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RESEARCH ARTICLE

Laboratory assessment of Alaska aggregates using Micro-Deval test

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ABSTRACT Aggregates suitable for use in asphalt concrete (AC) pavement construction must meet durability criteria. Thus, it is critical to select appropriate tests to properly characterize aggregate durability. In Alaska, durability tests currently being used for aggregates in AC pavement include Los Angeles (LA) abrasion test, sulfate soundness test and Washington degradation test. However, there have long been concerns arising over Washington degradation test used as an acceptance tool, motivating pavement practitioners to seek more suitable alternatives. This paper presents a study to investigate the feasibility of using Micro-Deval test, commonly used in other states, to evaluate the durability of Alaskan aggregates in AC pavement as well as its potential to replace Washington degradation test. Micro-Deval test, Washington degradation test and other tests currently specified in Alaska were conducted on aggregates from 16 batches representing statewide sources. Based on the testing results, it is found that using Micro-Deval test for durability assessment of Alaska aggregates was feasible and reproducible, and a high potential was revealed to use Micro-Deval test to replace Washington degradation test in Alaska. It is recommended that Micro-Deval test be considered as an additional test for a certain period, but in the long run should be used along with current LA abrasion and sulfate soundness tests to provide a more desirable durability assessment of Alaska aggregates used in AC pavement.

KEYWORDS aggregate durability, Washington degradation test, Micro-Deval test

1 Introduction

Aggregate is one of the most widely used materials in asphalt concrete (AC) pavement and the key aspect of aggregate quality is durability. Aggregates used in asphalt pavement must reach satisfied toughness and abrasion resistance to prevent crushing, disintegration and degradation during stockpiling, placement and compaction, as well as further service life under traffic loadings [1,2]. When subjected to wetting-drying and/or freezing-thawing cycles, in addition, aggregates must also be resistant to breakdown.

It is critical to select appropriate tests to properly characterize aggregate durability. The current Alaska specifications for durability assessment of aggregates used in AC pavement are specified by Alaska Department of Transportation & Public Facilities (AKDOT&PF) [3], including percentage of Los Angeles (LA) wear by the LA abrasion test, sulfate soundness test, and degradation factor by Alaska Testing Method (ATM) 313 (or Washington degradation test) [4]. The LA abrasion test and sulfate soundness test are common test methods for aggregates, among which the former used to indicate aggregate toughness and abrasion characteristics and the latter utilized to determine the aggregate's resistance to disintegration by weathering through freeze–thaw cycles.

The Washington degradation test is a wet test that measures the susceptibility of an aggregate to degrade into plastic fines when abraded in the presence of water. It was initiated by Washington State Department of Transportation (DOT) to replace the aggregate soundness test to determine a "degradation value" and was subsequently adopted by AKDOT&PF to screen material sources for non-degrading aggregates since the 1960s [5], due to its

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consideration of weathering. Platts and Lloyd [6] compared eight different degradation tests with base materials from 19 projects statewide in Alaska. It was found that the Washington degradation test was one of the two tests that correctly delineated degradable from non-degradable materials, and the only one that could be run in a field laboratory. Over the years, however, problems have developed when Washington degradation test was used as an acceptance test, and its accuracy and interpretation of the results have also been questioned [5].

Vinson et al. [7] conducted Washington degradation test on aggregates from 20 sources statewide in Alaska in order to develop a relationship from the Degradation Index and the amount of fines generated during the production of base course. It was found that the Degradation Index could not predict the final fines content in the field, and the repeatability of the test highly dependent on ratio of the harder and softer aggregates within a sample. In a study conducted by Johnson [5], it was claimed that the Degradation Index could vary 10 to 20 units even in relatively uniform material sources, thus it was recommended that a minimum of five samples be tested to quantify the variability of the source. Problems have also been observed outside Alaska. Some doubtable results were found based on testing performed on limestone [8]. In addition, Goonewardane [9] looked into the variations of the Washington degradation test values with consideration of particle sizes and times of agitation, and concluded that the Washington degradation test is a clay leaching test dependent on surface area of charge, and a finer sample will indicate more degradation. These issues have limited the reliability of Washington degradation test and motivated researchers and pavement practitioners to develop simpler and more reasonable durability tests for aggregate in Alaska.

