the Micro-Deval standard. Two other sources each had two aggregates fail to meet the standard (CA-10 and CA-11). The remaining two failing aggregates came from separate sources (CA-14 and CA-16). Only two aggregates tested failed to meet the maximum loss criteria for both the Micro-Deval and L.A. Abrasion. Both of the failing aggregates came from the same aggregate source, CA-11. Two aggregate sources, CA-13 and CA-17, had all three aggregates from the source fail to meet the L.A. Abrasion criteria. Micro-Deval loss values for the 72 aggregates tested ranged from 4.6% to 33.3% while the L.A. Abrasion values ranged from 10.6% to 50.7%. When the loss values for both tests are normalized against their respective criteria (18% for Micro-Deval and 40% for L.A. Abrasion), the disparity in the range of the values is evident. The normalized values for L.A. Abrasion range from 0.27 to 1.26 (0.99) where the Micro-Deval values had a significantly wider range from 0.26 to 1.85 (1.58).

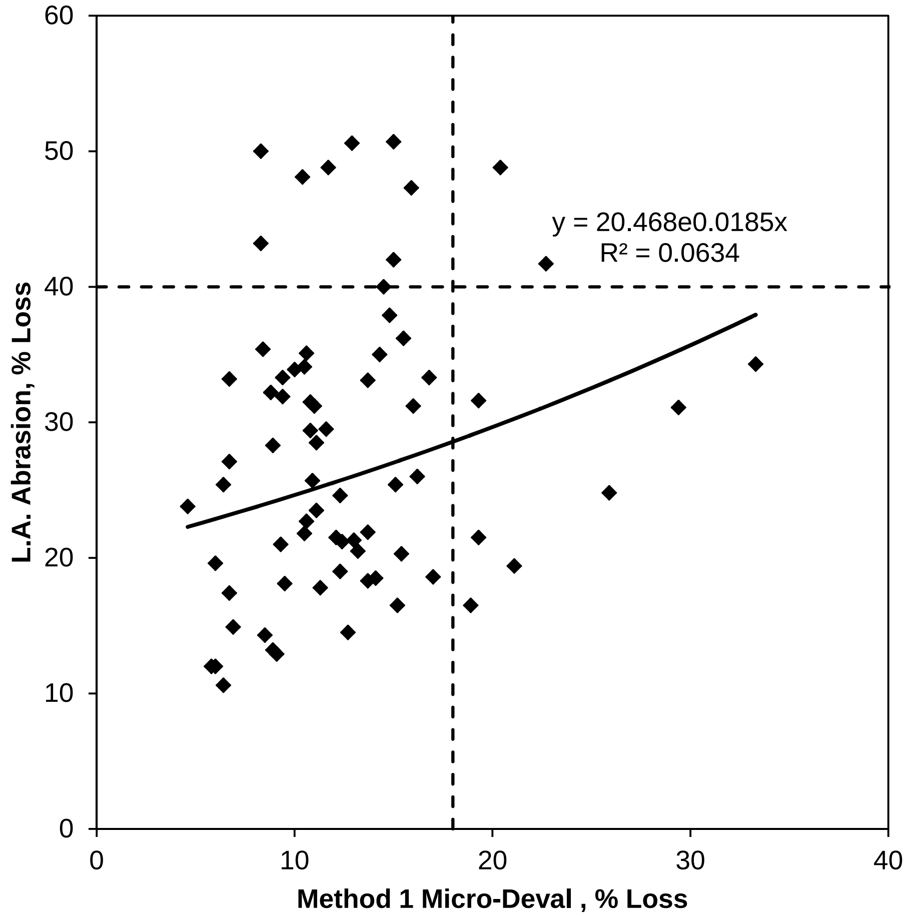


FIGURE 2 Comparison of L.A. Abrasion and Method 1 Micro-Deval loss values

In addition to the AASHTO Micro-Deval procedure, sieve analysis was performed on each aggregate sample after it had been tested in the drum. The resulting particle size distributions were used to calculate the Method 2 and Method 3 Micro-Deval loss values. FIGURE 3 displays the comparison between the Method 1 and Method 2 Micro Deval values. Also plotted is the recommended Method 2 criterion of 20%, used previously by researchers using the Fine Micro-Deval test (*9*). The Method 1 values significantly predicted the Method 2 values at $\alpha = 0.05$ using a linear regression model ($p < .001$) but the correlation between the two methods is very low ($R = 0.35$, $R^2 = 0.12$), suggesting that they are measuring separate anomalies. The Method 2 analysis produces larger loss values than the traditional AASHTO method, with average loss values of 19.4% and 12.7% respectively. The extra sieve analysis is also used to calculate Method 3 Micro-Deval values based upon the area between the gradation curves. The comparison between the Method 1 and Method 3 loss values for the 72 aggregates is shown in FIGURE 4 below. In order to create a meaningful comparison, the Method 3 values are normalized against the maximum area between the curves possible for each Micro-Deval grading size (a larger grading size has more total area on the plot and a smaller grading size has less total area on the plot). The normalization is performed in an attempt to remove any bias/influence of the initial sample grading. The Method 1 values significantly predicted the Method 3 values at $\alpha = 0.05$ using an exponential regression model ($p < .001$). The correlation between the two test values is relatively low ($R = 0.61$, $R^2 = 0.38$), but the correlation is the strongest found in this study. Although the trend suggests that with higher Micro-Deval loss values the Method 3 loss values will increase, the results show that several aggregates have extremely high Method 3 values and very low Method 1 values.

