IDAHO TRANSPORTATION DEPARTMENT

RESEARCH REPORT

Study of the Idaho Degradation Test and Other Methods for Assessing Aggregate Quality

RP 313

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16. Abstract

The Idaho Degradation Test was modified to standardize the procedure and improve the repeatability of the test. An evaluation of the temperature and time needed for sample preparation was conducted to accelerate the test process. Based on a national survey conducted by the research group, the Durability Index and the Micro-Deval abrasion loss tests were selected as supplement tests. Twenty-five samples from sixteen aggregate sources selected by the Districts throughout the State were evaluated using the Modified Idaho Degradation Test (MIDT), the Durability Index, and the Micro-Deval Tests for both coarse and fine aggregates. The X-ray Diffraction (XRD) test, the petrographic analysis, and the methylene blue test were used to identify the mineralogy of the aggregates, the clay content, and the reactivity of the clay components. The results indicated by the change in P200 values before and after the MIDT (D_{P200}) values showed similar repeatability to the sieve test using a uniform gradation. The effects of clay on the SE values in the MIDT were highly rock-type dependent. Although the Durability Index (D_f) was also determined using the SE test, there were no strong correlations between the Durability Index and the SE values from the MIDT. While the percentages of abrasion loss of the coarse aggregate lacked a relationship to the D_{P200} values, there was a strong correlation between the abrasion loss of the fine aggregates and D_{P200} (R^2 ~0.94). This strong correlation was used to calculate the recommended acceptable specification values for D_{P200}.

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Technical Advisory Committee

Each research project is overseen by a Technical Advisory Committee (TAC) led by an ITD project sponsor and a project manager. The TAC is responsible for monitoring project progress, reviewing deliverables, ensuring that study objectives are met, and facilitating implementation of research recommendations, as appropriate. ITD's Research Program Manager appreciates the work of the following TAC members who guided this research study:

- Project Sponsor: Kandace Stewart, P.E., District 4 Design Construction Engineer
- Project Manager: Adrienne Woods, Environmental Planner and District 4 Material Source Manager
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List of Abbreviations and Acronyms

AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
BSU	Boise State University
DOT	Department of Transportation
FHWA	Federal Highway Administration
IAS	Idaho Asphalt Supply, Inc.
ITD	Idaho Transportation Department
MBV	Methylene Blue Value
MIDT	Modified Idaho Degradation Test
NCAT	National Center for Asphalt Technology
P200	Passing No. 200 Sieve
PM	Project Manager
RD&T	Research, development, and technology transfer
SE	Sand Equivalent
SP&R	State Planning & Research (FHWA)
TAC	Technical Advisory Committee
XRD	X-ray Diffraction

Executive Summary

In the late 1950s, Leif Erickson presented a paper to address the degradation of aggregates and recent road failures in Northern Idaho. He attributed this to an increase in material passing the #200 sieve and in the formation of plastic fines. The aggregate used in these projects came from sources that had favorable results with traditional durability testing (Los Angeles (L.A.) Abrasion, Soundness, Micro-Deval). Idaho needed a test to predict the degradation that caused these road failures. The Idaho Degradation Test (IT-15) is a modified version of a degradation test from Washington State DOT (Minor, 1960). This test is one of several tests used to qualify or disqualify aggregate sources and products. With time, the original research data and criteria that established the Idaho Degradation Specification have been lost. This lack of data prevents the Idaho Transportation Department (ITD) from fully understanding the significance of the test results.

The Idaho Degradation Test has vaguely defined procedures that may cause variability in results between individuals and labs, especially during sample preparation. This test was developed and implemented when ITD performed the source testing, and consistency may not have been an issue. Currently, it is unknown if variations are inherent in the test procedure or attributable to differences in how the test is being performed by the individual testing firms. This test needs validation to gain a better understanding of the test method and its results as they relate to aggregate quality. This research is the first step in quantifying the differences within the test, establishing a clear direction in preparing the aggregates for testing, and comparing results to other nationally recognized test procedures on the same material.

As Idaho's current aggregate sources become depleted and a need for developing new sources arises, ITD needs to ensure that the specification is established on sound and current data. ITD seeks to prevent low-quality aggregate on the roadways while allowing for an appropriately conservative specification. To reduce the risk of poor aggregate quality, ITD must remain vigilant by utilizing the most accurate test procedures to evaluate aggregate quality on unprocessed and crushed aggregates.

In this research, the Idaho Degradation Test was modified to standardize the procedure and improve the repeatability of the test. An evaluation of the temperature and time needed for sample preparation was conducted to accelerate the test process. Based on a national survey conducted by the research group, the Durability Index and Micro-Deval abrasion loss tests were selected as supplement tests. Twenty-five samples from sixteen aggregate sources selected by the Districts throughout Idaho were tested using the Modified Idaho Degradation Test (MIDT), the Durability Index Test, and the Micro-Deval Tests for both Coarse and fine aggregates. The X-ray diffraction (XRD) test, the petrographic analysis, and the methylene blue test were used to identify the mineralogy of the aggregates, the clay content, and the reactivity of the clay components. The results indicated that the change in P200 values before and after the MIDT (D_{P200}) values had similar repeatability to the sieve test using a uniform gradation. The effects of clay on the SE values in the MIDT were highly rock-type specific. Although the Durability Index (D_f) was also determined using the same setup as the Sand Equivalent (SE) test, there were no strong correlations

between the Durability Index and the SE values from the MIDT. While the percentages of abrasion loss of the coarse aggregate determined by the Micro-Deval Test lacked a relationship to the D_{P200} values, there was a strong correlation between the abrasion loss of the fine aggregates from the Micro-Deval Test to D_{P200} determined from the MIDT (R^2 ~0.94). This strong correlation was used to calculate the recommended acceptable specification values for D_{P200}.

Main Findings

- The Idaho Degradation Chart, developed based on the data from the Idaho Degradation Test, was not helpful in setting numerical limits for the Idaho Degradation Test.
- There was no available research or written document on selecting the numerical limits used in the current specifications.
- Research project 029 failed to develop or suggest numerical specifications for the Idaho Degradation Test due to a lack of correlation between test methods.
- The specification of the current Idaho Degradation Test needs to be clarified and standardized.
- A uniform gradation is needed to increase the repeatability of the Idaho Degradation Test.
- Based on the survey conducted in this research on degradation tests nationwide, almost all states use the L.A. Abrasion test in testing Aggregate Degradation. However, this test does not address ITD's need for a wet abrasion test.
- There were significant variances in degradation test methods among agencies.
- The Research Team developed the new procedure for the MIDT by clarifying the language in the current Idaho Degradation Test.
- A uniform gradation was selected for the MIDT.
- An evaluation was conducted to change the test procedure to shorten the testing time by increasing the drying temperature from 60°C to 110°C and lower aggregate socking time from 16 hours to 1 hour. Based on the evaluation, the research group selected 110°C as the drying temperature and 16 hours as the soaking time.
- XRD can be used to identify not only the total clay content but also the mineralogy of various clays in the P200 material.
- Petrographic Analysis can be used to narrow down the causes of poor degradation. Due to the limitation of the sample size, the cause may not be identified.
- The Methylene Blue Value (MBV) provides a quick and easy method to identify the clay's reactivity, which can determine the total effect of different clays on aggregate performance.

- There were large spreads in test data of D_{P200}, the SE values before and after the MIDT (SE_B and SE_A). No significant correlations between D_{P200} and SE values were established, which indicated that the MIDT can be used to differentiate aggregate samples.
- The relationships between D_{P200} and SE values are related to differences in the type of rock.
- The SE specifications (SE_B > 30% and SE_A > 25%) should be used as relative indications of the aggregate's sustainability to degradation.
- Crushing increased the results of D_{P200} by 1%.
- The effect of clay content on the MIDT results is also rock-type dependent.
- There are significant differences between the average Durability Index values (D_c and D_f) in this project versus the results from ITD RP029. This indicated that there might be mistakes in the test method on the Durability Index Test used in ITD RP029.
- The Durability Index Test (AASHTO T 210 and CTM 229) is not a suitable replacement for the MIDT.
- The Micro-Deval Fine Aggregate Test (ASTM D7428) is a suitable substitute or companion test for the MIDT.

1. Introduction

Problem Statement

ITD's IT-15 test was developed to identify problematic basalt aggregates that caused significant early failures in base layers from 1954 to 1955 (Day, 1962; Collett, Warnick, and Hoffman, 1962). The Idaho Degradation Test was developed based on pavement needs and ITD's business model in the 1960s. It was used as a screening test to predict the degradation potential of the aggregate in a candidate aggregate source. If the Idaho Degradation sample failed, the department would evaluate the decision to purchase that aggregate source based on the differences between the failed test result and the specification and the availability of other materials sources in the area. The District Materials Engineers selected or designated one or more ITD-controlled materials sources for each project's materials needs. Since ITD designated materials sources, the Idaho Degradation test was conducted only by ITD at the source acquisition or approval level. If the Contractor mined material from the location designated on the ITD Materials Source Plat and crushed the material according to the product specification, ITD was confident that the aggregates would meet the quality requirements.

In the late 1990s, ITD began requiring the Contractors to provide their own materials sources, referred to as Contractor-furnished or Contractor-provided sources, for all projects. This changed the way ITD accepted materials. Instead of designating a source that ITD had developed and tested, the burden of providing acceptable material was now on the Contractor. ITD was no longer the only lab doing Idaho Degradation testing. Consulting firms and Contractors testing labs were now required to purchase, modify other test equipment, or build an Idaho Degradation machine. Shortcomings of the T-15 test became apparent when multiple labs and testers began testing aggregates and getting varying results.

