Comparative Analysis of Micro-Deval, L.A. Abrasion and Sulfate Soundness Tests

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Word count 4305
12 tables and figures..... 3000
Total word count........... 7305

ABSTRACT

Aggregates used in the construction of roads must be durable, abrasion resistant, and freeze-thaw resistant in order to perform well in pavement or as base course. The objective of this study was to investigate whether the Micro-Deval test will provide better and more repeatable information about the quality of an aggregate than other durability tests based on laboratory test data. This objective was realized by conducting: 1) a thorough analysis of aggregate durability data from around the U.S.; 2) a survey of the state-of-the-practice of state Departments of Transportation within the U.S.; 3) laboratory tests including Micro-Deval, L.A. Abrasion, and Sodium Sulfate; and 4) an extensive literature review. Test results were normalized to facilitate direct comparisons between Micro-Deval, L.A. Abrasion, Sodium Sulfate and Magnesium Sulfate tests. Linear regression of the data points and corresponding confidence intervals were plotted to qualitatively assess agreement or disagreement between test methods. Results of this study indicate that the Micro-Deval test is a suitable replacement for the Sodium Sulfate test as the primary method for evaluating aggregate durability, with limitations. Due to some inconsistent durability determinations between test methodologies, the authors recommend that the Micro-Deval test results be further supported by a second aggregate durability test whenever the Micro-Deval results fall within a certain range (i.e., between 18 and 27 percent loss). It was also concluded that the most conservative test is the Micro-Deval followed by Magnesium Sulfate, L.A. Abrasion and Sodium Sulfate tests, respectively.

BACKGROUND

Aggregate used for road construction must be durable, abrasion resistant and freeze-thaw resistant in order to perform well in pavement, base course or sub-base. There are a variety of test methods used to quantify the durability of aggregates, as listed in Table 1. These tests use different mechanisms to quantify the relative durability of an aggregate that will be subjected to processing, construction and traffic loadings. Presently, the two most commonly used tests in the U.S. are the L.A. Abrasion and the Sodium Sulfate Soundness tests. The validity and repeatability of these tests have been questioned by transportation officials and researchers across the country. For instance, it has been shown that the Sodium Sulfate test has poor repeatability between laboratories and even between samples within a single laboratory (*1*). Over the past decade, there has been a movement in the industry to find a more reliable, repeatable and accurate durability test.

TABLE 1 Common Aggregate Durability Test Methods (from *2*)

Test Name	Methodology
L.A. Abrasion	Abrasion (dry)
Micro-Deval Abrasion	Abrasion (wet)
Nordic Ball Mill	Abrasion (wet)
Magnesium Sulfate Soundness	Simulated freeze-thaw
Sodium Sulfate Soundness	Simulated freeze-thaw
Freeze-Thaw Soundness	Freeze-thaw
Canadian Freeze-Thaw	Freeze-thaw plus sodium chloride solution
Aggregate Impact Value	Impact
Aggregate Crush Value	Compressive load
Degradation in the SHRP* Gyratory Compactor	Compaction
Petrographic	Geologic analysis

*SHRP stands for Strategic Highway Research Program

For example, the authors recently completed a study for the Montana Department of Transportation (MDT) to determine the feasibility of widespread incorporation of the Micro-Deval test in place of the Sodium Sulfate test, which MDT currently uses (*3*). The Micro-Deval, L.A. Abrasion and Sodium Sulfate tests were evaluated by conducting multiple tests on 32 aggregate sources obtained from around Montana. This study also included durability data obtained from participating DOTs throughout the U.S., as well as Magnesium Sulfate test results.

Past Studies

An extensive literature review was conducted to synthesize applicable aggregate durability studies. Of 16 studies that were reviewed as part of this investigation, 15 considered the Micro-Deval test, 12 considered the L.A. Abrasion test, 11 considered the Magnesium Sulfate test, and 5 considered the Sodium Sulfate test within their research or analysis. Results from the literature were mixed, but some trends emerged. A tabulated summary of pertinent results, conclusions, and recommendations is provided in Table 2. The evaluation of the literature was based on general comparisons and did not differentiate between specific components of the research such as aggregate type, particle size, etc.

TABLE 2 Literature Review Summary Table

Author(s)	Tests Considered	Aggregate Information	Research Components	Brief Summary/Recommendations
Arm 2003 (*4*)	L.A., M-D, F-T		mechanical properties of recycled aggregates	M-D and L.A. ranked materials similarly. M-D offered the best differentiation between the various material types.
Bjarnason et al., 2002 (*5*)	L.A., M-D, $MgSO_4$, F-T	20 sources	correlations between test results	Tests were broken into three categories: 1) fragmentation (e.g., L.A.), 2) weathering or durability (e.g., $MgSO_4$, F-T) and 3) abrasion (e.g., M-D). Tests within each category correlated well to one another, so using any test within a particular category will help assess aggregate quality.
Brandes and Robinson, 2006 (*6*)	M-D, L.A., $MgSO_4$, $NaSO_4$	12 quarries	mechanical and chemical tests on aggregates, statistical correlations between results, correlations with pavement performance	Correlation between M-D and L.A. was low. M-D and Sulfate Soundness tests correlated well. $MgSO_4$ and $NaSO_4$ correlated well to one another. L.A. and M-D had poor correlations with pavement performance. $MgSO_4$ had best correlation to pavement performance. $NaSO_4$ had second best correlation to pavement performance.
Cooley et al., 2002 (*7*)	M-D, L.A., $MgSO_4$, $NaSO_4$	72 aggregates from 8 states	statistical correlations between the various methods and between repeated tests	No correlation between M-D and L.A., M-D and $MgSO_4$ or M-D and $NaSO_4$. Aggregate type may affect correlations between M-D and performance ratings.
Fowler et al., 2006 (*8*)	M-D, L.A., $MgSO_4$, ACV, F-T, H_2O, G_s	117 sources within US and Can.	correlations between test results, correlations with field performance	Very little correlation between tests, best being the L.A. to British ACV (R^2 = 0.650), M-D to $MgSO_4$ (R^2 = 0.600). M-D works well to predict field performance, works even better when used in conjunction with Canadian F-T, $MgSO_4$ or G_s.
Hunt, 2001 (*9*)	M-D, NBM, L.A.	44 samples from 22 sources	investigating alternative means of measuring aggregate durability	M-D results repeatable between two technicians. Little differences between the M-D and L.A. in predicting field performance. NBM was able to identify aggregate quality.
Jayawickrama et al., 2006 (*10*)	M-D, $MgSO_4$, Pet	52 aggregate sources	statistical analysis, correlations between repeated tests	Correlation between M-D and $MgSO_4$; M-D more repeatable than $MgSO_4$, recommends using M-D as a quality control tool.