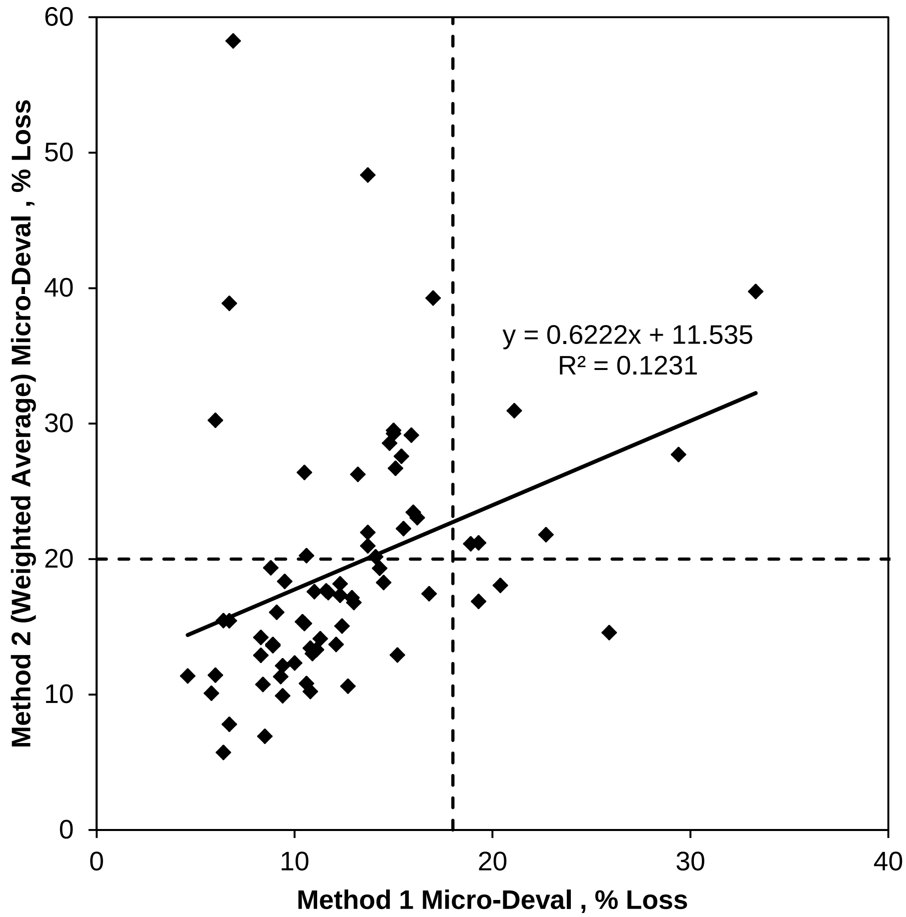


FIGURE 3 Comparison of Method 1 and Method 2 Micro-Deval loss values

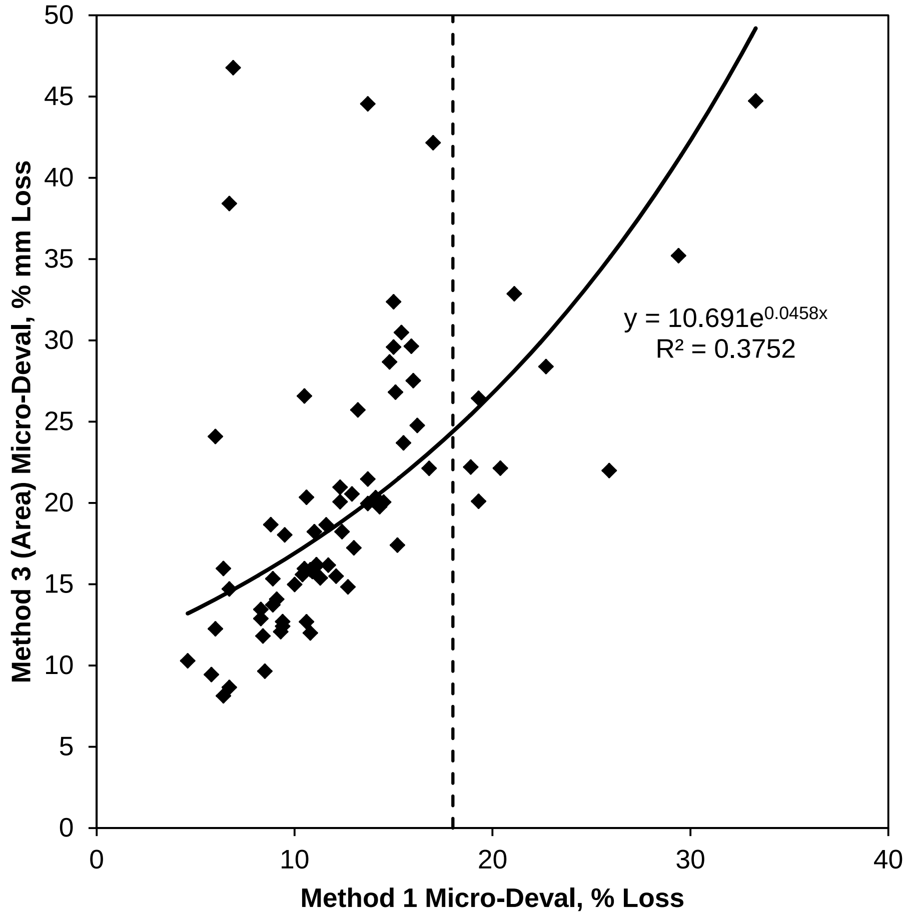


FIGURE 4 Comparison of Method 1 and Method 3 Micro-Deval loss values

One area of concern within the data is the number of aggregates that have large Method 2 and Method 3 loss values and acceptable Method 1 loss values (located in the top left quadrant of FIGURE 3 and FIGURE 4). These aggregates pass the 18% maximum loss criteria of the Micro-Deval test, but the sieve analysis of the particle size distribution shows a significant amount of degradation of the material. Previous researchers have suggested that the particle size distribution of the test sample after it is tested will give an indication of the mode in which it was degraded (*10*). Analysis showed that samples that were well-graded after the Micro-Deval test appeared to degrade through fragmentation and abrasion while poorly graded samples degrade through abrasion alone. A well-graded particle size distribution suggests that larger particles break into smaller fractions as well as abrade under the action of the Micro-Deval apparatus. The study further found that material with poor quality is more likely to be distressed by both abrasion and fragmentation. The Method 2 and Method 3 values measure the change in particle size distribution for the aggregate after testing in the Micro-Deval. Twenty