The degradation test used by ITD (IT-15) has not been significantly modified in test equipment, test procedures, and reports since its creation in 1958 (Appendices A and B). This test still reflects the circumstances that were present when it was developed. The procedures in the specifications have created confusion among practitioners in preparing the test samples and disagreements among engineers about the specification limits presented in ITD's specification book, which makes IT-15 highly technician-dependent and low reproducibility among laboratories. Several of the key problems regarding IT-15 are listed below:

- Non-Standardized Testing Equipment due to Rotational Action: IT-15 was modified from Minor's degradation factor test on similar aggregates, using the Deval tester and rotating the jars in an end-over-end fashion to allow more samples to be run simultaneously (Day, 1962). The modified Deval wet abrasion tester was fabricated in-house and was modified over the years. Although certain parts were replaced, it is essentially the same piece of equipment used since the beginning of this test. The test rotational speed, pattern, and setup were all designed based on the Deval Abrasion Tester, which could no longer be purchased domestically.

- Lack of Clear Definitions in the Testing Procedure: The Idaho degradation Testing was performed in the Aggregates Laboratory by the same technicians working in the lab when the test was being developed or learned from those who created the test. By the mid to late 1990s, these longtime ITD Headquarters lab technicians began to retire, and the interpretation of the testing procedure was lost during this period. The procedure by itself provided limited guidance in sample preparation. For example, drying aggregate in an oven at 140°F is time-consuming. There is no guidance on the drying time needed to achieve the "dry state".
- No Guidance on the Calculation of the Results: The report section of IT-15 is poorly written and confusing. The amount of degradation is defined as "the difference in test values." ITD's current specification on aggregate only listed a maximum % loss without any explanation of the calculation of the results (ITD, 2023). In the initial development of the test, these results were designed to be used to categorize the aggregate source into A, B, and C zones to rank the quality of the aggregates (Day, 1962). However, the current specification has no instruction on such efforts, which produces confusion in interoperating the data.

The Idaho Degradation Test was developed in the 1960s based on pavement needs. Today, with higher traffic volume and much higher axle loads, the test, as it is currently written, does not adequately meet the department's current needs. ITD needs to reevaluate the Degradation test based on the current aggregate properties in the State of Idaho and design a more reliable test method to prevent poor pavement performance due to aggregate degradation.

Research Objectives

Standardize the Test Procedure of the Idaho Degradation Test

As indicated in the previous section, the IT-15 procedure was not written with the current testing needs in mind. IT-15 needs updated procedural language to clarify the process.

Modify the Idaho Degradation Test to Increase the Repeatability and Reproducibility

Best practices must be used to develop procedures for conducting the tests consistently, improving the repeatability of the results and reproducibility of the Idaho Degradation Test.

Establish Proper Test Criteria for the Idaho Degradation Test

The current specification on the Idaho Degradation test requires the change in % P200 to be less than 5% or 8% based on the applications. The reason why these values were selected is no longer known. A detailed, scientific explanation is needed.

Evaluate the Alternative Degradation Test

The Idaho Degradation Test is not an AASHTO or ASTM test, as is the Micro-Deval test or the Durability Index test method. The research team incorporated the Micro-Deval test and the Durability Index test as possible alternatives.

Understand the Effect of Clay Mineralogy on the Degradation Test

To understand the effect of clay mineralogy on aggregate degradation, petrographic analysis was used to identify the clay and clay-like minerals in Idaho's aggregates (Day, 1962). X-ray Diffraction (XRD) was used to determine the mineral structure of the clay.

Research Approach

Task 1: Project Kick-Off Meeting

In this task, the researchers conducted a meeting at the start of the project with the ITD Project Manager (PM) and the members of the Technical Advisory Committee (TAC) to discuss the following:

- Project tasks and deliverables
- Project schedules and timelines
- Data and information needs
- Data management plan
- Staff responsibilities and assignments
- Proposed schedule for project meetings
- Communication plan and expectations.

Task 2: Literature Review

The research group performed a review of applicable literature and provided a written summary of the following subjects.

- The implementation history of the Idaho Degradation Test.
- The review of ITD research programs regarding the Idaho Degradation Test to understand the test methodology, the test criteria, and the practices in Idaho.

- The summary of the survey sent out to DOTs on the current practices on aggregate degradation tests throughout the nation.

After presenting the review, the research group met with the ITD Project Manager (PM), the Technical Advisory Committee (TAC), and the Research Program staff. The TAC evaluated and revised the project tasks based on the literature review.

Task 3: Tests and Material Source Selection

The research group worked with the PM and collected materials from sixteen (nine gravel sources and seven quarry samples) material sources covering all six districts of ITD. The research team presented a sub-work plan with the suggested changes in the testing procedure for the Idaho Degradation Test. Based on the literature review, the current Idaho Degradation Test was modified. At the same time, the Micro-Deval tests (AASHTO T 327 for Coarse Aggregate and ASTM D7428 for Fine Aggregate) and the Durability Index test (AASHTO T 210) were chosen as the alternative or companion test methods for the Idaho Degradation tests.

Task 4: Testing

Upon receiving the PM's approval of the sub-work plan, the research team conducted the tests and presented the proposed Modified Idaho Degradation Test (MIDT). The TAC approved such changes, as well as the test plan for the rest of the project. A total of twenty-five samples were prepared (sixteen crushed samples (gravel and quarry) and nine uncrushed samples (gravel sources)). For each sample, the following tests were conducted: the MIDT, the Mico-Deval Tests (Coarse and Fine), and the Durability Index Test (Coarse and Fine).

Task 5: Clay Identification

Petrographic analysis and XRD were used to identify the clay mineralogy of the samples. The MBV test was also conducted. These results were used to analyze the mineralogy of the rock, the clay content, and the clay components in each sample.

Task 6: Data Analysis

The research team analyzed data to assess the accuracy and reliability of the Idaho Degradation Test and compare all results. The results of this analysis were presented quarterly to the PM and the TAC. The TAC provided feedback to ensure the analysis was comprehensive and adequate, and the researchers incorporated that feedback for subsequent analysis.

Task 7: Recommendation for Implementation

Using analysis from Tasks 4 - 6 above, the research team developed a revised, well-documented MIDT method with suggested supplemental tests to assess aggregate quality.

Task 8: Provide Training to ITD Staff

Following recommendations in Task 7, the research group prepared a video for conducting the MIDT for ITD staff on the processes and procedures of the updated test method.

Task 9: Prepare the Draft Report

The researchers prepared a draft report that included the research methodology, results, analysis, findings, and recommendations. The report covered all aspects of the project and summarized information and data found in the research.

Task 10: ITD Initial Review of Report Draft

The research team submitted the draft report to ITD and the research team for initial review.

Task 11: Revise the Draft and Present the Final Report

The final report document incorporated feedback and addressed any concerns identified by ITD during the initial review of the draft report.

Report Organization

This report consists of seven chapters and twelve appendices.

- Chapter 1 introduces this research project. It presents the problem statement, project objectives, work plan, and report organization.
- Chapter 2 conducts a literature review of the history, previous studies, and research on the Idaho Degradation Test. It summarizes the survey results conducted by the research team on the current practices of degradation tests throughout the nation.
- Chapter 3 presents the materials used in this research.
- Chapter 4 discusses the test methods involved in this research.
- Chapter 5 explains the development of the Modified Idaho Degradation Test (MIDT).

- Chapter 6 analyzes the data obtained in this research, studies the effects of different aggregates, and conducts statistical comparisons among different test methods to identify the suitable method.
- Chapter 7 summarizes the main findings from this project, suggests the criteria for implementing the modified test procedure, and presents recommendations for future work for ITD consideration.
- The appendices provide additional information and figures that were cited and discussed in this report.

2. Literature Review

Pavements are designed as load-bearing structures that maintain contact with the wheels. Aggregates are the principal components of an asphalt pavement structure that supports loads and distributes them to the prepared roadbed. Aggregate properties play major roles in the long-term performance of pavements. One of the critical characteristics is an aggregate's ability to resist degradation. Aggregates with low degradation resistance tend to experience particle breakdown that subsequently leads to gradation changes and adversely alters the function of the pavement structure. Some of the harmful effects that degradation can create are (West, et al, 1970):

- Raveling and instability in asphalt mixes.
- Loss of base course support.
- Excessive and differential settlement.
- Reduction of drainage.
- Creation of frost-susceptible material.
- Distress in Portland cement concrete.

Aggregate's degradation resistance is often defined as interchangeable with the durability of the aggregate (Hveem and Smith, 1964; West, et al. 1970; Weyers, et al. 2005, Willams and Cunningham, 2012; Wu, et al. 1998). Both terms are used to describe the deterioration of aggregate properties under internal stresses (volume changes caused by chemical reactions such as oxidation, carbonation, and silicification, or weathering such as freezing and thawing, repeated wetting and drying) and external stresses (wear caused by mechanical elements: surface abrasion, impact, shearing, crushing, compaction, and repeated loading), As summarized by Adrienne Woods (the Project Manager of this research project), "the chemical and/or physical deterioration of an aggregate that will compromise the intended use".