Author(s)	Tests Considered	Aggregate Information	Research Components	Brief Summary/Recommendations
Kline et al., 2007 (*1*)	$NaSO_4$	50 tests	literature review, comparisons of $NaSO_4$ to various physical properties	$NaSO_4$ not related to other aggregate material properties, literature review stated low repeatability is evident in $NaSO_4$, recommended not to use the $NaSO_4$ to determine whether a particular aggregate should be used.
Lim, 2004 (*11*)	WAV, L.A., M-D	ballast material	investigate correlations between a simulated box test and other aggregate durability tests	M-D, WAV and L.A. all worked well to identify ballast field performance.
Prowell et al., 2005 (*12*)	L.A., M-D, $MgSO_4$, $NaSO_4$	N/A	survey, literature review, performance data review	Replace Sulfate Soundness tests with Micro-Deval, use freeze-thaw test in conjunction with Micro-Deval to improve results.
Rangaraju et al., 2005 (*13*)	M-D, L.A., $MgSO_4$, $NaSO_4$	23 sources (19 classified as granite) in South Carolina	correlations between test results, correlations with field performance	No correlation between M-D and L.A., $MgSO_4$ and $NaSO_4$ had very good correlation. M-D better than L.A. to identify marginal aggregates based on field performance, aggregate size affects outcome of M-D test – smaller aggregates show greater loss.
Rismantojo, 2002 (*14*)	L.A., M-D, $MgSO_4$	5 course, 6 fine	statistical correlations of test results, test sections	Good correlation between M-D and $MgSO_4$, correlation between M-D and water absorption.
Rogers et al., 1991 (*15*)	$MgSO_4$, M-D,	fine aggregates	several factors compared and test methods	$MgSO_4$ not very precise for fine aggregates and is time consuming; M-D correlates well with $MgSO_4$, M-D variability is low and well-suited to identify fine aggregates that are derived from weak and poor rocks.
Senior and Rogers, 1991 (*16*)	F-T, M-D, AIT, PSV, AAV, L.A., $MgSO_4$, H_2O, Pet	granular base courses, Portland cement concrete, surface course asphalt concrete	statistical correlations of test results, correlations with field performance	Granular bases: M-D+Pet works well to distinguish between good and bad aggregates, M-D alone able to distinguish between marginal and good aggregates, M-D+H_2O able to identify poor aggregates; PCC: M-D+F-T able to distinguish between marginal and poor aggregates, H_2O+M-D or H_2O+F-T able to identify poor aggregates; Surface Course Asphalt Concrete: M-D+PSV able to identify good aggregates.
Tarefder et al., 2003 (*17*)	M-D, L.A., F-T, ADI, G_s, H_2O	18 aggregates	compare results between various tests, evaluate repeatability, correlations with field performance	M-D highly repeatable, M-D correlates well with other tests for sandstone and not as well for limestone, L.A. did not accurately predict field performance, M-D did accurately predict field performance of aggregates.
Wu et al., 1998 (*2*)	L.A., AIV, ACV, M-D, Gyr, $NaSO_4$, $MgSO_4$, F-T, DIT, F-T (Can.)	16 sources from 12 states	survey, literature review, performance data statistical review	L.A. and $NaSO_4$ did not predict pavement performance as well as M-D and MgSO4.

Notes: AAV = Aggregate Abrasion Value
ACV = Aggregate Crushing Value
ADI = Aggregate Durability Index
AIT = Aggregate Impact Test
AIV = Aggregate Impact Value
F-T = Freeze-Thaw
G_s = Specific Gravity
Gyr = Gyratory Compactor
H_2O = Water Absorption
L.A. = L.A. Abrasion
M-D = Micro-Deval
$MgSO_4$ = Magnesium Sulfate Soundness
$NaSO_4$ = Sodium Sulfate Soundness
NBM = Nordic Ball Mill
Pet = Petrographic Analysis
PSV = Polished Stone Value
WAV = Wet Attrition Value

Generally, most of the authors were able to obtain favorable or useful results using the Micro-Deval test. The Micro-Deval test was considered repeatable by those who studied its repeatability (*9*, *10*, *17*). Four studies specifically indicated that the Micro-Deval test related well with field performance (*2*, *8*, *13*, *17*); however, one study indicated that it did not (*6*). Several studies indicated that the L.A. Abrasion test does not accurately predict field performance (*2*, *6*, *17*). Studies that examined the Sodium Sulfate test indicated that it was not very repeatable, and it appeared to have only a limited relationship to field performance or to aggregate properties (*1*, *2*, *12*). In contrast, one study indicated that the Sodium Sulfate test had a fairly high correlation with field performance (*6*). The Magnesium Sulfate test generally rated higher overall than the Sodium Sulfate test, especially in terms of field performance (*2*, *6*), while another study reported that the Magnesium Sulfate test was less reliable when fine aggregates were used (*15*).

Several studies correlated results from different durability test methods. Good correlations were generally found when the Micro-Deval test results were compared to Magnesium Sulfate test results (*6*, *8*, *10*, *14*, *15*). However, in contrast, one study found poor correlations between the Micro-Deval test and other durability tests (*7*). Correlations between the Micro-Deval and the Sodium Sulfate tests were also mixed. One study reported good correlation (*6*), while another reported a relatively poor correlation (*7*). One study reported a good correlation between the Micro-Deval and the Water Absorption test (*14*). Correlations between the Micro-Deval and the L.A. Abrasion tests were mostly poor (*6*, *7*, *8*, *13*); however, one study reported a relatively good correlation (*4*).