The recent attention has been focused on the Micro-Deval test, another wet test of how aggregates degrade when tumbled in a rotating steel drum with water and steel balls. In contrast to LA abrasion test, the Micro-Deval test uses much smaller drum and spheres, in the presence of water other than under a completely dry condition. Thus, Micro-Deval test may serve as a more reliable alternative to predict the abrasion resistance of aggregate, since it tends to "polish" the aggregate particles while LA abrasion test tends to break them. Different from the Washington degradation test, Micro-Deval test takes into account both weathering and degradations due to mechanical abrasion, which better simulates field performance during pavement placement and compaction, under traffic and in undesirable environment. Therefore, the potential of using Micro-Deval test to assess aggregate durability has become more attractive within the pavement industry in Alaska.

Since developed in France during the 1960s, Micro-Deval test has been used in the Province of Quebec and adopted by The Ministry of Transportation of both Ontario and British Columbia for measuring aggregates quality for transportation construction [10,11]. In the United States, researchers from several states have examined the Micro-Deval test particularly for aggregates in base course and hot mix asphalt (HMA) applications. In several National Cooperative Highway Research Program (NCHRP) studies, the Micro-Deval test was found to be a good indicator of aggregate durability, toughness, and abrasion resistance. According to NCHRP Report 405 [12], HMA performance (raveling, popouts or potholes) was found to be related to the results of the Micro-Deval and sulfate soundness tests, and a maximum loss of 18 percent could be adopted by both the two tests to separate "good" or "fair" aggregates from "poor" ones. In a subsequent NCHRP study, Micro-Deval and magnesium sulfate soundness tests were recommended with 15 and 20 percent as maximum loss limits, respectively, to evaluate aggregates used in HMA for all climates and traffic loading conditions [13]. The Micro-Deval test was recommended for its relation to "toughness and abrasion resistance" of base course aggregates in another NCHRP study [14]. Based on a study conducted by Virginia DOT [15], the Micro-Deval test showed higher accuracy and precision than traditional tests such as LA abrasion and magnesium sulfate tests in terms of aggregate durability evaluation. It was found to be capable of characterizing quality difference between similar aggregates with various weathering levels, and differentiating good aggregates from poor ones at least 70 percent of the time. In addition, specification requirement of Micro-Deval loss values has been implemented by several state DOTs (such as Colorado, Texas, South Carolina, Montana, Oregon, Oklahoma, etc.) for acceptance of quality aggregates used in HMA. Furthermore, the Micro-Deval test is a rapid, simple test that can be completed in 2 days with standardized equipment and testing procedures (AASHTO TP 58 and ASTM D 6928-08). Smaller equipment size, lower sample quantities and a simpler procedure make the method easier and less costly to perform than conventional methods. This test gives a more reproducible result and is not "technician sensitive" based on results of bituminous aggregates from a total of 52 sources located in Texas, Oklahoma, Arkansas, New Mexico, and Missouri, USA [16].

The above-mentioned studies have shown successful applications of Micro-Deval test used in AC aggregate assessment. However, if the Micro-Deval test will provide a better means of establishing aggregate quality for use in Alaska AC pavement is unknown yet. Therefore, efforts are needed to evaluate the feasibility of utilizing Micro-Deval test to assess the aggregate durability in view of Alaska local materials and environmental conditions. There also needs to explore the possibility of using Micro-Deval test to replace Washington degradation test currently used by AKDOT&PF as a better alternative in the long run. For comparison purpose, other tests currently specified by AKDOT&PF are also evaluated including the LA abrasion and sodium sulfate soundness tests.

2 Objectives

The objectives of this present study are:

1) to evaluate the feasibility and reproducibility of using Micro-Deval test to assess Alaska Aggregates in AC pavement from different sources;

2) to compare and correlate different aggregate assessment tests currently specified by AKDOT&PF; and

3) to investigate whether the Micro-Deval test will serve as a better alternative to the Washington degradation test specified by AKDOT&PF.