of the 72 aggregates tested have acceptable Method 1 Micro-Deval values (less than 18% loss) but have Method 2 Micro-Deval values greater than 20%. The results suggest that these aggregate particles may tend to degrade to smaller particles readily, but not to the point of passing the critical sieve for the AASHTO method of evaluating the test (No. 16 sieve).

INFLUENCE OF AGGREGATE GRADING ON MICRO-DEVAL RESULTS

FIGURE 5 shows the Micro-Deval test results of all aggregate sources for which tests were performed on each of the three gradings – MD-A, MD-B, and MD-C for each of the three analysis methods. The sources included in this analysis comprised 45 total aggregates from 15 separate and unique sources. At each source a 9.5mm, 12.5mm, and 19.0 mm aggregate stockpile was tested using the grading of MD-C, MD-B, and MD-A respectively. The line in FIGURE 5(a) indicates the MDOT maximum Micro-Deval loss value of 18% for combined HMA aggregate blend gradations. The particle size distribution of the test sample also appears to have an effect on the Method 2 loss values in FIGURE 5(b), where the line on the figure indicates the suggested maximum Method 2 Micro-Deval loss value of 20%. The influence of the initial gradation of the sample on the results is apparent for all three analysis methods. At least 80% of the sources for each analysis methods yielded MD-C grading values larger than the MD-A grading values.