Several authors suggested using combinations of various tests to better distinguish aggregate quality. Two studies suggested combining the Micro-Deval test with the Freeze-Thaw test (*8*, *12*). One study suggested using the Micro-Deval test with the Magnesium Sulfate test or specific gravity test to better predict field performance (*8*). Another study suggested using the Micro-Deval test with Petrographic analysis and the Water Absorption test to better assess the durability of base course aggregates (*16*). A major shortcoming of these studies is the lack of specific analytical procedures to practically merge or evaluate data from multiple test methods.

The relationship between Micro-Deval test results and field performance was not examined in this study; however, evaluations by several authors indicate that Micro-Deval test results relate well with field performance (*2*, *8*, *13*, *17*). A good correlation between rutting performance and Micro-Deval test results was reported by one study, which suggested that using a maximum cutoff value of 15 percent loss for the Micro-Deval test would limit rutting in hot mix asphalt to 12.5 mm at 20,000 wheel passes (*18*).

Repeatability

Repeated in-lab tests were conducted on 28 different aggregates using the Micro-Deval test and 19 different aggregates using the L.A. Abrasion test to investigate the repeatability of tests conducted on the same material. The coefficient of variation (COV) was calculated for each material source using data from Micro-Deval and L.A. Abrasion tests. The average COV for the Micro-Deval tests was 6.8% and the average COV for the L.A. Abrasion test was 6.7%. If the major outlier for each test is eliminated (28% for the Micro-Deval and 23.6% for the L.A. Abrasion), the average COV values are 6.1% for the Micro-Deval test and 5.8% for the L.A. Abrasion test. These correspond to average standard deviations of 0.7 and 1.7 percent loss for the Micro-Deval and L.A. Abrasion tests, respectively. This single-lab repeatability study indicates that both the Micro-Deval and the L.A. Abrasion tests have good repeatability with no

statistically significant difference between the two tests. Similar conclusions regarding the repeatability of the Micro-Deval test were reported in literature reviewed as part of this study (*9*, *10*, *17*).

The majority of COV values measured in this study fall within a range of 3% to 15%, as shown in Figure 1a. No particular trends were observed in the variability of the COV between material types as shown graphically in Figure 1b. The large COV value of 28% for Micro-Deval is attributed to the very small average test result for this sample, which was 2.1% loss.

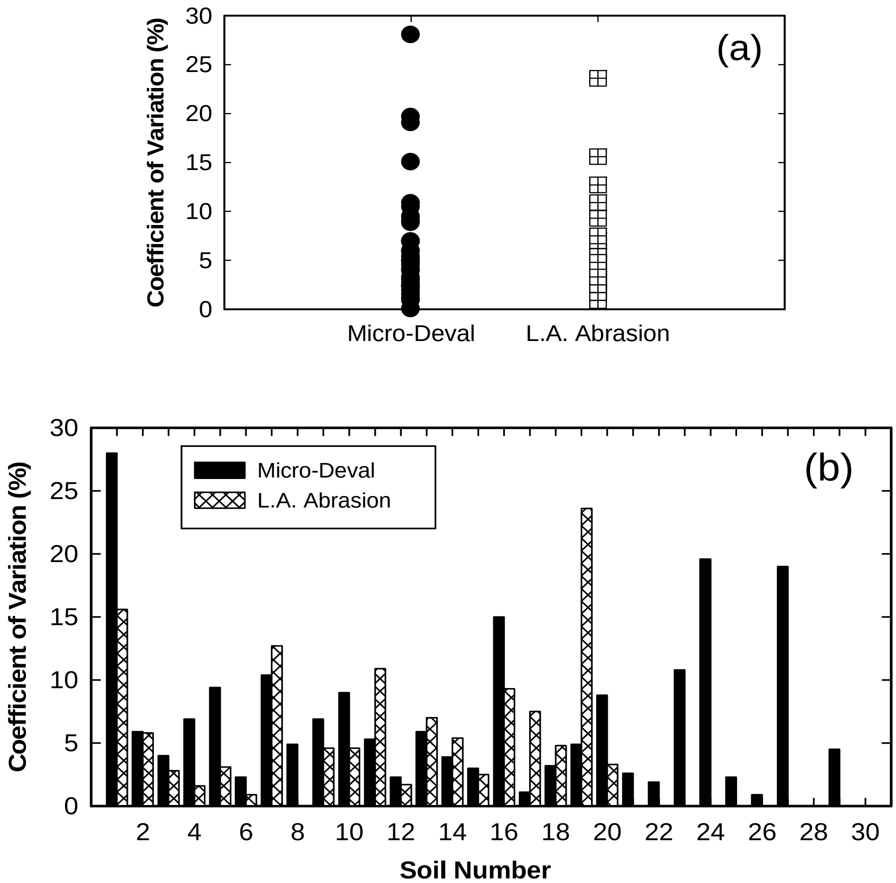

FIGURE 1 COV for the Micro-Deval and L.A. Abrasion tests: a) compilation of all test data and b) data displayed by aggregate number.

The Sodium Sulfate test has a reported coefficient of variation of 41% for multi-laboratory testing and 24% for a single laboratory testing, as stated in the AASHTO T104 test standard (*19*). Therefore, the COV for the Sodium Sulfate test is greater than the measured COV for the Micro-Deval and the L.A. Abrasion tests by a factor of about 3.5.

Test Methods

The Micro-Deval Abrasion Test (AASHTO T327 and ASTM D 6928) is an abrasion and durability test that induces aggregate wear by rotating a mixture of aggregate, steel balls (charge) and water for two hours in a smooth drum. The aggregate sample is then washed, dried, and sieved to obtain the percent loss. The L.A. Abrasion test (AASHTO T96, ASTM C131, and

ASTM C535) uses impact and grinding to quantify degradation under these types of loads. A rotating steel drum with an interior steel shelf is loaded with aggregate and steel balls. As the drum rotates, the shelf picks up and subsequently drops the aggregate and the balls, thereby inducing an impact load on the aggregate. After 500 revolutions, aggregate degradation from specific gradation sizes is measured and reported in percent loss. Sodium and Magnesium Sulfate Soundness tests (AASHTO T104 and ASTM C88) subject the aggregate to simulated freeze-thaw cycles using a sodium or magnesium sulfate solution. After five cycles, the loss in weight from specific gradation sizes is measured, weighted, and reported as percent loss. The primary difference between the Sodium Sulfate and the Magnesium Sulfate tests is the chemical composition of the solution (*19*, *20*).