3 Laboratory experiments

3.1 Materials

Sixteen batches of aggregates were selected from three Regions in Alaska: Central Region, Northern Region, and South-east Region defined by AKDOT&PF. Much of the interior of Alaska is underlain by thaw-unstable permafrost, thus the frost susceptibility is one of the key features that determines the applicability of an aggregate for construction use. A non-frost susceptible aggregate is defined to possess less than 3% of particles passing 0.02 mm sieve based on Casagrande's Criteria [17]. According to Table 1, four aggregates from Central Region, seven aggregates from Northern Region and five aggregates from South-eastern Region were selected in this study covering nine frost susceptible and seven non-frost susceptible materials that represent statewide sources.

The gradation of each aggregate is illustrated in Fig. 1. The dotted lines indicate the upper and lower limit for D-1 type base coarse aggregate specified in AKDOT&PF Standard Specifications [3]. It can be seen that most of the aggregates selected in this study fit the D-1 requirements while only a few slightly fall outside the gradation limits.

Table 1 Aggregate sources

aggregate ID	region	frost susceptible
C-1	central	yes
C-2		no
C-3		yes
C-4		yes
N-1	northern	yes
N-2		yes
N-3		yes
N-4		no
N-5		yes
N-6		yes
N-7		no
SE-1	south-eastern	yes
SE-2		no
SE-3		no
SE-4		no
SE-5		no

3.2 Testing procedures

Aggregate property tests were conducted on the selected materials including Micro-Deval, LA abrasion, Washington degradation, and sulfate soundness tests. All tests were conducted at University of Alaska Fairbanks (UAF) or AKDOT&PF materials laboratories according to appropriate testing standards, with three replicates for each sample.

3.2.1 Micro-Deval test

Micro-Deval test was conducted according to ASTM D6928 utilizing a Micro-Deval testing apparatus (Fig. 2).

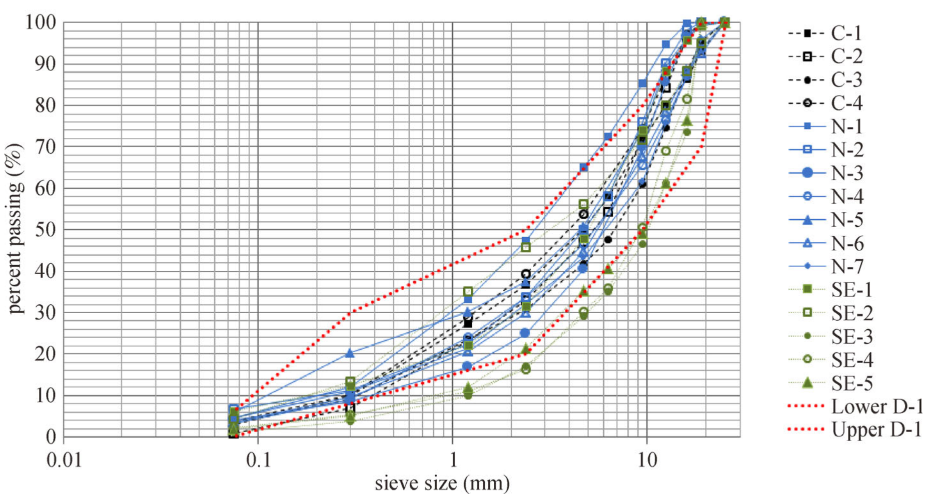

Fig. 1 Aggregate gradation

A sample with total mass of 1500 +/ − 5 g was selected, with the weight recorded as "A," and immersed in 2 L water for a minimum of 1 h in the Micro-Deval container shown in Fig. 2. Prior to starting the test, the container was charged with 5000 g steel balls. The whole test was run at 100 rpm for 2 h. Upon achievement of the set time, the sample was sieved by No. 4 (4.75 mm) sieve and steel spheres were manually removed. The remaining materials were then sieved by No. 16 (1.18 mm) sieve and passing materials were discarded. The materials retained on both No. 4 and No. 16 sieves were dried to a consistent mass at 110°C, weighed and recorded as "B." The calculation for Micro-Deval loss is expressed by Eq. (1). The higher the value, the more loss of an aggregate after abrasion in the presence of water.

$$micro\ Deval\ loss(\%) = \frac{(A-B)\times 100\%}{A}. \quad (1)$$

Fig. 2 Micro-Deval testing apparatus

3.2.2 LA abrasion test

The LA abrasion test was conducted conforming to AASHTO T96. A sample of 5000 g with specific gradation was loaded in a steel rotating drum charged with steel spheres and rotated for 500 revolutions at 30 to 33 rpm. Then the sample was washed, reduced and dried at 110°C to a constant mass. The materials retained on 1.7 mm (No. 12) and above were weighed. The LA abrasion loss value was calculated as the difference between original weight and weight after rotation divided by original weight times 100. The calculation was rounded to the nearest 1%. A higher loss value indicates that the tested aggregates are less abrasion resistant.