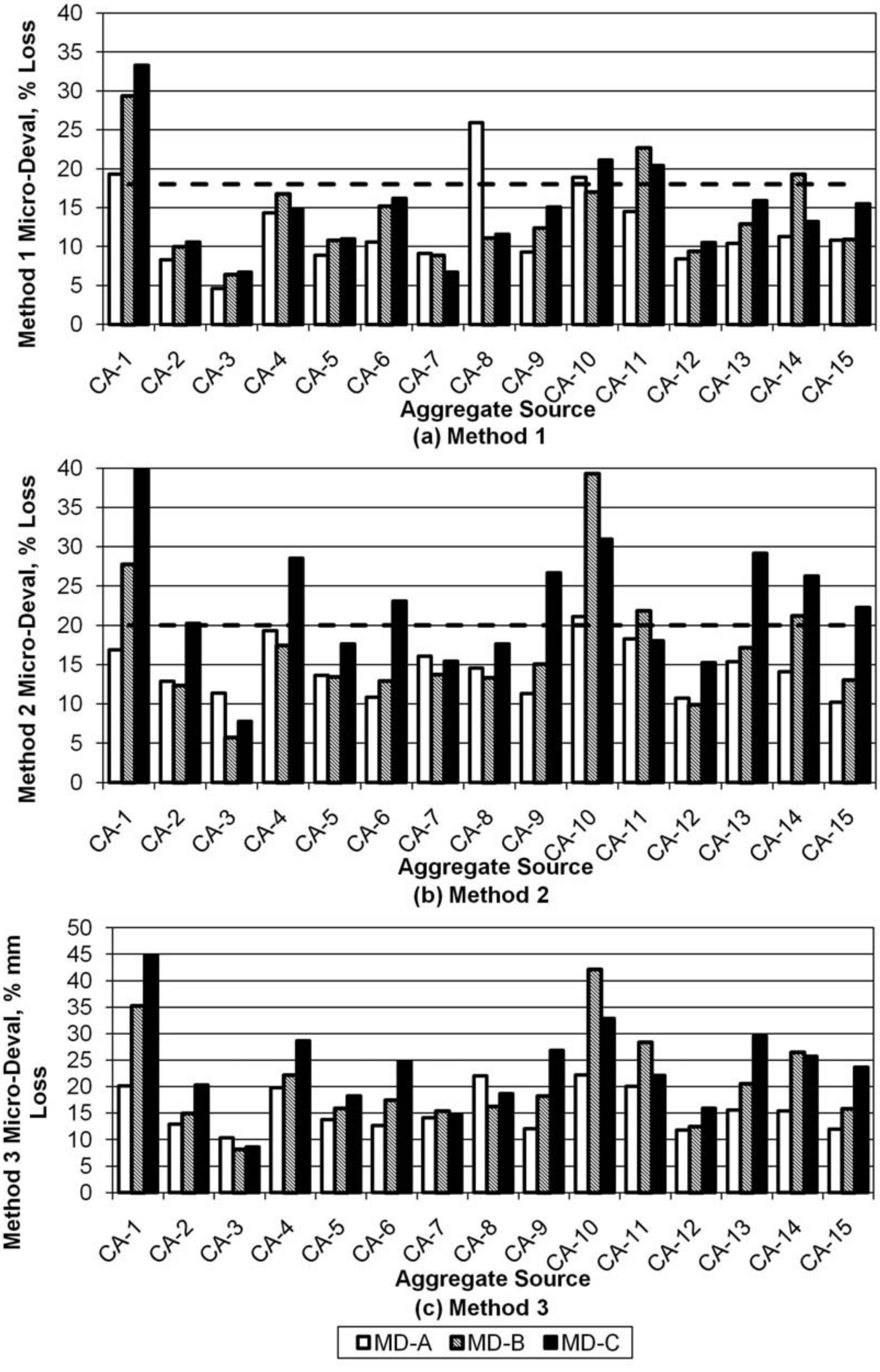


FIGURE 5 Micro-Deval loss values of MD-A, MD-B, and MD-C gradations for: (a) Method 1 analysis; (b) Method 2 analysis; (c) Method 3 analysis