Current State-of-the-Practice

A telephone survey of state DOTs was conducted to assess the current state-of-the-practice regarding aggregate durability testing. The result of the responses received from 43 states is provided in Table 3. The L.A. Abrasion test is the most commonly used test: 41 out of 43 states indicated that they use the L.A. Abrasion test as at least one metric for evaluating aggregate durability. The Micro-Deval and Sodium Sulfate tests are used by approximately 50 percent of the states. Five DOTs indicated they have experimented with the Micro-Deval test, but have not incorporated it as a standard method because of reportedly unfavorable results. The most popular combinations of tests are the Micro-Deval plus the L.A. Abrasion and the L.A. Abrasion plus the Sodium Sulfate tests.

TABLE 3 State DOT Use of Durability Tests

Test Method	Number of States
Micro-Deval (MD)	20
L.A. Abrasion (L.A.)	41
Sodium Sulfate (SS)	20
Magnesium Sulfate (MS)	9
No Response	7
MD + L.A.	11
L.A. + SS	10
MD + L.A. + SS	9
MD + L.A. + MS	4
L.A. + MS	4
L.A. only	3
L.A. + SS + MS	1
SS only	1

COMPARATIVE ANALYSIS

This section describes a detailed comparative study of results obtained from the four most popular aggregate durability tests: Micro-Deval, L.A. Abrasion, Sodium Sulfate and Magnesium Sulfate tests. Because of differences in test methodologies, each test produces a unique value of percent loss, which is used to distinguish between durable and non-durable aggregates. Although each test method determines aggregate durability differently, this analysis treats all of these test methods equally in terms of their ability to accurately predict the field performance of the aggregates. Material that has a percent loss greater than the respective cutoff value is considered non-durable; likewise, material that has a percent loss less than the respective cutoff is considered durable. For the purpose of this study, the following percent loss pass-fail standards were used for each test.

- **Micro-Deval**: passing (i.e., durable) if % loss ≤ 18%
- **L.A. Abrasion**: passing (i.e., durable) if % loss ≤ 40%
- **Sodium Sulfate**: passing (i.e., durable) if % loss ≤ 12%
- **Magnesium Sulfate**: passing (i.e., durable) if % loss ≤ 20%

Data for the comparative analysis were collected from 38 states – either directly from DOTs or indirectly from research reports. Aggregate sources from a wide geographic area within the U.S. are represented, as shown graphically in Figure 2.

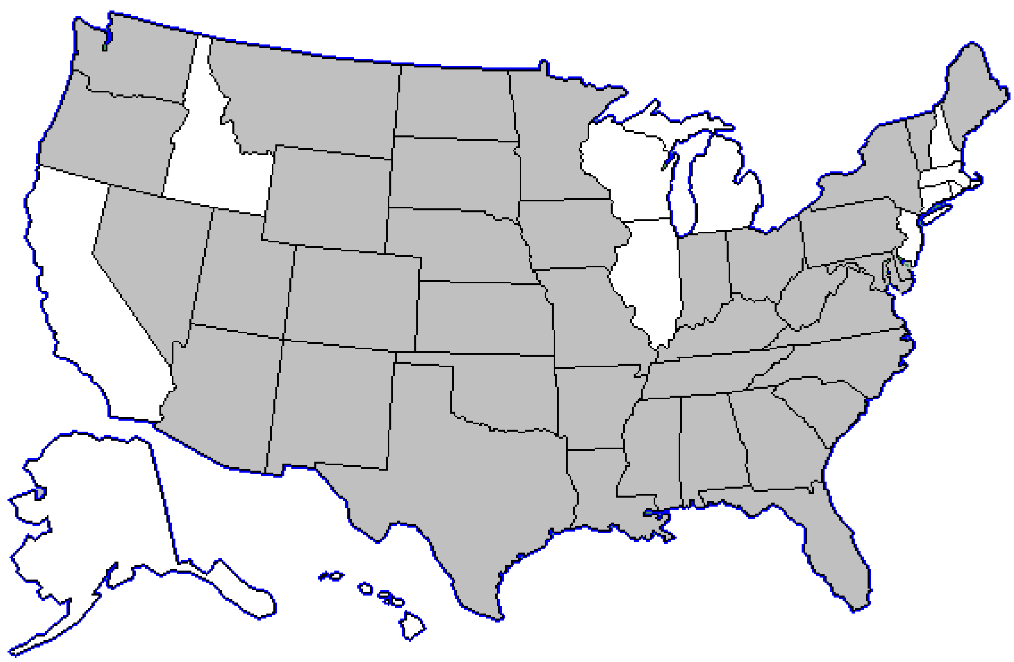

FIGURE 2 States from where data were obtained (shaded).

Data collected from these studies were normalized to facilitate direct comparisons between the four test methods. Normalized test results were obtained by dividing the percent loss for a particular aggregate sample by the respective cutoff for that test, as follows:

$$normalized\ \ value = \frac{percent\ \ loss\ (\%)}{cutoff\ \ (\%)}$$

A normalized value less than 1.0 indicates the percent loss is less than the cutoff value for that test and the material would be classified as durable. A normalized value greater than 1.0 is considered failing; that is, the material would be classified as non-durable. This approach was used to make direct comparisons between the Micro-Deval, L.A. Abrasion, Sodium Sulfate and Magnesium Sulfate tests. Normalized values were plotted to obtain graphical representations between tests. Each plot is divided into four quadrants, explained as follows:

1. Top right quadrant (NE), sample failed both the x-axis test and y-axis test;
2. Bottom left quadrant (SW), sample passed both the x-axis test and y-axis test;
3. Top left quadrant (NW), sample passed the x-axis test and failed the y-axis test; and
4. Bottom right quadrant (SE), sample failed the x-axis test and passed the y-axis test.