The focus of this project is on the aggregate degradation and deterioration caused by external stresses induced by mechanical/non-chemical reasons, which include 1) wear: rotation, rearrangement, or relocation of particles, and 2) breakage: when the mechanical action of traffic or the contact pressure exceeds the strength or toughness of the particles (Mainfort and Lawton, 1953; Erickson, Lief F., 1958; Moavenzadeh and Goetz, 1963; Aughenbaugh, et. al., 1966; Novak and Mainfort, 1966; Deen and Southgate, 1972). "Degradation" is then considered as "A breaking down and/or disintegration of particles of sand, gravel, or stone, primarily due to the alteration and subsequent decomposition of their mineral components, accelerated by the action of mixers, mechanical equipment, traffic or the elements" (Erickson, Lief, F. 1960; Day, H. L., 1962).

Review of the Idaho Degradation Test

Development of the Idaho Degradation Test

The Idaho Degradation Test was developed to identify the problematic basalt aggregates that caused significant early failures in base and HMA layers in the latter half of the 1950s (Erickson, 1958; Erickson, 1960; Collett et al., 1962; Day, 1962). Researchers from different states in the northwestern region indicated that the increase in the number of plastic fines under repeated traffic loading was one of the key causes of these failures (Minor, 1960; Ekse and Morris, 1960; Collett et al., 1962; Dunn, 1969; Burchfield and Hicks, 1981). As early as 1956, the Idaho Transportation Department (ITD) initiated its degradation testing using either the kneading compactor or the Los Angeles (L.A.) Abrasion tester (Erickson, 1958). The standard specification for the Idaho Degradation Test in 1958 (IT-15-58) listed both machines as options for conducting the degradation test (Erickson, 1960). The aggregate sample for the test was combined using the following gradation:

- 16% passing the ¾ in. sieve and retained on the ½ in. sieve.
- 17% passing the ½ in. sieve and retained on the 3/8 in. sieve.
- 17% passing the 3/8 in. sieve and retained on the No.4 sieve.
- 50% passing the No. 4 sieve.

For the Idaho Degradation Test conducted using the Kneading Compactor, the sample was mixed with sufficient water to get a moisture content slightly higher than the optimum moisture content. The sample was compacted in a 4-inch steel mold under 1000 blows at 250 psi pressure. For the Idaho Degradation Test conducted using the L.A. Abrasion tester, a 30-lb oven-dried sample (maximum drying temperature 140°F (60°C)) was tested under 1000 revolutions without steel balls. For both test conditions, the amount of degradation was indicated by 1) the gradation changes at each sieve (not only No. 200); and 2) the change in Sand Equivalent (SE) before and after the test. Even without the steel balls, the L.A. Abrasion test produced more materials passing the No. 200 sieve than the results from the Kneading Compactor method (Erickson, 1958). Although the tests simulated both the impact from the compaction and the grinding and abrasion actions between aggregate particles, the abrading conditions caused by both machines were considered too severe, and both tests were abandoned and replaced by a wet abrasion testing process (Day, 1962).

In 1959, Minor in Washington State DOT developed a new degradation test using the Degradation Factor calculated from the quantity and quality of the manufactured fine through wet abrasion (Minor, 1960). ITD modified Washington's procedure and developed an updated Idaho Degradation Test (Day, 1962). Table 2.1 lists the key differences between these two tests. Day also developed a chart to plot the test results based on the SE results and the minus 200 numbers before and after the tests (Day, 1962). The results can be divided into three different zones: Zone A, where the aggregate has a large decrease

in sand equivalent; Zone C, where the aggregate has an excessive increase in minus 200; and Zone B is the desired area where the limits have not been exceeded (Figure 2.1). The limits of these zones were arbitrarily determined by considering the test values from aggregate sources with marginal and poor service records.

Table 2.1: Washington Degradation Factor vs. Idaho Degradation Test (Minor, 1960; Day, 1962)

	Washington Degradation Factor	**ITD Degradation Test**
Sample Size	1000 g	1100 g
Sample Gradation	500 g ½ in. to ¼ in. 500 g ¼ in. to No. 10	183 g ¾ in. to ½ in. 183 g ½ in. to 3/8 in. 184 g 3/8 in. to No. 4 550 g minus No. 4
Sample Preparation	Washed and Dried	Dried and not Washed
Sample Drying Temperature	230 °F	140°F
Sample Conditioning Time in Water	None	16 hrs.
Container	1 gal Glass or Polyethylene Jar with a rough interior	1 gal Glass Jar in Reference, but no mention of material in standard
Rotating axis	Longitudinal	End over end
Rotating time	1 hr. at 28 to 30 rpm	1850 rotations at 30 to 33 rpm
Final Results	Calculated through measured final SE	SE and P200 before and after
Total Testing Time	2 days	3 days

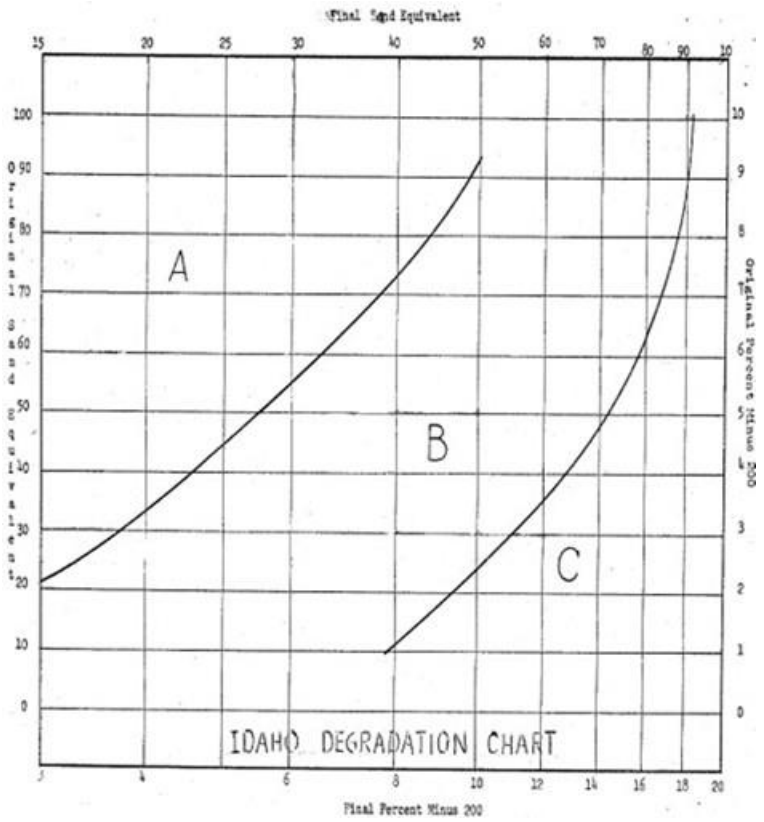

Figure 2.1: Idaho Degradation Chart (Day, 1960; Howard, 1966)

The test method of the Idaho Degradation Test has stayed virtually unchanged since the 1960s. Appendix A lists the 1995 version of the ITD IT-15 (ITD, 1995). Appendix B lists the 2019 version of the ITD IT-15 (ITD, 2019). Version 2019 is the current version of the procedure for the Idaho Degradation Test used by ITD. The procedures in the specifications for both 1995 and 2019 show no significant changes to the original procedure presented in Day's paper.

In the 1995 and 2019 versions, three blending ratios were used to batch an 1100 g sample for testing:

- ½ in or larger size aggregate shall have the following gradation:

  16.6% passing the ¾ in. and retained on the ½ in. …… 183 g

  16.6% passing the ½ in. and retained on the 3/8 in. …… 183 g

  16.7% passing the 3/8 in. and retained on the No. 4 …… 184 g

  50% passing the No. 4 …… 550 g

- 3/8 in. size aggregate shall have the following gradation:

  25% passing the ½ in. and retained on the 3/8 in. …… 275 g

  25% passing the 3/8 in. and retained on the No. 4 …… 275 g

  50% passing the No. 4 …… 550 g

- No. 4 size aggregate shall have the following gradation:

  50% passing the 3/8 in. and retained on the No. 4 …… 550 g

  50% passing the No. 4 …… 550 g

The three blending ratios are designed to target different applications: the ratio for ½ in or larger size is for standard source approval, HMA, and Rock Cap; the ratio for 3/8 in. aggregate is for anti-skid and cover coat; and the ratio for No. 4 size aggregate is designed for slurry, blotter sand, and mortar sand.

Determination of Specification Limits of the Idaho Degradation Test

In Day's initial paper, the limits to determine the Zones were only explained as arbitrary limits that "were determined by considering the test values for sources with marginal and poor service records" (Day, 1962). There was no equation or detailed explanation to show the calculations of these limits. No numerical values for the standard requirements of the Idaho Degradation Test were given due to the lack of testing data when the paper was published. Although no standard values were established, a reduction of SE to less than 30% and an increase of P200 by 5% were used to determine the Degradation potentials of different aggregates by ITD (Howard, 1965).

Research Project 029 on the Idaho Degradation Test

In 1965, ITD started Research Project (RP) 029 to clarify these issues (Howard, 1966). The goals of this research project were a) to create a finite number value to be assigned to the Idaho Degradation Test, or b) to substitute the Idaho Degradation Test with the California Degradation Test (Hveem, 1964) if needed. Twenty aggregate sources throughout Idaho were selected, with degradation potentials ranging from "acceptable" to "undesirable". The Idaho Degradation Tests were conducted on both unwashed samples with passing No. 200 sieve materials (P200) and washed samples (without P200). All samples were also evaluated using the California Degradation Test, which was the initial version of both Caltrans CTM 229 and AASHTO T 210 test methods.