3.2.3 Washington degradation test

The Washington degradation test was carried out in accordance with ATM 313 [3]. A pre-treated sample was agitated, washed over No.10 sieve (2 mm), dried and reduced to a sample of 1,000 g. The sample was then washed with distilled water until the wash water was clear and had reached the 500 ml mark on a graduated cylinder. The solids in the graduated cylinder were put into suspension and poured into the Sand Equivalent cylinder with Stock Sand Equivalent Solution to the 15 in. mark. The height of the sediment was recorded to nearest 0.1 gradation mark. The degradation factor was determined following Eq. (2). The higher the degradation factor, the less degradable the aggregates can be.

$$D = \left(\frac{15-H}{15+1.75H}\right)\times 100\%, \quad ((2)$$

where D = degradation factor, and H = height of sediment in tube.

3.2.4 Sodium sulfate soundness test

Sulfate soundness test was conducted following procedures specified in AASHTO T104. Sodium sulfate solution was used in this study. First, the sample was oven-dried to a consistent mass and separated based on specific sieve sizes. Then the sample was soaked in a saturated solution of sodium sulfate for 18 h. Upon completion, the sample was removed from the solution and dried to a constant mass at 110°C. This cycle was repeated five times. The sample was then washed to remove the salt and dried. A loss for specific sieve sizes was determined as a percentage of the original mass. This test reveals an aggregate's resistance to disintegration by weathering such as freeze–thaw cycles. The higher the loss, the less resistant the aggregates can be.

4 Results and analysis

4.1 Results of Micro-Deval test

Table 2 summarizes the results of Micro-Deval test including the mean (% loss), the standard deviation (SD), and the coefficient of variation (COV). The COV indicates the variability of the test procedure. The higher the COV value, the greater the variability among replicates. As shown in Table 2, the average COV and SD for the Micro-Deval tests were 5.33% and 0.43%, respectively. These values were both lower than those from the LA abrasion tests presented in another study (i.e., 6.7% of COV and 1.7% of SD [18]). It should also be noticed that all COVs obtained in the present study were lower than 15% indicating good repeatability. These findings indicate that using Micro-Deval to assess Alaskan aggregates is feasible and reproducible.

Table 2 Micro-Deval testing results

aggregate ID	mean (% loss)	SD (%)	COV (%)
C-1	7.78	0.08	1.01
C-2	7.22	0.93	12.88
C-3	6.91	0.69	10.02
C-4	6.35	0.09	1.42
N-1	7.93	0.04	0.55
N-2	8.73	0.16	1.80
N-3	5.22	0.12	2.27
N-4	6.67	0.72	10.73
N-5	3.81	0.03	0.73
N-6	18.33	1.36	7.41
N-7	13.71	0.60	4.38
SE-1	5.36	0.15	2.82
SE-2	6.04	0.15	2.54
SE-3	7.15	0.88	12.33
SE-4	5.95	0.42	7.04
SE-5	6.84	0.50	7.28
average	7.75	0.43	5.33

4.2 Correlation of testing methods

Table 3 shows the recommended durability criteria for Micro-Deval, LA abrasion, Washington degradation, and sodium sulfate soundness tests for base course materials. Criteria for LA abrasion, Washington degradation, and sodium sulfate soundness tests were specified by AKDOT&PF, while the Micro-Deval criterion is based on the recommendation from Cuehlo et al. [18].