Micro-Deval versus L.A. Abrasion

Comparisons between Micro-Deval and L.A. Abrasion tests were made using results from tests conducted on 827 aggregate samples obtained from various sources throughout the U.S. Normalized Micro-Deval and L.A. Abrasion results are shown in Figure 3. The dotted line drawn at a 45 degree angle represents a perfect correlation between test methods. Data points close to the dotted line represent good correlation between tests, while data points that plot relatively far from the 45 degree line indicate poor correlation between tests. The most concerning results are those that fall into one of the two cross-hatched zones and are far removed from the 45-degree line. The confidence intervals shown in the figures define a range of values in which the percent loss can be located with a 95 percent probability (confidence level) based on the data that was assimilated in this study. The points shown as diamonds represent data from tests conducted by the authors on 32 Montana aggregates.

Results from these tests agree 77.6 percent of the time (i.e., pass-pass or fail-fail). The 22.4 percent disagreement; however, is considered problematic because one of the tests indicated the material was non-durable (failure) but the other indicated the material was durable (passing). These data points are located in the SE and NW cross-hatched quadrants in Figure 3. The majority of the points that disagree fall within the SE quadrant, indicating the Micro-Deval test is more “conservative” for the materials examined in this study. In this context, the term “conservative” means the Micro-Deval test results imply the aggregate is less durable than the L.A. Abrasion test.

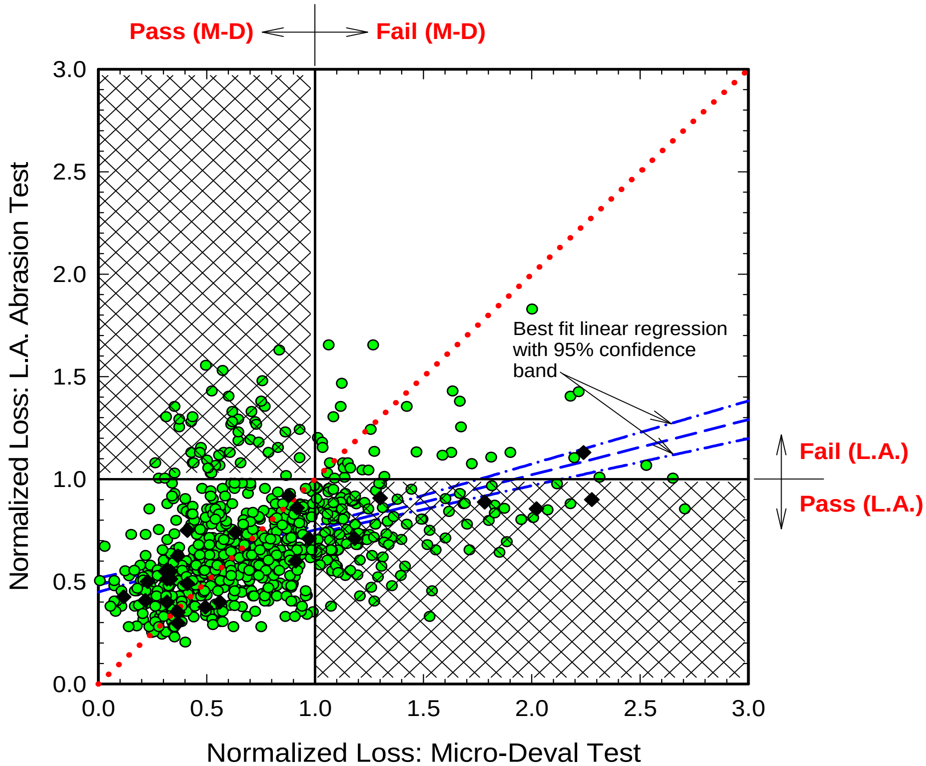

FIGURE 3 Normalized comparisons between Micro-Deval and L.A. Abrasion tests.

Micro-Deval versus Sodium Sulfate

Comparisons between Micro-Deval and Sodium Sulfate tests were made using results from tests conducted on 338 aggregate samples obtained from various sources throughout the U.S. The normalized Micro-Deval versus the normalized Sodium Sulfate data is shown in Figure 4. In this comparison, the results agree 84 percent of the time; the remaining 16 percent of the materials tested did not agree. The majority of these data points are located in the SE cross-hatched zone in Figure 4, indicating the Micro-Deval test provided more "conservative" results than the Sodium Sulfate test for the materials examined in this study.

Micro-Deval versus Magnesium Sulfate

Comparisons between Micro-Deval and Magnesium Sulfate tests were made using results from tests conducted on 501 aggregate samples obtained from various sources throughout the U.S. The normalized Micro-Deval versus the normalized Magnesium Sulfate data is shown in Figure 5. In this comparison, the results agree 91.2 percent of the time; the remaining 9.8 percent of the materials tested did not agree. Again, the majority of these data points fall in the SE quadrant in Figure 5; indicating once more that the Micro-Deval test is more "conservative" for the materials examined in this study. The Magnesium Sulfate test was not performed by the authors; consequently, no diamond-shaped data points are shown in Figure 5.