All aggregate sources used in the project were blended using the same ratio used in Day's paper to meet a ¾ in Nominal Maximum Size Type B Aggregate Base Course. Surface area (S.A.) and fineness modulus (F.M.) were also calculated on gradation before and after each test. Table 2.2 lists the key differences among the tests used in RP029.

Table 2.2: California Degradation Test and Idaho Degradation Test (ITD, 1966)

	California Degradation Test (Coarse)	**California Degradation Test (Fine)**	**ITD Degradation Test (Unwashed)**	**ITD Degradation Test (Washed)**
Sample Size	2500 g	500 g	1100 g	1100 g
Sample Gradation	1050 g ¾ in. to ½ in. 550 g ½ in. to 3/8 in. 900 g 3/8 in. to No. 4	Minus No.4 from the aggregate as is	183 g ¾ in. to ½ in. 183 g ½ in. to 3/8 in. 184 g 3/8 in. to No. 4 550 g minus No. 4 (With P200)	183 g ¾ in. to ½ in. 183 g ½ in. to 3/8 in. 184 g 3/8 in. to No. 4 550 g minus No. 4 (Without P200)
Sample Preparation	Oven Dried and Washed	Oven Dried and Washed	Oven Dried	Oven Dried and Washed
Sample Drying Temperature	230°F (110°C)	230°F (110°C)	140°F (60°C)	140°F (60°C)
Sample Conditioning Time in Water	1 min.	2 hrs.	16 hrs.	16 hrs.
Total Testing Time	2 days	2 days	3 days	3 days

Although the research showed that the California Degradation Test was much easier to run than the Idaho Degradation Test, the ratings from the results of the California test did not coincide with the field performance of the aggregates (Appendix C). The results showed a significant spread between the values of D_c and D_f from the same aggregate, which indicated that the California Degradation Test Method might not be suitable for evaluating Idaho's aggregates. After further reviewing the report, the spread of the data might be caused by two deviations from the standard testing procedure in the steps of preparing aggregate samples for determining D_f.

1. In the correct steps of CTM 229 and AASHTO T 210, the fine aggregate should only be shaken for 2 minutes before the modified SE test. The aggregates were then evaluated as a regular SE sample with only one modification in the steps: being abraded in the mechanical shaker for 10 minutes instead of 45 seconds to simulate the aggregate abrasion (Hveem, 1953; Hveem and Smith, 1964). In Step 7 of Part 1 (b) of Section I (C) in Appendix B of the report of RP029, the fine aggregate for the California Degradation Test was first shaken inside the sieve shaker for 20 minutes instead of 2 minutes (Howard, 1966). The extra 18 minutes of shaking in the sieve shaker might have produced a higher number of fines.

2. Per the procedures used in RP029, the passing #200 fines were added back into the samples before the SE test, while the fines were discarded in the correct procedure. The added fines produced even lower D_f values and resulted in more tests with "poor" ratings.

A fresh evaluation of the Durability Index test using AASHTO T 210 is recommended to correctly determine the feasibility of using it to evaluate the degradation of aggregates in Idaho.

The results from RP029 also indicated that the rating of "Good" and "Poor" assigned by the unwashed and washed methods of the Idaho Degradation test demonstrated a poor correlation with the rating from the service reports. Using the guidance of an increase in P200 of no more than 5% and a SE value higher than 35%, both the unwashed and the washed Degradation Tests produced five incorrect ratings. Although 75% accuracy was still positive for research purposes, it did not provide a high confidence for these numerical limitations to be used as the specification requirements. The division of Zone A, B, and C did not indicate a good correlation with field performances either. Seven of the twenty ratings did not match field estimations, which produced a lower rating of 65% accuracy. The unwashed results from the Idaho Degradation Test suggested a simple mathematical calculation method to assign an acceptable or undesirable rating to the test results (Figure 2.2). Figure 2.2 indicates the comparisons between the original SE and the final SE, and between the original P200 and the final P200 for the unwashed aggregates. Based on both Figures 2.1 and 2.2, the Zones A, B, and C for degradation potential were divided based on the following equations:

Zone A and Zone B: $y_2 = m_2x_2 + b_2$ or Original SE = 1.96*(Final SE) – 5.88

Zone B and Zone C: $y_1 = m_1x_1 + b_1$ or Original P200 = 0.657*(Final Original P200) – 4.14

In Zone A (Too much drop in SE): $y_2 > m_2x_2 + b_2$, Original SE > 1.96*(Final SE) – 5.88

In Zone C (Too much increase in P200): $y_1 < m_1x_1 + b_1$, Original P200 < 0.657*(Final P200) – 4.14

In Zone B, or the good area:

The following two conditions must be met:

$y_2 \leq m_2x_2 + b_2$, Original SE ≤ 1.96*(Final SE) – 5.88

$y_1 \geq m_1x_1 + b_1$, Original P200 ≥ 0.657*(Final P200) – 4.14

Based on the above equations, for an aggregated to be considered as "good" or desirable",

$$Final\ P-200 \leq \frac{Original\ P-200+4.14}{0.657} \quad (1)$$

$$Final\ S.E. \geq \frac{Original\ S.E.+5.88}{1.96} \quad (2)$$

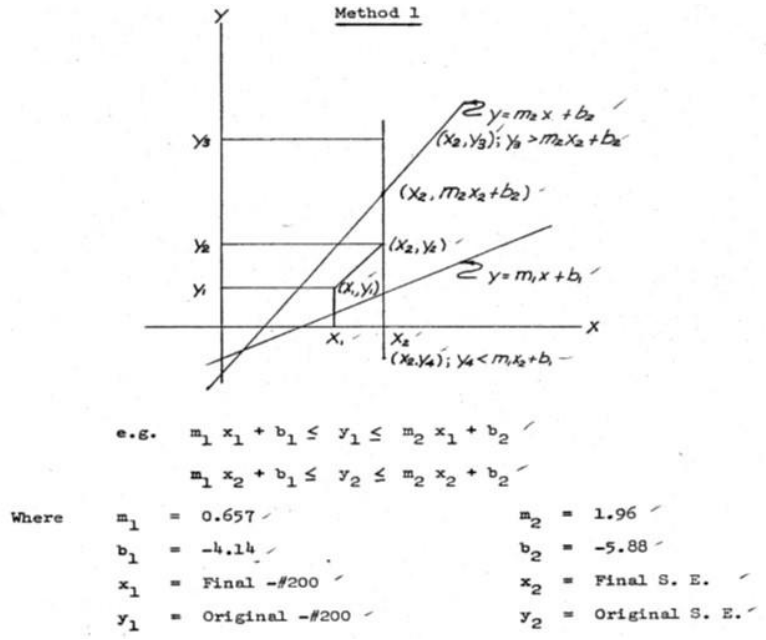

Figure 2.2: Mathematical Formula to Determine the Degradation Potential (Howard, 1966)

The researchers of RP029 indicated that the above rating measurements showed promise in setting the specification limits. The results obtained from plotting the original SE against the final SE, and the original P200 against the final P200 of the unwashed Idaho Degradation Test showed high correlation coefficients (Figure 2.3). The R^2 value for P200 data was 0.77, while the R^2 value for SE values was 0.86. Figure 2.3 was reconstructed based on the data in the report due to the missing of the related figure in the report. The difference in dividing lines between Figure 2.1 and Figure 2.3 was caused by the scales in the primary and secondary horizontal axes.

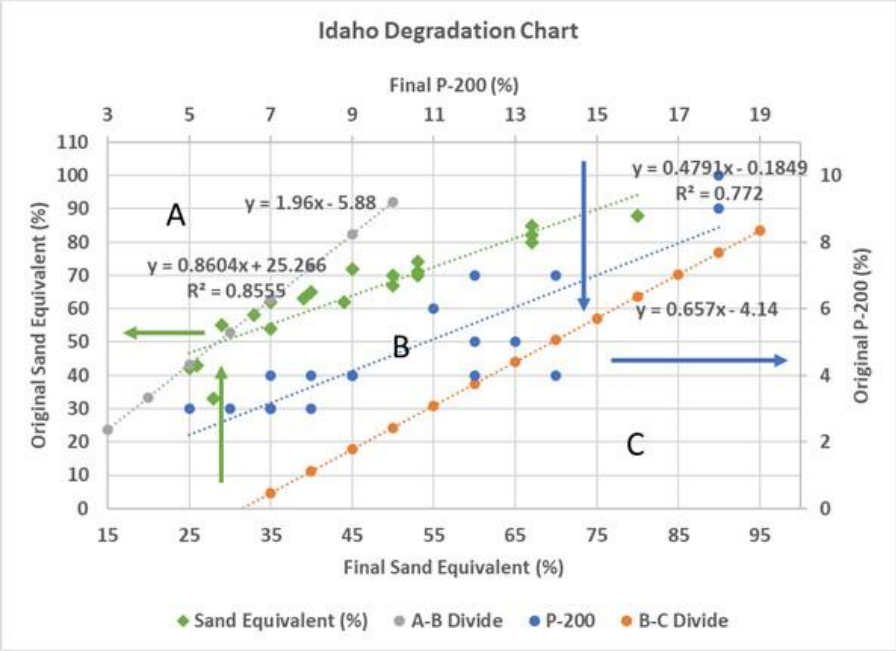

Figure 2.3: Testing Data in Idaho Degradation Chart (Linear Scale)

Figure 2.4 shows the correlated data under logarithmic scales. The researchers of RP029 recognized that these limits were estimated based on field performances or service records of different aggregates and suggested that a yearly review or evaluation is needed to revise the zone limits from time to time. Based on the data in Appendix C, a new correlation was proposed for Final P200.

$$Final\,P-200 \leq \frac{Original\,P-200.+4.7}{0.85} \qquad (3)$$

Using equation (3), sixteen ratings based on the zones showed a one-to-one correlation with the service report. The comparative rating improved from 65% to 80%. Figure 2.5 shows the updated Idaho Degradation Chart based on the new equations.