TABLE 4 displays the average differences between the different grading sizes for all three methods of analysis for the Micro-Deval test. Although some of the difference could be explained by variability in the material (certain particle sizes more susceptible to degradation than others), these results suggest that the grading size does have an influence on the Micro-Deval loss values. The disparity between the sample gradation sizes is most significant for the Method 2 and Method 3 values, with differences between the MD-A and MD-C sizes greater than 8%. The influence of the aggregate size on Micro-Deval values has been noted by previous researchers who attributed the differences to the increased surface area of aggregate with the finer aggregate sizes (*1*). Over 84% of the sources in this study showed an increase in Micro-Deval values with finer gradations. The Micro-Deval test primarily degrades the aggregate through abrasion so finer aggregate will have more surface area available and exhibit higher loss values.

TABLE 4 Difference in Micro-Deval Loss Values between Grading Sizes

Analysis Method	Difference MD-B - MD-A	Difference MD-B - MD-C	Difference MD-C - MD-A
Method 1 Micro-Deval, % Loss	1.91	0.63	2.53
Method 2 Micro-Deval, % Loss	2.49	5.65	8.13
Method 3 Micro-Deval (Normalized), %	4.97	3.09	8.06

DISCUSSION

Based on the results observed in this study, it appears that the Micro-Deval loss value has no significant correlation with the L.A. Abrasion test for Maine aggregates. Although not presented in this paper, the Method 2 and Method 3 Micro-Deval values also failed to display any significant correlation to L.A. Abrasion. The lack of correlation is expected as the two different durability tests have been shown to measure separate properties of construction aggregate. The L.A. Abrasion test measures aggregates' resistance to impact and fracture as opposed to the Micro-Deval test that is designed strictly to measure abrasion resistance of aggregates. Among the aggregates evaluated in this study, nine aggregates (12.5%) failed to satisfy the maximum allowable loss value for Micro-Deval as recommended by the NCHRP 04-19 study. Ten aggregates (13.9%) tested failed to meet the maximum allowable L.A. Abrasion loss value of 40% that is typically used by highway agencies. The range of Micro-Deval loss values observed in the study was quite large (28.7%) and greater than that of L.A. Abrasion testing, suggesting that a significant amount of blending is being accomplished in order for the HMA aggregate blends to meet MDOT's 18% maximum allowable loss specification.

The Method 2 (weighted average) and Method 3 (area between the curves) analysis methods for the Micro-Deval test were used to help quantify the change in particle size distribution of the sample through testing. The alternative analysis methods were included so that the mode of degradation of the aggregate material could be explained as well as to capture any degradation not reflected in the traditional AASHTO Micro-Deval procedure. According to the results from the 72 aggregates tested for this study, it appears that the Method 2 Micro-Deval values have no significant correlation ($R = 0.35$) to the Method 1 values. The same phenomenon is observed between the Method 1 and Method 3 Micro-Deval values as well ($R = 0.61$), although the relationship did have the strongest correlation). The lack of a significant correlation suggests that the two measures are quantifying different modes of degradation. A significant portion of the aggregates tested (22.2%) yielded Method 2 loss values over 25%, suggesting that degradation through fracture in the Micro-Deval is evident in those materials. Of the 16 aggregates that exhibited high Method 2 values, thirteen (81.3%) yielded acceptable Method 1 values. An analysis of the Method 3 results yielded the same conclusions, a significant portion of the aggregates has high values and a majority of those aggregates exhibited acceptable Method 1 Micro-Deval values. Previous work has established that when sieving Micro-Deval samples after being run in the ball mill, a poorly graded sample is degraded primarily by abrasion. The Micro-Deval test and computed loss value is founded on the assertion that the primary mode of degradation is abrasion and the test is most effective in that case. The traditional Micro-Deval loss value does not account when the sample is well-graded after testing, suggesting that the primary mode of degradation in the aggregate is from fracture. Aggregates in this category tend to degrade readily through fracture into smaller particles, but not to the point of passing the critical sieve for the test. This kind of degradation suggests a very poor quality aggregate, yet the way the loss value is traditionally calculated the degradation is not taken into account. FIGURE 6 displays a comparison between two aggregates that yielded nearly identical Method 1 Micro-Deval values (15.2% and 15.4%) as an example. Both aggregates are 12.5 mm NMAS material tested using grading MD-B. Although the Method 1 values are nearly identical, examination of the particle size distribution shows that CA-18 yielded significantly more degradation in the test as compared to CA-6. The Method 2 analysis procedure is effective in measuring the difference, with values of 12.92% for CA-6 and 27.59% for CA-18. The addition of either Method 2 or Method 3 to the traditional Micro-Deval criteria would help to identify those aggregates prone to fracture as well as abrasion.