Table 3 Durability criteria for selected tests

testing parameter	Micro-Deval loss	LA abrasion loss	Washington degradation factor (*D*)	sodium sulfate loss
durability criteria	18% max	50% max	45% min	9% max

Table 4 presents the results of the LA abrasion, Washington degradation, and sodium sulfate soundness tests for aggregates from all 16 sources. Combining Table 2 and Table 4, it can be seen that most of these results fall within acceptable durability range presented in Table 3 regardless of testing methods. In addition, in most cases different tests show consistent results. For example, the N-5 aggregate had the lowest Micro-Deval loss (3.81% *vs.* 18% max criteria) indicating high resistance to abrasion and degradation. Meanwhile, similar results can be found from LA abrasion and Washington degradation tests (25% *vs.* 50% max and 88% *vs.* 45% min, respectively). However, results from different tests were not always consistent. For example, the N-6 aggregate failed to be acceptable according to the results from Micro-Deval and Washington degradation tests (18.3% *vs.* 18% max and 4% *vs.* 45% min, respectively). On the contrary, the LA abrasion loss of this aggregate was significantly lower than the specified criteria (21% *vs.* 50% max). Another example is the N-1 aggregate, considered acceptable by Micro-Deval and LA abrasion tests, but marked as unacceptable by Washington degradation test. This may be due to the different degradation and abrasion mechanisms of these tests. Thus, there is a need to conduct correlation analysis between different tests.

Table 4 Results of the LA abrasion, Washington degradation, and sodium sulfate soundness tests

aggregate ID	LA abrasion loss (%)	Washington degradation factor (D) (%)	sodium sulfate loss (%)
C-1	12	75	0
C-2	12	73	0
C-3	16	62	0
C-4	13	75	1
N-1	27	32	1.2
N-2	25	66	5
N-3	13	84	0
N-4	32	78	1
N-5	25	88	0
N-6	21	4	-
N-7	41	67	1
SE-1	13	48	0
SE-2	31	96	0.4
SE-3	14	54	1
SE-4	13	54	2
SE-5	12	51	1

Table 5 presents the results of correlation analysis. A correlation value (r) of 1 means that selected tests completely correlate, and a negative r value indicates an inverse correlation. It can be seen from Table 5 that higher correlations were found between results from the Micro-Deval test and other tests. The highest correlation value of −0.65 was found between Washington degradation and Micro-Deval tests, indicating a high potential of using the latter to replace the former. The value was negative since the Washington degradation test gives higher values for more durable aggregates while low values are obtained from the Micro-Deval test. It is odd, however, that the r value was positive between LA abrasion data and Washington degradation results.

A more precise method of comparing test data can be achieved by normalizing each test result to its standard limiting criteria for durability. For instance, the Micro-

Table 5 Correlation (r) between different durability tests

test method	Micro-Deval	LA abrasion	Washington degradation	sodium sulfate soundness
Micro-Deval	1.00	0.35	–0.65	0.35
LA abrasion	–	1.00	0.13	0.22
Washington degradation	–	–	1.00	–0.23
sodium sulfate soundness	–	–	–	1.00

Deval test result for aggregate from Granite Birchwood is 7.8% according to Table 4 and the maximum value is 18% according to Table 3, then the normalized value can be calculated as 7.8%/18% and 0.43 is obtained. The same calculation method can be applied to LA abrasion and sodium sulfate soundness tests. For these tests, a normalized value of 1 or greater indicates that the aggregate has a percent loss greater than the respective threshold and corresponding aggregate is considered non-durable. For the Washington Degradation test, the minimum value is specified as 45% (Table 3), so the normalized values are calculated as $(100-D)/(100-45)$ to receive comparable numbers. Since Micro-Deval is the testing method of interest in this study, comparisons in normalized values were made between Micro-Deval results and other results only as illustrated by Figs. 3–5.

The comparison between normalized values from Micro-Deval and LA abrasion tests is shown in Fig. 3. It can be seen that 15 out of 16 aggregates were considered durable under the criterion of both the two tests, indicating a high agreement (15/16, or 93.8%) regarding overall pass/fail determination. Inconsistency was found on only one aggregate, N-6, which was indicated durable (pass) by LA abrasion test but marked as non-durable (fail) by Micro-Deval test. The slope of the linear fit of the data was less than 1 (0.3217), indicating that the Micro-Deval test was more likely to fail than LA abrasion test. In another words,