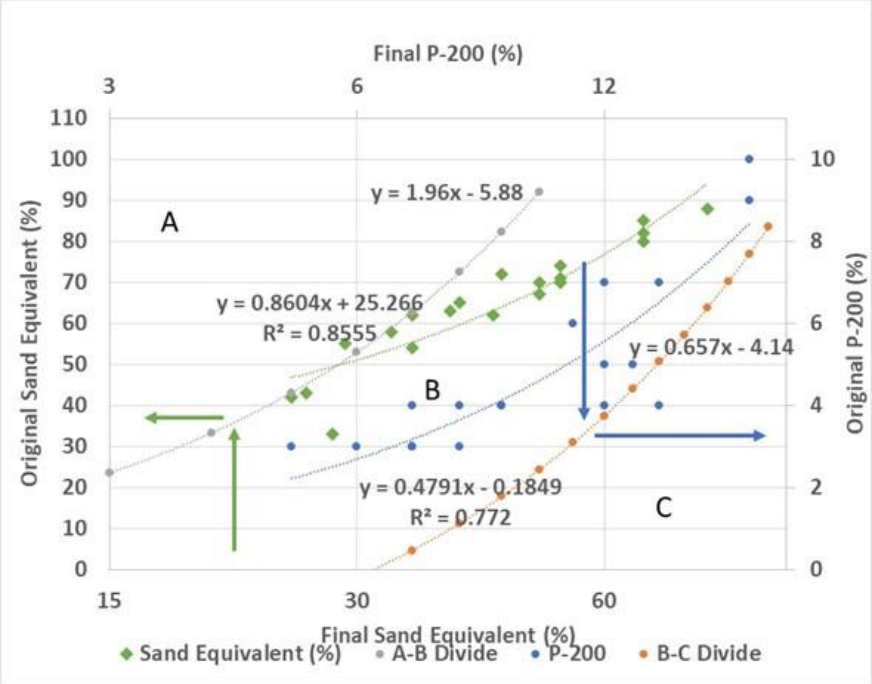

Figure 2.4: Testing Data in Idaho Degradation Chart (Logarithmic Scale)

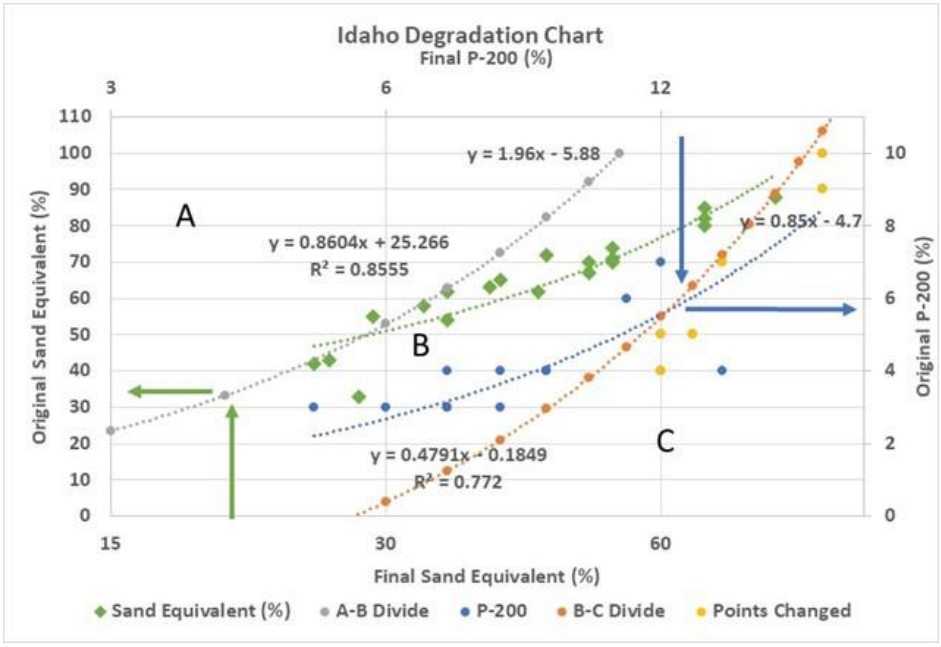

Figure 2.5: Testing Data in Updated Idaho Degradation Chart (Logarithmic Scale)

Research project 029 failed to develop or suggest numerical specifications for the Idaho Degradation Test and the unwashed aggregate test was kept as the procedure for the test. An increase in No. 200 of 5% and a drop in SE to less than 30% had since been considered by ITD as a warning that serious degradation might occur in service (Howard, 1965). However, the higher P200 or lower SE did not

exclude the possibility of using these aggregates in pavement structures. The failed or questionable aggregates could be used by either wasting the fines to meet the limits before use or proceeding with additives such as cement, lime, or asphalt (Howard, 1965; Sylvies, 1972).

Changes in the Standards of the Idaho Degradation Test

The Idaho Degradation Test's specification requirements stayed virtually the same from 1995 to 2007 (Table 2.3), and they remained the same for different aggregate applications.

Table 2.3: Idaho Degradation Test Specification (1995 to 2007) (For all aggregate sources)

Original P200 (%)	Final P200 (%)	Original SE (%)	Final SE (%)
5 to 8	No greater than Original plus 5	40 or above	30 min
9	14 max.	36 through 40	30 min
10	15 max.	30 through 35	25 min

In the supplemental specifications published in January 2008, the requirements on SE were removed from the specification book (ITD, 2008). Table 2.4 lists the specification requirements of the Idaho Degradation Test that have been used from 2008 to the present. The main reason for eliminating the SE tests was to shorten the time needed to complete the test. ITD Headquarters (HQ) lab was conducting verification testing on the aggregates. The contractor had already eliminated any source or material that did not meet specifications. Therefore, ITD HQ Lab believed that cutting the SE tests would not negatively impact the accuracy of the test. (Mike Santi, Phone Conversation with author, July 22, 2023).

Table 2.4: Idaho Degradation Test Specification (2008 to 2023)

Aggregate Type	Difference Between Final and Original P200 (%)
Fine and Coarse Aggregate for Concrete	5
Aggregate for Untreated Base, Treated Base, and Road Mix	8
Aggregate for Superpave HMA Pavement	5
Aggregate for Cover Coat Material	5
Aggregate for Blotter and Choke Sand	Not Required
Aggregate for Open Graded Rock Base (Rock Cap)	8
Aggregate for Extrusions	8
Aggregate for Anti-Skid, Type 1, 3, 4, 5	Not Required
Aggregate for Anti-Skid, Type 2	5
Aggregate for Granular Subbase	8

Needs for Modifying the Idaho Degradation Test

The obsolete and ambiguous language in the specification of the Idaho Degradation Test has created significant confusion among practitioners and deliberate modifications in sample preparation to pass the specification. These variations make the test a highly technician-dependent test and result in not

only low repeatability among the laboratories outside of ITD but also poor reproducibility, especially when the results from the commercial labs were compared with the results from ITD HQ (Smith, 2001; Bannan, 2004). Before conducting tests for this research project, several of the key problems that need to be addressed regarding the test procedure of IT-15 are listed below:

No Standardized Testing Machine

The initial IT-15 was modified from Minor's Degradation Factor Test based on the Deval Tester, where the jars were rotated in an end-over-end fashion to allow more than one sample to be run simultaneously (Day, 1960). The rotational speed, the pattern of movement, and the setup of the test apparatus were all designed based on the Deval Abrasion Tester. However, the Deval machine was developed in 1878 and has been withdrawn as an ASTM test method since 1968 (ASTM, 1968). There is no domestic manufacturer of the Deval machine in the United States. The practitioners were forced to modify different test equipment or build their own devices to accommodate the testing needs. These modifications relied on each technician/lab's interpretation of the test device based on the description in the IT-15 specification. Several laboratories built the machine from scratch, while others used different modified L.A. Abrasion machines (Personal Communications with Practitioners, August 2023). A clearly defined and readily available testing apparatus is urgently needed to standardize the test method.

Lack of Clear Description of the Testing Container

The procedure in IT-15 only listed the containers as "wide-mouth one-gallon jars with lids" (ITD, 2019). Both plastic (polyethylene) and glass jars were allowed to be used in the development of the test in Washington's Degradation Factor Test (Minor, 1960). In the initial development stage of the Idaho Degradation Test, the State used a glass jar as the container (Day, 1962; Howard, 1966). There is no statement about the recommended dimensions and material for the jars in all the available versions of IT-15. In practice, both glass jars and polyethylene containers have been used by practitioners in Idaho, with the state labs using both glass and plastic jars and the commercial labs choosing the plastic containers (Personal Communications with Practitioners, August 2023). The glass jar usually has a much harder surface than that of plastic containers. The harder surface tends to cause more impact on the aggregates when the aggregate particles interact with the glass walls during the test, which may result in a higher number of P200 particles and a lower SE value after the test when compared to those obtained using plastic containers. Since the goal of the Idaho Degradation Test is to have the aggregates to abrade within itself (Day, 1962), softer polyethylene containers might be the better choice.