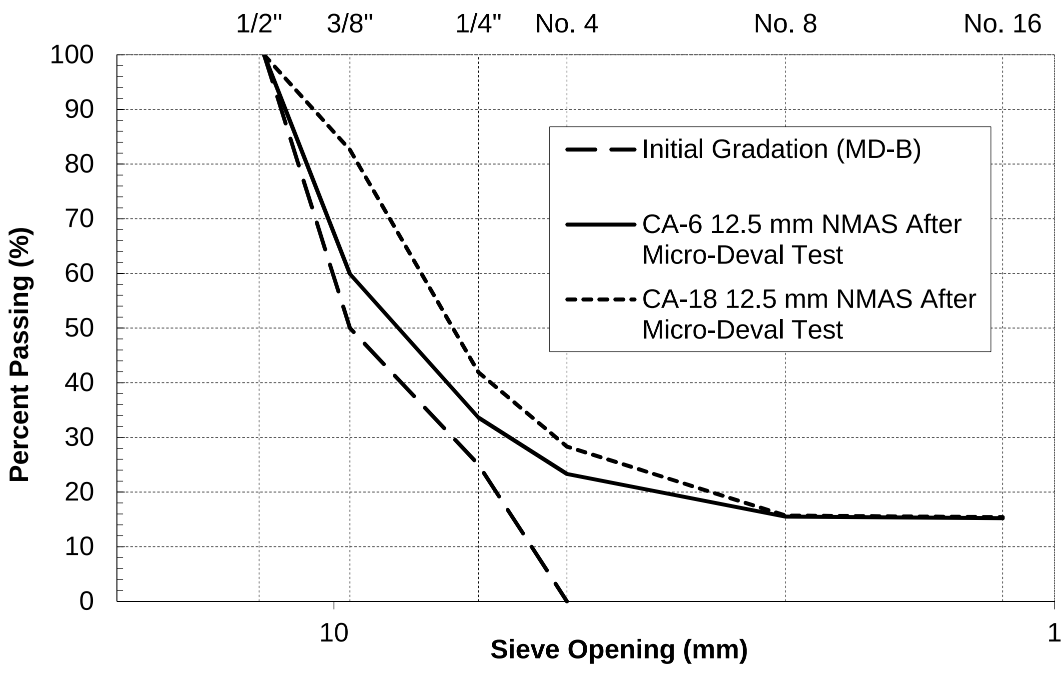


FIGURE 6 Grain size distribution: initial vs. after Micro-Deval test for CA-6 12.5 mm aggregate and CA-18 12.5 mm aggregate

It is apparent from the above discussion and previous research that although the Micro-Deval is a more accurate predictor of pavement performance than the L.A. Abrasion test, the

Micro-Deval is not effective in capturing the fracture of aggregates in the test as opposed to abrasion. However, it is also evident from the testing results of the 72 Maine aggregates that all three Micro-Deval methods of analysis used in this study are influenced by the original gradation size of the test sample. Although a portion of the increase in loss value could be attributed to variability in the aggregate material, the existence of a trend in the values is noteworthy. The increase in loss values, most pronounced in the Method 2 and Method 3 results, suggest that the increase in surface area of the test sample, caused by using finer material is influencing the results.