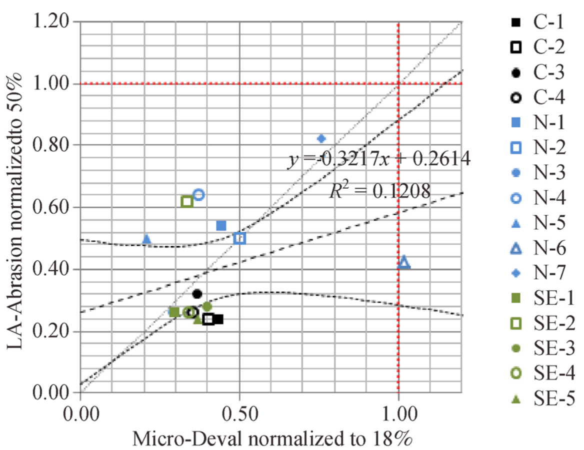

Fig. 3 Normalized LA abrasion vs. Micro-Deval results

the Micro-Deval test tended to provide more "conservative" assessment than the LA abrasion test. A poor R^2 value of 0.12 and the wide 95% confidence band range (black dashed curves) both indicated the overall poor correlation between these two tests.

Figure 4 illustrates the normalized comparison between the Micro-Deval and Washington degradation tests. Similarly, the two test methods were in high agreement (93.8%) regarding an overall pass/fail determination for 15 out of 16 aggregates. One aggregate (N-6) was found to fail both the two tests, while the other 14 were marked as "pass." However, the N-1 aggregate would be considered problematic because of the contradicting results obtained from the two tests. The linear fit of the data had a slope greater than 1 (1.3563) indicating the Washington degradation test was more likely to fail than the Micro-Deval test. However, the slope is also relatively close to 1 indicating a better correlation between these two tests than that shown in Fig. 3. The better correlation can also be reflected by a less scattered data with a relatively higher R^2 value of 0.416. This finding is consistent with that from Table 5.

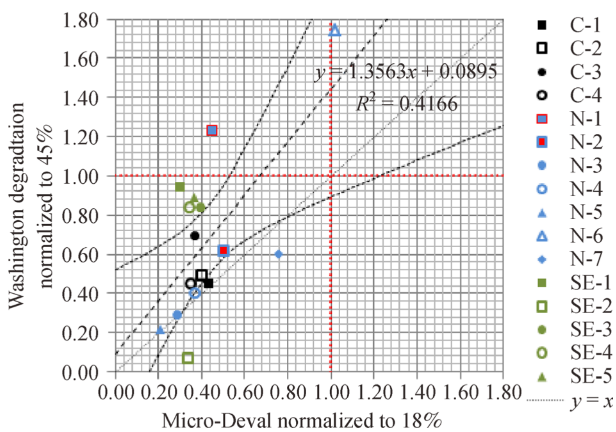

Fig. 4 Normalized Washington degradation *vs*. Micro-Deval results

As shown in Fig. 5, the Micro-Deval and sodium sulfate soundness tests had similar passing results with a 93.8% agreement rate. One aggregate (N-6) was considered problematic because sodium sulfate soundness test indicated an acceptably durable aggregate while the Micro-Deval test did not. The linear fit of the data had a slope less than 1 (0.4052) indicating the Micro-Deval test was more likely to fail than the sodium sulfate soundness test. A low R^2 value of 0.121 indicated poor correlation between the two tests.

The correlation analysis results indicated that the correlation between Micro-Deval test and LA abrasion test or sodium sulfate soundness test was fairly poor. This was expected since the three tests are designed to evaluate aggregate durability in different aspects. LA abrasion tests an aggregate's toughness and abrasion resistance in a dry