There were also significant differences in the dimensions among the testing containers. The practitioners and even ITD technicians had different interpretations regarding the shape and size of the acceptable jars (Walters, 2001). Unlike the test designed by Minor, the rotating action of the container in the Idaho Degradation Test is an end-over-end movement. The differences in the dimensions, especially the height of the container, could cause the aggregate particles to tumble at different speeds

or momentums inside containers with different dimensions, which would cause differences in the energies of abrasion and, thus, differences in the test results. The container variations could have contributed to the high variances in the reproducibility of the results among different labs.

Lack of Detailed Instruction in Sample Preparation

The guidance in the current IT-15 regarding sample preparation is vague and somewhat misleading. For example, how should a technician separate the samples into different fractions? Based on the language in Note 1 in section 4.3, the coarse aggregate shall be hand-shaken (ITD, 2019). Is this hand-shaken after sieving through the mechanical shaker, or does the technician need to hand-shake the whole sample? There is no mention of washing the aggregates before fractionating the sample, including coarse portions. Concerns have been raised that not washing the aggregate would cause significant fines to adhere to the coarse particles and affect the SE results (Walters, 2001).

The current method only allows the aggregates to be oven-dried at 140°F (60°C). Although the drying temperature at 140°F (60°C) potentially lowers the impact of the drying temperature on clay aggregation (Basma, 1994; Nayak, 2020), drying aggregate in an oven with no more than 140°F is a time-consuming process (sometimes more than 24 hrs). There is no clear language on the required minimum drying time or how to determine the “dry stage”. Drying aggregate at 230°F (110°C) has been the practice for preparing oven-dry samples for almost all regular AASHTO tests on aggregates. Since the amount of clay in the starting samples of the Idaho Degradation Test is usually low (< 10%) and the samples will be soaked for 16 hours before the test, the possible effects of a higher drying temperature on the gradation and SE results should be minimal.

The makeup of the samples in the Idaho Degradation Test has caused noticeable variances in aggregate gradations between different samples. There are no requirements or control points on the gradation of passing the No. 4 portion, which amounts to 50% of the total sample. The two tests used by the Idaho Degradation Test, % pass #200 and the SE test, are all related to the fine aggregate portion passing the No. 4 sieve. Gradation is one of the most important factors affecting degradation (Aughenbaugh, et al., 1961; Moavenzadeh and Goetz, 1963; Dunn, 1969; Deen and Southgate, 1972; Subramanyam and Pratapa, 1989; Gatchalin, 2005). The denser the mix, the less degradation there will be (Erickson, 1958; Moavenzadeh and Goetz, 1963).

ITD also realized that the test results from the Idaho Degradation Test showed sensitivity to the graduation makeups and did suggest a uniform gradation for passing the No. 4 portion to be used (ITD, undated) (Table 2.5). This gradation suggested is the average gradation for the Idaho Degradation test in District 2 of ITD (ITD, undated). It meets both ½ inch and ¾ inch B Aggregate Base specifications in Table 703.04-1 – Nominal Maximum Size of Section 703.04 Aggregate for Untreated Base, Treated Base, and Road Mix (ITD, 2023). This gradation is also within the gradation range listed in RP029.

Table 2.5: Idaho Degradation Test Uniform Gradation (ITD, Undated)

Sample Make UP	Sieve	Weight (g)	% Passing
	¾ in	**0**	**100**
16.6% passing the 3/4 in. and retained on the 1/2 in	½ in	**183**	**83**
16.6% passing the 1/2 in. and retained on the 3/8 in	3/8 in	**183**	**67**
16.7% passing the 3/8 in. and retained on the No. 4	No.4	**184**	**50**
19.1% passing the No.4 and retained on the No. 8	No. 8	**210**	**31**
10.5% passing the No.8 and retained on the No. 16	No. 16	**115**	**20**
5.9% passing the No.16 and retained on the No. 30	No. 30	**65**	**15**
3.6% passing the No.30 and retained on the No. 50	No. 50	**40**	**11**
3.2% passing the No.50 and retained on the No. 100	No. 100	**35**	**8**
2.7% passing the No.100 and retained on the No. 200	No. 200	**30**	**5.0**
5.0% passing No. 200	Pan	**55**	
	Total	1100	

In section 4.2 of the current Idaho Degradation Test specification, the sample should be prepared by combining "oven-dried and crushed portions representative of the gradation of the material as intended for use." This is interpreted as meaning that the received samples can be crushed and blended to meet the gradation. However, there are no detailed instructions on how to deal with samples from different origins, such as pit run, quarry, and crushed stockpile.

With a diminishing supply of high-quality aggregates and demands to increase the longevity of pavement structures, ITD has an urgent need to identify and maintain high-quality aggregate sources. The Idaho Degradation Test was developed based on pavement needs and practices in the 1960s. After more than 60 years, not only has the traffic condition in Idaho changed, but the aggregate requirements have also changed. With higher traffic volumes and higher axle loads across the State, ITD needs to reevaluate and modify the Idaho Degradation test. ITD should also select some supplemental tests based on the current test methods of the degradation tests used by other states. Using the modified Idaho Degradation Test and the selected supplemental tests, ITD hopes to design aggregate testing criteria with more reliable test methods to prevent poor pavement performances initiated by aggregate degradation.

Survey of Test Methods for Aggregate Degradation

To understand the status of aggregate degradation tests around the country, the Technical Advisory Committee (TAC) directed the Research Group to submit a questionnaire to each of the fifty states and Washington, D.C. in the middle of July 2023. A copy of the questionnaire is included in Appendix F. The questionnaire generated twenty-six replies from states, not including the state of Idaho.

The tests on Aggregate Degradation can also be categorized into two groups: a) tests that measure aggregate abrasion resistance and breakdown during handling, mixing, lay down, and under traffic, and

b) tests that address aggregate weathering when aggregate is exposed to freezing and thawing or wetting and drying (Prowell, et al., 2005). The test methods evaluated or reviewed in this study focus on the abrasion or breakdown resistance of the aggregates, such as L.A. Abrasion test, AASHTO T 96 (AASHTO, 2022), Micro-Deval Degradation Test for Coarse Aggregate, AASHTO T 327 (AASHTO, 2022), and Micro-Deval Degradation Test for Fine Aggregate ASTM D7428 (ASTM, 2022). The Soundness tests, such as Soundness by Use of Sodium Sulfate or Magnesium Sulfate, AASHTO T 104 (AASHTO, 2022) and Soundness by Freezing and Thawing, AASHTO T 103 (AASHTO, 2022) are not included in this study. Other forms of wear tests related to the abrasion on the pavement surfaces, such as polishing, are also beyond the scope of this study and will not be addressed in depth.

The summarized results of the survey are listed in Appendix G. The contact information from each state listed in the questionnaire is used to clarify any questions during analysis and is not included in the summary table. Several states have included tests on Soundness under "Other." These inputs are excluded from the table. Only tests related to mechanical abrasion are included. The information on the degradation tests in Idaho is also included in the table. Several states include links to reports on their research of evaluations on degradation test methods. Those research reports are not listed in the table and will be addressed in the sections below.

The research team has reviewed each agency's current standard specifications for the other twenty-four states and Washington, D.C. The test methods used to evaluate aggregate degradation are listed in Appendix H.

Definition of Aggregate Degradation

Although no state has an official definition of aggregate degradation, twenty-three states have explained their interpretation of Aggregate Degradation. Nine states, including Alaska, Colorado, Maine, Michigan, Minnesota, Nebraska, North Carolina, Oklahoma, and Vermont, use the pass or fail of the testing criteria as the definition of Aggregate Degradation. Iowa uses the service life of the final structure as the real measure of Aggregate Degradation. Nine states, including Arkansas, Illinois, Louisiana, Missouri, Montana, New Jersey, Oregon, Texas, and Wyoming, define the degradation as the breakdown of aggregate under mechanical or physical wear and tear. Idaho, Massachusetts, Nevada, and New York also included the breakdown of particles due to chemical reactions as a part of Aggregate Degradation.

Test Methods of Aggregate Degradation

AASHTO T96 L.A. Abrasion Test

Based on the results summarized from Appendices G and H, forty-nine states and Washington D.C. selected the L.A. Abrasion test (AASHTO T 96/ASTM C131) as one of the tests to evaluate the degradation. Twenty-three states use the L.A. Abrasion test as the only test for aggregate degradation.

The only state that does not use the L.A. Abrasion test is New York, which uses the soundness test as its only measurement for Aggregate Degradation. The L.A. Abrasion machine is shown in Figure 2.6.