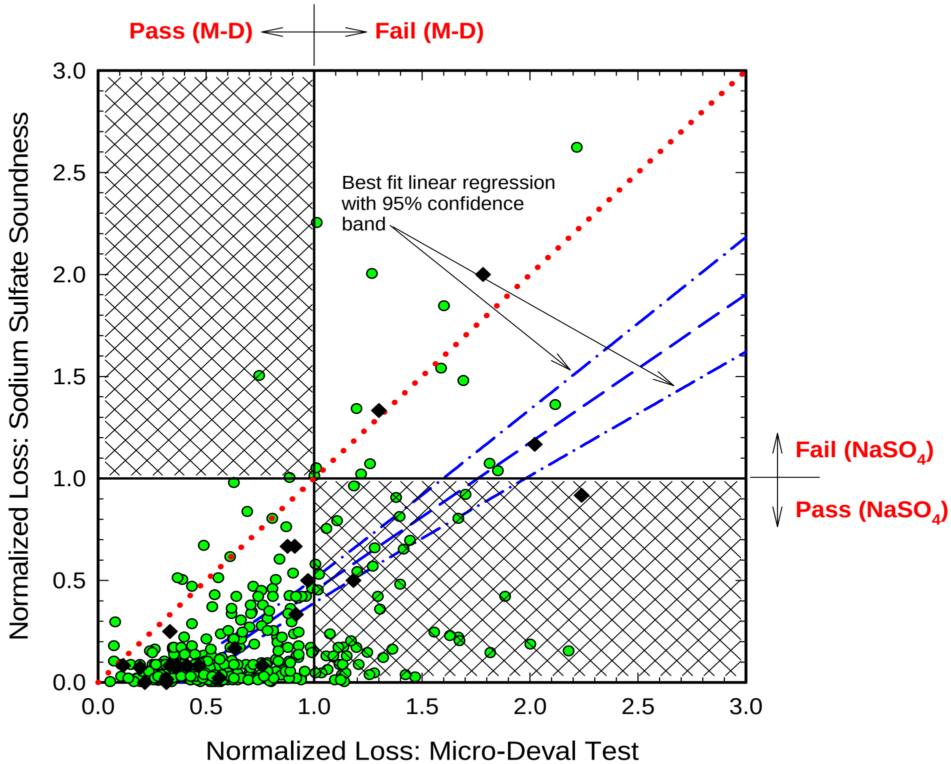

FIGURE 4 Normalized comparisons between Micro-Deval and Sodium Sulfate tests.

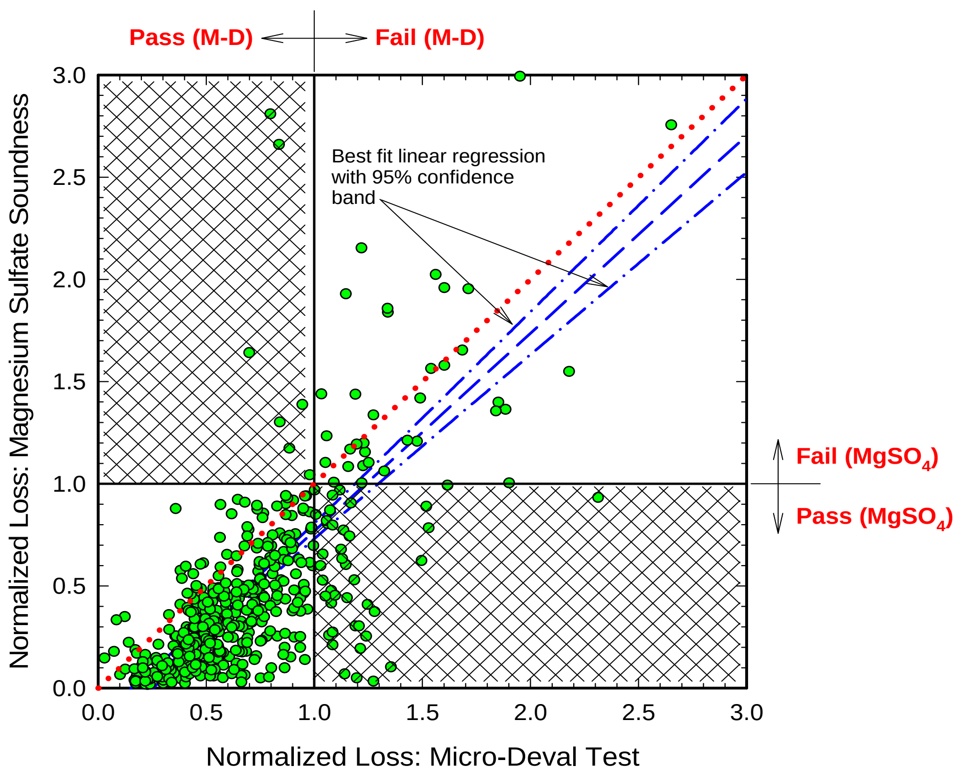

FIGURE 5 Normalized comparisons between Micro-Deval and Magnesium Sulfate tests.

L.A. Abrasion versus Sodium Sulfate

Comparisons between L.A. Abrasion and Sodium Sulfate tests were made using results from tests conducted on 326 aggregate samples obtained from various sources throughout the U.S. Results from this comparison, shown in Figure 6, indicated that there was disagreement between the two tests 20.2 percent of the time. The majority of these points fall within the SE quadrant, indicating that the L.A. Abrasion test is more "conservative" than the Sodium Sulfate test for the materials examined in this study.