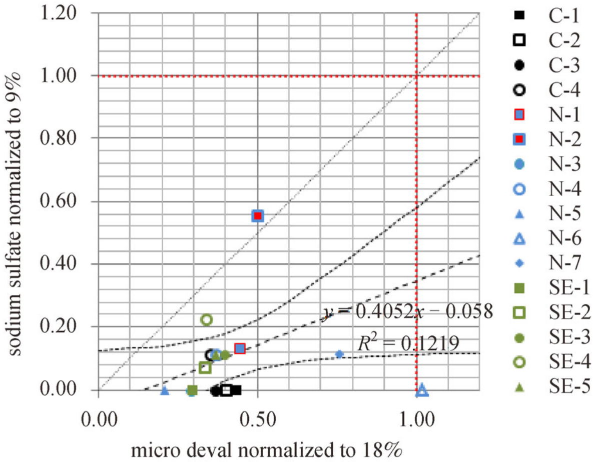

Fig. 5 Normalized sodium sulfate soundness *vs.* Micro-Deval results

environment while sodium sulfate soundness test mainly measures an aggregate's resistance to disintegration by freeze-thaw cycles. The Micro-Deval test, meanwhile, assesses an aggregate's resistance to degradations due to both mechanical abrasion and weathering. However, a relatively high correlation was observed between results from the Micro-Deval test and Washington degradation test. This indicated a high potential to use the former to replace the latter, since both the two tests were developed to evaluate the resistance to degradation in the presence of water. It should also be noted that the mechanism of Micro-Deval test is more sound and reasonable, which is to be presented in the following "Discussion" part.

5 Discussion

It is critical to select appropriate tests to characterize aggregate durability. According to guidelines proposed by NCHRP Report 453 [14], the qualified tests must relate to pavement performance, be consistent with the current state of knowledge and can be easily performed by most state DOT's. Meanwhile, in situ factors must be considered and the procedures should be as simple as possible [14].

According to the literature search by the research team, Washington degradation test has been used in Washington and Alaska only within the US Its applicability and consistency with the current state of knowledge may be limited based on Saeed et al.'s guidelines [14]. Johnson (Johnson E. Personal communication, Fairbanks, AK, 2012) pointed out that the original intent of using Washington degradation test in Alaska was to determine the general quality of aggregate pits. However, the results were in a broad range with poor repeatability and had more variations than other tests. The degradation test correlated fairly well with fines produced, but not well for specification. Bingham (Bingham N. Personal communication, Anchorage, AK, 2012) and MaHattie (McHattie R. Personal communication, Fairbanks, AK, 2012) further explained the mechanism of Washington degradation test. A higher sediment height (clay height) in the sand equivalent cylinder used in Washington degradation test leads to a lower degradation value, but may not indicate a higher degradation resistance. This is because the Washington degradation results calculated based on sand equivalent test is more dependent on the size or volume of the fines, rather than the quantity. It indeed measures how fine but not how much of the fines.

On the contrary, Micro-Deval test takes into account both weathering and degradations due to mechanical abrasion, which better simulates field performance during AC pavement placement and compaction, under traffic and in undesirable environment. Furthermore, the Micro-Deval test is a rapid, simple test taking only a couple of hours to complete (Schaefer H. Personal communication, Fairbanks, AK, 2012). Aggregate suppliers could run it more often to ensure compliance and state agencies could also perform quality checks on a more frequent basis or spot check more rapidly. Smaller equipment size, lower sample quantities and a simpler procedure make this testing method easier and less costly to perform than conventional methods, particularly Washington degradation test. Therefore, the potential of using Micro-Deval test to replace Washington degradation test in current Alaska specification can be very attractive.

6 Conclusions and recommendation

This study conducted a variety of durability tests on aggregates used in AC pavement from 16 sources in Alaska, including Micro-Deval, LA abrasion, sodium sulfate soundness, and Washington degradation tests. Based on the testing results and statistical analysis, the following conclusions can be summarized:

1) Using Micro-Deval test for durability assessment of Alaska aggregates was feasible and reproducible;

2) Micro-Deval test was in high agreement with any other testing methods currently specified in Alaska regarding an overall pass/fail determination in durability;

3) Micro-Deval tended to be more likely to fail than LA abrasion test and sodium sulfate soundness test, while was less prone to failure than Washington degradation test;

4) The best correlation was found between the Micro-Deval and Washington degradation tests, indicating a high potential to use Micro-Deval test to replace Washington degradation test in Alaska.

Our study along with practices from other states verified the feasibility and reproducibility of utilizing Micro-Deval test as a tool for assessing durability of Alaska aggregates used in AC pavement. It is recommended that Micro-Deval test be considered as an additional test for a certain period, thus allowing for a history of performance to be built as well as a comfort level with the results. Evaluation of aggregates from more paving projects in three regions of Alaska and also correlating to field performance of AC pavements where aggregates were used are needed to facilitate the implementation of specification requirement of Micro-Deval loss values for "good-performing" aggregates. It is suggested, in the long run, the Micro-Deval test along with current sodium sulfate soundness and LA abrasion be used to provide a more reliable assessment of Alaska aggregates' durability.

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