Figure 2.6: L.A. Abrasion Machine

(Source: https://www.globalgilson.com/los-angeles-abrasion-machine)

The L.A. Abrasion test, invented in 1916 by engineers in the Los Angeles City Engineer's Office, is still one of the most popular methods for determining the quality of coarse aggregate (Woolf, 1937; Prowell et al., 2005). It was designed as a replacement to overcome the shortcomings of the Deval Test (ASTM, 1968), which was the very first abrasion test designed in France and was adopted by ASTM in 1908 (Rushing, 1963; Deen et al., 1972; Amirkhanian et al., 1991). The test involves placing a specially graded aggregate sample of 5000 grams in a revolving steel drum with 6 to 12 steel spheres (charges). The steel drum is then rotated for 500 revolutions at a rate of 30 to 33 revolutions per minute (AASHTO, 2022). At each rotation, a steel shelf inside the drum lifts and drops the aggregate and steel spheres. These movements simulate a combination of actions, including abrasion or attrition, impact, and grinding. Following the 500 revolutions, the resulting sample is dry-sieved over a No. 12 sieve. By comparing the gradations of aggregate before and after the test, a percentage loss is calculated. The lower the percentage loss, the greater the aggregate's resistance to degradation caused by impact and abrasion.

The test showed good correlations with the degradation potential of carbonate rocks but not for some of the basalts (Ekse and Morris, 1960; Minor, 1960; Wu et al., 1970). The loss in the L.A. Abrasion test is largely caused by the impact and breakdown of the steel balls, which diminishes the effects of particle abrasions. (Woolf, 1937; Senior and Rogers, 1991; Kandhal and Paker, 1998; Prowell et al., 2005). This test is considered more suitable for evaluating degradation during handling and construction, but it may not be a good indicator of particle-to-particle abrasion and attrition during the pavements' lifespan

(Folliard and Smith, 2002). Despite several attempts by researchers to run wet samples using the L.A. Abrasion machine (Larson, 1971), this test remains a dry test. This was the key reason ITD dropped the L.A. Abrasion Test from the Degradation Test (Day, 1962). Despite the shortcomings, States prefer this test due to its simplistic procedure and the ease of interpreting results. Prowell et al. (2005) stated that there was no evidence to suggest that the LA abrasion test should be replaced for assessing breakdown during handling, mixing, and replacement.

AASHTO T327 Micro-Deval Test (Coarse Aggregate)

Based on the results from Appendices G and H, eighteen states reported using the Micro-Deval apparatus to test coarse aggregates' resistance to degradation (AASHTO T 327/ASTM D6928) in their current specifications. They are Alaska, Colorado, Indiana, Kansas, Maine, Michigan, Missouri, Montana, New Mexico, Ohio, Oklahoma, Oregon, Pennsylvania, South Carolina, Texas, Utah, and Wyoming. Based on the questionnaire, eight states, Alaska, Maine, Montana, New Jersey, Oklahoma, Oregon, Texas, and Wisconsin, have evaluated the Micro-Deval test (Liu et al., 2012; Nener-Plante, 2012; Cuelho et al., 2007; Harris et al., 2005; Hunt, 2001; Gransberg et al., 2010; Titi, et al., 2018). New Jersey and Wisconsin have decided not to include AASHTO T 327 in their specifications.

The Micro-Deval test was developed by the French in the 1960s and was brought to North America by the Ontario Ministry of Transportation in the late 1970s (Senior and Rogers, 1991; Rogers, et al., 1991). In this test, a specifically graded and soaked sample is placed in a mill jar with 20 ± 5°C water and 5 kilograms of steel balls, each 5 mm in diameter. The sample, water, and balls are then revolved at 100 ± 5 rpm for 12,000 ± 100 revolutions. Afterward, the sample is washed and oven-dried, and the amount passing the No. 16 sieve is calculated as a percent loss.

The Micro-Deval tends to polish the aggregate, whereas the L.A. Abrasion tends to break it (Li, et al., 2013). Several NCHRP projects have evaluated the Micro-Deval Test to determine the aggregate toughness and abrasion resistance (Kandhal and Parker, 1998; Saeed et al., 2001; Powell et al., 2005). Saeed, et al. (2001) determined that the Micro-Deval test is the only commonly used test that could adequately correlate aggregates abrasion resistance. This was also validated by other researchers (Wu et al., 1998). Kandhal and Parker (1998) recommended that Micro-Deval evaluate aggregates for HMAs based on the good correlations between the test results and the performances on raveling, pop-outs, and potholing. Powell, et al. (2005) indicated that the Micro-Deval test is related to abrasion of particles in the pavement and should be used for measuring aggregates' resistance to abrasion, wetting and drying, and slaking. The Micro-Deval device is shown in Figure 2.7.

Figure 2.7: Micro-Deval Device

(Source: https://www.globalgilson.com/blog/aggregate-abrasion-testing-part-1-the-micro-deval-test-method**)**

Alaska DOT researched the feasibility of using the Micro-Deval Test to evaluate aggregate durability (Liu et al. 2012). The research confirmed that the Micro-Deval test could be used to assess the durability of Alaska's aggregate, and the results showed fewer variations than the results from the Washington Degradation Test. Maine DOT used the Micro-Deval and the L.A. Abrasion to evaluate the durability of coarse aggregates used for HMA in Maine (Nener-Plante, 2012). The Micro-Deval results showed no correlation with results from the L.A. Abrasion. The research also showed that materials with finer initial gradations produced higher loss values, which indicates an influence of the aggregate gradation on the test results. Montana DOT concluded that the Micro-Deval test could be the primary method for evaluating aggregate durability (Cuelho et al., 2007). However, due to the difference in the ways of detecting degradation among different test methods, a second test method, such as soundness and the L.A. Abrasion results, should be included.

New Jersey DOT decided not to use the Micro-Deval Test owing to low repeatability (New Jesey's reply in Appendix G). Oklahoma DOT used the Micro-Deval to study the durability and abrasion resistance of aggregates and saw better correlations from the Micro-Deval test than that from the L.A. Abrasion (Li, et al., 2019). The results from the same research also showed that they could not identify a good correlation between the results of the Micro-Deval and the L.A. Abrasion. Ginsberg et al. (2010) suggested that the Micro-Deval test should be included in evaluating aggregates for chip seals in Oklahoma, owing to a need for a wet abrasion test. Hunt (2001) from Oregon DOT concluded that the Micro-Deval test was no better than the L.A. Abrasion test in distinguishing the abrasive resistance of different aggregates. Jayawickrama et al. (2007) concluded that Texas DOT should use the Micro-Deval as an effective project-level quality control test. Weyers, et al. (2005) suggested that the Micro-Deval test should be added to the WisDOT testing protocol to evaluate the abrasion resistance of aggregate

because this test provided reasonable simulations of the degradation that occurs during handling and mixing. Titi, et al. (2018) found that fine aggregate showed more mass loss in the Micro-Deval Test than the coarse aggregate from the sample source. This indicated that the fine and coarse aggregates may react differently in the test owing to a difference in absorption.

Cooley et al. (2003) evaluated the durability of seventy-two aggregates from eight states using the Micro-Deval test, the L.A. Abrasion, and the Soundness Test. The eight states were Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, and Tennessee. Researchers found there was no relationship between the L.A. Abrasion and sodium sulfate soundness test results and the Micro-Deval test results when evaluating each state's data separately or by considering the data as a whole. It was recommended that the specification of the Micro-Deval test be developed based on the parent aggregate type. More states have conducted research projects to use the Micro-Deval test to measure the durability/degradation of the aggregates (Brandes, 2006; Hossain et al., 2007; Richardson, 2009; Williams, S. G., 2012; Rangaraju et al., 2017). All research showed the Micro-Deval test can be used to better predict the long-term performance of pavement structures. ITD has also evaluated the feasibility of using the Micro-Deval test to replace the Idaho Degradation Test (Allam and Ebrahimpour, 2014). Although the initial data indicated correlations between these tests, the analysis was not completed, and no final specification change was recommended.

ASTM D7428 Micro-Deval Test (Fine Aggregate)

Based on the results from Appendices G and H, only six states used the Micro-Deval apparatus to test fine aggregates' resistance to degradation (ASTM D7428): Alaska, Maine, New Jersey, Oregon, Texas, and Wyoming. Although New Jersey did not select AASHTO T 327/ASTM D6928 for the coarse aggregate test, it still uses ASTM D7428 to evaluate the resistance to degradation of fine aggregates.

AASHTO T210 Aggregate Durability Index

Based on the results from Appendices G and H, Idaho, Minnesota, Nevada, and Oklahoma are the only states using the Aggregate Durability Index (AASHTO T 210/ASHTM D3744) to evaluate aggregates' resistance to degradation (AASHTO, 2022). The Aggregate Durability Index, described in AASHTO T 210, was developed from the California Durability test created by Hveem in the early 1960s (Hveem and Smith, 1964) (Figure 2.8).

Figure 2.8: Durability Index Agitator

(Source: https://www.globalgilson.com/durability-index-agitator**)**

Although AASHTO T 210 and Caltrans CTM 229 are not technically identical, the procedures for testing and calculating durability indexes for coarse and fine aggregates (D_c and D_f) are almost identical (Caltrans, 2011). For coarse aggregates, the test involves shaking an aggregate sample (2500 g) in a steel container with water. Afterward, the fines are collected and mixed with a calcium chloride solution and placed in a cylinder. The height of the sediment is then used to calculate the durability index, D_c. For the fine aggregate (passing No. 4 sieve), the sample is evaluated using the same procedure as the Sand Equivalent test, except with 10 minutes of shaking in a mechanical shaker instead of 45 seconds.

The durability index represents an aggregate's ability to resist producing detrimental claylike fines when subjected to prescribed mechanical methods of degradation in the presence of water (AASHTO 2022). The procedure was designed for the aggregates in the West and is especially suitable for Basalt-type aggregates containing interstitial montmorillonite (Kandhal et al., 1998). The index number represents a relative quantity of claylike fines produced during wet degradation. A higher value of the durability index indicates that the material is more resistant to breakdown (Brandes, 2006).