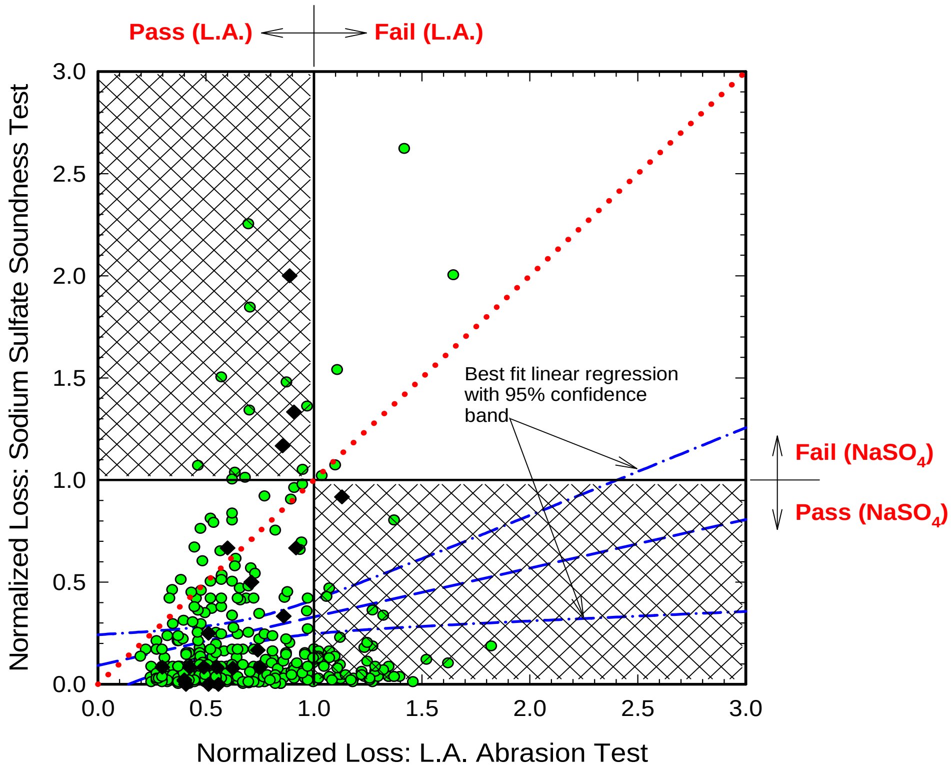

FIGURE 6 Normalized comparisons between L.A Abrasion and Sodium Sulfate tests.

L.A. Abrasion versus Magnesium Sulfate

Comparisons between L.A. Abrasion and Magnesium Sulfate tests were made using results from tests conducted on 300 aggregate samples obtained from various sources throughout the U.S. Results from this comparison, shown in Figure 7, indicated that there was disagreement between the two tests 11.3 percent of the time. These data points are located in the SE and NW cross-hatched zones in Figure 7; however, since slightly more points fall within the NW quadrant, the Magnesium Sulfate test is more "conservative" than the L.A. Abrasion test for the materials examined in this study.

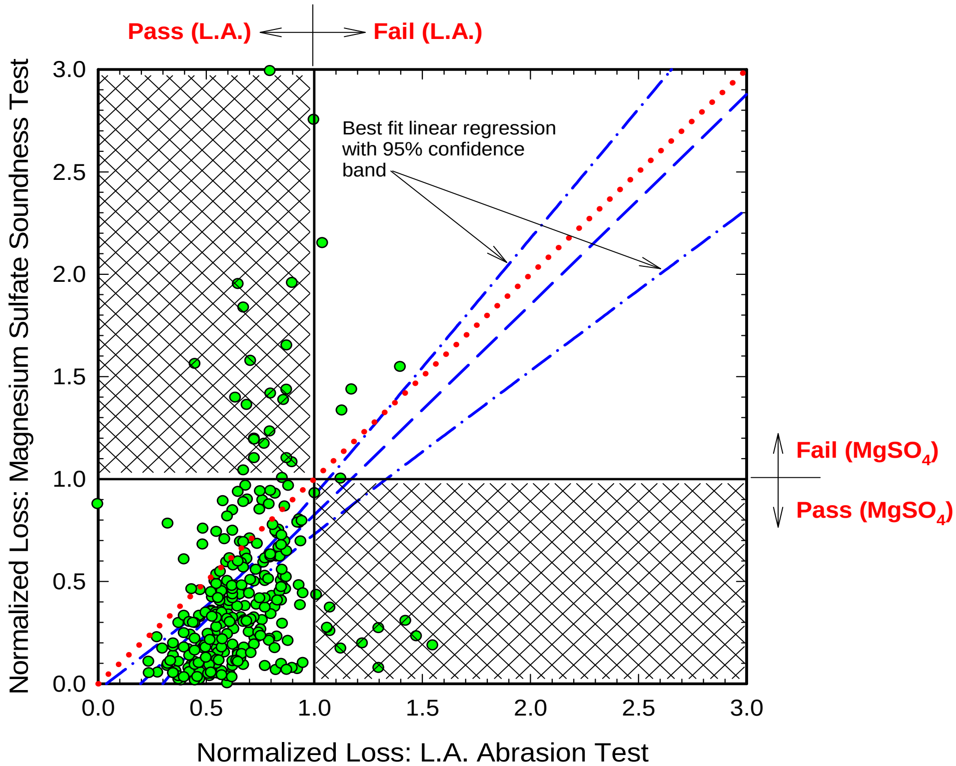

FIGURE 7 Normalized comparisons between L.A Abrasion and Magnesium Sulfate tests.

Sodium Sulfate versus Magnesium Sulfate

Comparisons between Sodium Sulfate and Magnesium Sulfate tests were made using results from tests conducted on 16 aggregate samples obtained from various sources throughout the U.S. Results, shown in Figure 8, indicated that there was disagreement between the two tests 12.5% of the time (two points). More data is necessary to reliably categorize these two tests with respect to one another.