CONCLUSIONS

Based on this study's presented results and discussion of the durability testing performed on Maine aggregate sources, the following conclusions are drawn:

- The Micro-Deval loss values did not correlate substantially with L.A. Abrasion loss values as was expected and shown in significant studies.
- The wide range of Micro-Deval values and the existence of 12.5% of aggregate blends with values larger than the 18% maximum allowable HMA aggregate blend loss value suggests that blending is occurring to meet MDOT's aggregate durability specification. The blending of a significant amount of poor quality aggregate material may be causing aggregate breakdown during construction and service life, leading to the material loss observed by the MDOT.
- The alternative analysis methods for Micro-Deval did not exhibit a strong relationship with the traditional Micro-Deval values, suggesting the measurement of different degradation mechanisms between the methods.
- The Method 2 and Method 3 Micro-Deval loss values indicate that a portion (>20%) of the aggregate blends tested undergo significant degradation in the Micro-Deval test procedure, most likely through fracturing of the aggregate, and is not captured in the AASHTO Micro-Deval value. The alternative analysis methods measure the particle size distribution of the sample posttest, where a well-graded sample suggests degradation through fracture as well as abrasion.
- The use of the Method 2 or Method 3 analysis methods in addition to the AASHTO Micro-Deval value would improve the tests' ability to detect all modes of aggregate degradation.
- The sample grading appears to have an influence on the Micro-Deval loss values for all three analysis methods, with finer initial gradations producing elevated loss values. The positive influence on the loss values is observed in 84.4% of the aggregate sources used in the analysis.

RECOMMENDATIONS

Based on the findings from this study, it is recommended that the MDOT continue to evaluate the Micro-Deval results and its tie to the material loss exhibited in the state. It is further recommended that a correlation between Micro-Deval values, including the Method 2 and Method 3 values, and pavement performance measures be established. The viability of the alternative analysis methods for Micro-Deval, including the suggested influence of initial gradation be investigated further. Finally, the use of individual aggregate requirements for durability using Micro-Deval should be considered in lieu of the combined aggregate blend requirement.

ACKNOWLEDGEMENTS

The author would like to acknowledge the support provided by the MDOT for this project. Gratitude is also extended to all the contractors and the Maine Asphalt Pavement Association who generously provided the aggregates for the study. Thanks are extended to Mr. Brian Fogg and his staff in the Bangor Laboratory for help with conducting the testing for this project.

REFERENCES

1. Kandhal, P. S., and F. Parker. *Aggregate Test Related to Asphalt Concrete Performance in Pavements.* NCHRP Report No. 405, Transportation Research Board, National Research Council, Washington, D.C., 1998.
2. Brandes, H.G., and C.E. Robinson. Correlation of Aggregate Test Parameters to Hot Mix Asphalt Pavement Performance in Hawaii. *Journal of Transportation Engineering,* Vol.132, No. 1, 2006, pp. 86-95.
3. Tarefder, R. A., M. Zaman, and K. Hobson. Micro-Deval Test for Evaluating Properties of Roadway Aggregate. *International Journal of Pavements,* Vol. 2, No. 1–2, 2003, pp. 8–19.
4. Cooley, L. A., Jr., and R. S. James. Micro-Deval Testing of Aggregates in the Southeast. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1837, Transportation Research Board of the National Academies, Washington, D.C., 2003, pp. 73-79.
5. White, T. D., J. E. Haddock, and E. Rismantojo. *Aggregate Tests for Hot-Mix Asphalt Mixtures Used in Pavements*. NCHRP Report No. 557, Transportation Research Board, National Research Council, Washington, D.C., 2006.
6. Hossain, M.S., Lane, S.D., and B.N. Schmidt. Results of Micro-Deval Test for Coarse Aggregates from Virginia Sources. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 2059, Transportation Research Board of the National Academies, Washington, D.C., 2008, pp. 1-10.
7. Rangaraju, P.R. and J. Edlinski. Comparative Evaluation of Micro-Deval Abrasion Test with Other Toughness/Abrasion Resistance and Soundness Tests. *Journal of Materials in Civil Engineering,* Vol. 20, No. 5, 2008, pp. 343-351.
8. Wu, Y., F. Parker, and K. Kandhal. *Aggregate Toughness/Abrasion Resistance and Durability/Soundness Tests Related to Asphalt Concrete Performance in Pavements.* Report No. 98-4. National Center for Asphalt Technology, Auburn, Ala., 1998.
9. Hossain, M.S., Lane, S.D., and B.N. Schmidt. Use of the Micro-Deval Test for Assessing Fine Aggregate Durability. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 2059, Transportation Research Board of the National Academies, Washington, D.C., 2008, pp. 11-19.
10. Erichsen, E., Ulvik, A. and K. Sævik. Mechanical Degradation of Aggregate by the Los Angeles-, the Micro-Deval- and the Nordic Test Methods. *Rock Mechanics and Rock Engineering,* Vol. 44, No. 3, 2011, pp. 333-337.