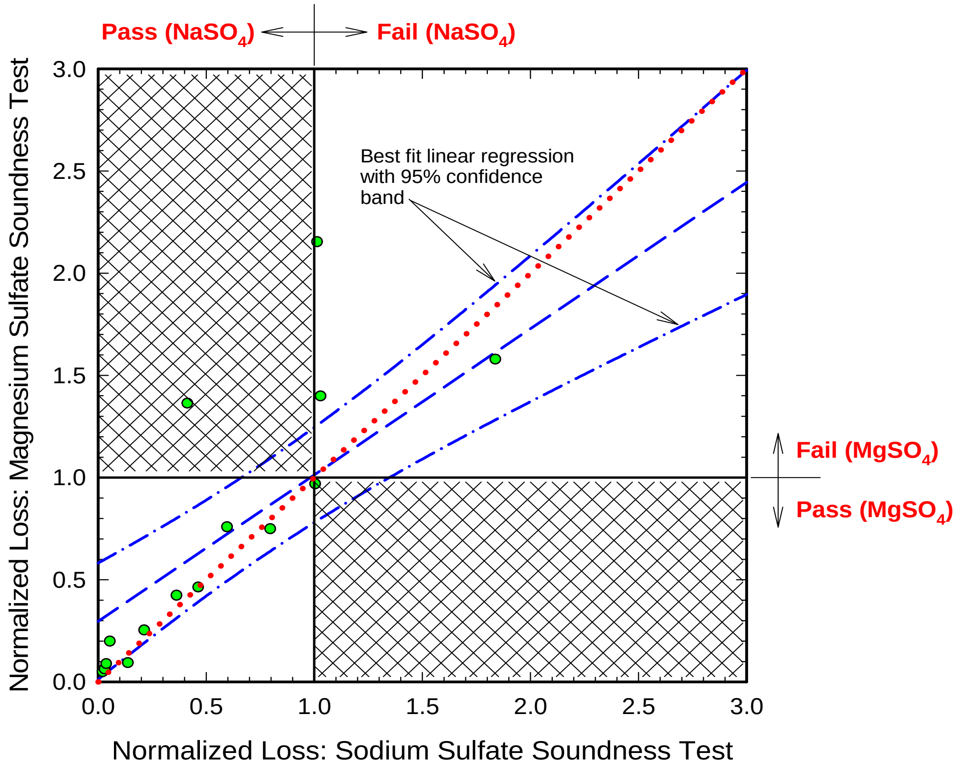

FIGURE 8 Normalized comparisons between Sodium Sulfate and Magnesium Sulfate tests.

Summary of Comparisons

A compilation of test results from 1030 aggregate samples was used to directly compare the Micro-Deval test with the L.A. Abrasion, Sodium Sulfate, and Magnesium Sulfate tests. Based on these comparisons, the Micro-Deval, L.A. Abrasion, Sodium Sulfate, and Magnesium Sulfate tests appear to correlate well for aggregates that have a relatively low percent-loss value. The best agreement between methods was between the Micro-Deval and the Magnesium Sulfate tests, similar to results found by others (*6*, *8*, *10*, *14*, *15*). The worst agreement was between the Micro-Deval and L.A. Abrasion tests, which compares favorably with other reported comparisons (*6*, *7*, *8*, *13*). Data near the cutoff values appear to be most problematic with respect to consistency between test results. Further examination of the data analyzed in this study revealed that the majority of the points in disagreement fell within the range of 1.0 to 1.5 on the normalized Micro-Deval scale. Increasing the cutoff point for the Micro-Deval test to 27 percent loss (a 50 percent increase) improves the agreement between the various tests significantly. The effect of increasing the failure cutoff for the Micro-Deval test is summarized in Table 4. Overall, it can be concluded that the most conservative test is the Micro-Deval followed by Magnesium Sulfate, L.A. Abrasion and Sodium Sulfate, respectively.

TABLE 4 Percent Agreement between Micro-Deval and Other Durability Tests

	Percent Agreement	
Failure Cutoff	**18%**	**27%**
MD vs. L.A.	77.6	90.7
MD vs. SS	84.0	96.7
MD vs. MS	90.2	97.8

SUMMARY AND CONCLUSIONS

The objective of this study was to determine if the Micro-Deval test provides better and more repeatable information about the quality of an aggregate than other durability tests based on laboratory test data. A laboratory testing program was conducted to compare Micro-Deval, L.A. Abrasion and Sodium Sulfate durability test methods on 32 different Montana aggregates. Data from an additional 1030 aggregate samples were obtained from state DOTs and research reports for aggregate samples from various sources throughout the U.S., including results from Magnesium Sulfate tests. A survey of the state-of-the-practice of state DOTs and an extensive literature review were also conducted.

Comparison of the results obtained from these four tests relative to aggregate durability were at times inconsistent (i.e., one test method indicated a passing grade, while another test failed the same aggregate). An important part of this study was to investigate and describe the similarities and inconsistencies between the test results. The following observations are based on a qualitative review of the results, and the 95% confidence bands that were created through a statistical evaluation of the data.

1. Aggregates that pass the Micro-Deval test will likely also pass the L.A. Abrasion, Sodium Sulfate and Magnesium Sulfate tests; that is, the Micro-Deval test is more "conservative."
2. Based on the 95% statistical confidence bands, the authors suggest that the greatest likelihood of pass-fail conflicts will occur when the percent loss of a sample is slightly greater than the Micro-Deval cutoff criteria.
3. If the Micro-Deval test is selected as the primary test for evaluating aggregate durability, the authors recommend that an alternate test be implemented whenever Micro-Deval results fall between 18 and 27 percent loss.
4. The largest scatter of data occurred in the comparison between the Micro-Deval and the L.A. Abrasion tests.
5. Of the three tests, the Sodium Sulfate appears to be the most difficult and time-consuming test to perform. This test also has the poorest record for repeatability and the poorest correlation to field durability.

Aggregate durability data from tests conducted on Montana aggregates using the Micro-Deval and L.A. Abrasion tests were also used to investigate same-lab repeatability of the test methods. The coefficients of variation for the multiple tests were less than 10% for both methods. These measured variations are considered relatively low, indicating good repeatability of the test methods, similar to other reported findings (*9*, *10*, *17*). Repeatability of the Sodium

Sulfate test was not examined; however, the AASHTO T104 test standard gives a coefficient of variation approximately 3.5 times greater than the Micro-Deval and the L.A. Abrasion results measured in this study.

The authors of this study conclude that the Micro-Deval test is suitable as the primary test for evaluating aggregate durability; however, there were some inconsistent durability determinations between test methodologies. Therefore, before any conclusions are made regarding the durability or quality of an aggregate, the authors recommend that the Micro-Deval test results be further supported by a second aggregate durability test whenever the Micro-Deval results fall between 18 and 27 percent loss. Suggested alternative tests include recognized methods such as the L.A. Abrasion, Sodium Sulfate or Magnesium Sulfate tests. This research treated each test method equally in terms of its ability to predict true behaviors in the field; future studies should include a full-scale field test to more accurately assess this important attribute.

ACKNOWLEDGEMENTS

Acknowledgment of financial support for this research is extended to the Montana Department of Transportation and to the Research and Innovative Technology Administration (RITA) at the United States Department of Transportation through the Western Transportation Institute at Montana State University. The contents of this report reflect the views of the authors, who are responsible for the facts and accuracy of the data presented. The contents do not necessarily reflect the official policies of the supporting agencies.

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