In several studies that compare the effectiveness of different tests on aggregate degradation, the Durability Test showed the ability to rank asphalt mix performances (Clemmons, 1979; Wu et al., 1998; Saeed et al., 2001; Brandes, 2006; Geitz; 2006). Idaho has attempted to correlate the Idaho Degradation Test with the California Degradation Index in RP 029 (Howard 1966).

Other Tests

Based on the results from Appendices G and H, seventeen states are using sixteen other tests to test aggregate degradation.

- AASHTO T 278 (2022) British Pendulum Tester: Tennessee and Utah
- AASHTO T 279 (2022) British Wheel: New Jersey, Tennessee, and Utah
- AASHTO T 330 (2022) Methylene Blue: Kansas and Pennsylvania
- ARDOT TM 399 (2019) Slake Durability Index: Arkansas
- ASTM C295 (2022) Petrographic Analysis: Georgia, New Mexico, and New Jersey
- ATM 312 (2022) Nordic Abrasion Value: Alaska
- ATM 313 (2022) Degradation Value: Alaska
- CTM 229 (2011) Durability Index: California (Same as AASHTO T 210)
- GDT 75 (2010) Durability Index: Georgia
- IT-15 (2019) Idaho Degradation Test: Idaho
- ITM 220 (2015) Aggregate Degradation Loss: Indiana
- MTM 111 (2023) Aggregate Wear Index: Michigan
- MSMT 216 (2012) Dynamic Friction Value: Maryland
- New Mexico Aggregate Index (2019) New Mexico
- ODOT TM 208 (2023) Air Aggregate Degradation: Oregon
- WSDOT T 113 (2018) Degradation Value: Maine and Washington

AASHTO T 278 British Pendulum Tester, AASHTO T 279 British Wheel, MTM 111 Aggregate Wear Index, and MSMT 216 Dynamic Friction Value are all tests for polishing value or skid resistance of the aggregates, which are related to the friction characteristics of the pavement surface (Underwood, et al., 1972; Groeger, et al., 2010). Although aggregate's ability to degrade or abrase relates to skid resistance, these tests are not direct measurements of aggregate degradation and will not be included in this study.

Arkansas DOT's Slake Durability Index Test is a modified version of ASTM D4644 (ARDOT, 2021). It is mainly used to measure the degradation called "slaking" when fine-grained sedimentary rock disintegrates under wetting and drying conditions and when they are exposed to air after being

excavated (PennDOT, 2022). Slaking is not a concern in the State of Idaho due to low shale/mudstone contents in the aggregates (Gillman and Weppner, 2014). It can play a role in the foundation design of bridges or road construction close to the river, where rock scour could become a concern (Dickenson and Baillie, 1999; Ureel and Momayez, 2014).

Indiana's ITM 220 is used to evaluate coarse aggregates for constructing Stone Matrix Asphalt (SMA) mixtures, including the abrasion loss from the Micro-Deval test and the Aggregate Degradation Loss test (Indiana DOT, 2015). The aggregate Degradation Loss Test is a compaction test using the gyratory compactor. The gradations of extracted aggregate samples from uncompacted and compacted specimens are measured. The difference in the % passing No. 8 sieves between uncompacted and compacted samples is the Aggregate Degradation Loss. The aggregate samples must pass both tests before being used in SMA mixtures.

New Mexico DOT's Aggregate Index (AI) is a factor calculated by combining test results from three tests: the L.A. Abrasion Test (AASHTO T 96), the Soundness Test (AASHTO T 104), and the Absorption Test (AASSHTO T 85). It represents the aggregate's overall quality (NMDOT, 2019). The L.A. Abrasion test measures aggregate degradation.

Alaska DOT's ATM 312 Nordic Abrasion Value Test, also called "Nordic Ball Mill Test," has been used in Alaska to evaluate aggregate's ability to resist studded tires since the early 1990s (Hunt, 2001; Frith et al., 2004; Liu et al. 2012). The setup is shown in Figure 2.9. This test was first developed in Sweden during the 1980s (Schouenborg and Viman, 1994). The current specification or procedure uses a similar machine to the Micro-Deal machine (Hunt, 2001). Unlike the smooth interior of the Micro-Deval container, the three ribs inside the container simulate the impact of studded tires and also lift and drop the steel balls and the aggregate particles like the shelf in the L.A. Abrasion Machine, which improves the abrasion of the aggregate particles and the steel balls. This creates a testing environment that combines both the L.A. abrasion (impact created by dropping the chargers) and the Micro-Deval (Wet Abrasion) (Ureel and Momayez, 2014). Due to the similarity of the set-up, the results from the Nordic Abrasion Test showed a strong correlation with the results from the Micro-Deval Test (Bjamason, et al. 2002). Hunt indicated that the Nordic Abrasion Test showed larger differences among hard or good abrasive-resistant aggregates than the results from the regular Micro-Deval test, which would help agencies to identify the "premium" aggregates for higher-traffic roads (Hunt, 2001; Frith, 2004). Although this test is a good candidate for testing aggregate degradation in Idaho, there is no approved AASHTO or ASTM specification for it. The research data on this test in the USA is also limited, which makes standardizing the specification limits difficult.

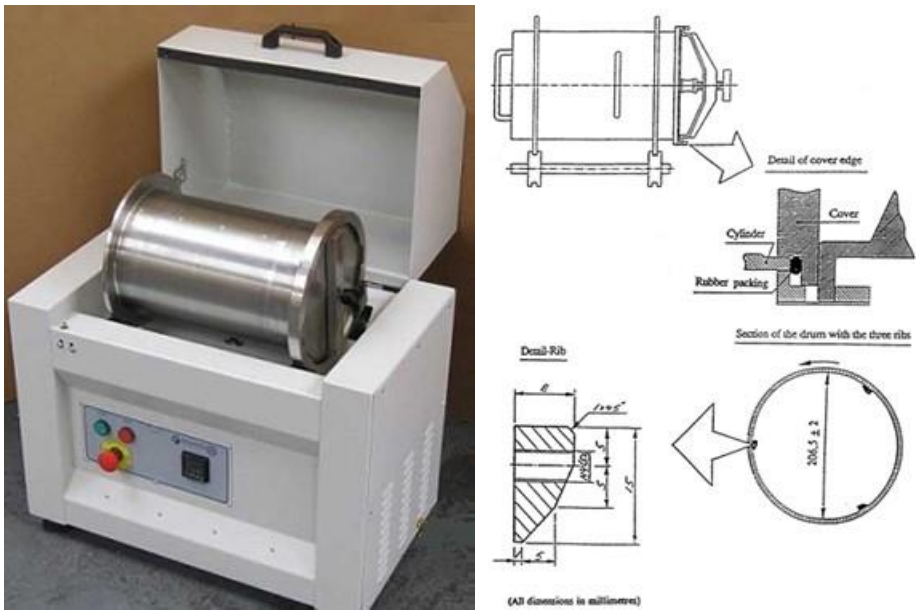

Figure 2.9: Nordic Abrasion Test (Alaska, 2022(1))

(Picture Source: https://www.impact-test.co.uk)

Petrographic Analysis has been used by three states (Georgia, New Mexico, and New Jersey) as another method to study Aggregate Degradation. ASTM C295 is the procedure used to conduct analysis using a microscope. This method uses geology to define the characteristics of the aggregate to determine its durability and has been used since the initial development of different degradation tests (Scott, 1955; Moavenzaden and Goetz, 1963; Aughenbaugh, et al., 1966; Van Atta and Ludowise, 1974; Senior and Rogers, 1991; Kandhal, et al., 1998; West, et al., 1998; Cuelho, 2007). In the development of the Idaho Degradation Test, Day used the petrographic analysis with X-ray diffraction (XRD) and Differential Thermal Analysis (DTA) to establish the tentative limits for ranking basalt quarries based on clay content (Day, 1962): 0 to 15 % Good; 15 to 25%, Borderline, and 25% above, poor quality. However, the analysis is subjectively dependent on the technician who performs the test. The technician's experience or knowledge regarding geology would significantly influence the outcome of the test. Both DTA and XRD can provide more accurate information. However, both tests require expensive equipment. Petrographic analysis should be combined with other qualitative abrasion tests (such as the Micro-Deval or Durability index) to understand the effect of aggregate components on the degradation potential. It should not be used as a reliable test for aggregate quality control. ITD has conducted a study (RP212) on the lithologic characterization of aggregate sources in Idaho (Gillerman and Weppner, 2014). The information from this study can be used to guide the current research group to better conduct petrographic analysis.

Methylene Blue Test (AASHTO T 330), like the Sand Equivalent Test, measures the clay content inside the aggregate. AASHTO T 330 test quantifies the number of harmful clays of the smectite (montmorillonite) group and indicates the surface activity of aggregate (AASHTO, 2022). The principle of the test is to add 0.5 ml of a standard solution of methylene blue to a P200 aggregate sample in water

until a well-defined circle of MB-stained dust is formed and is surrounded by an outer ring of clear water. The endpoint is reached when a light blue “halo” is observed in this ring and remains for 5 minutes (Prowell et al., 2005; Nikolai et al., 2007; Pitre, 2012). The Methylene Blue Value (M) is reported as milligrams of solution per gram of P200 material (AASHTO, 2022). The M value is proportional to the product of the clay content times the specific surface of the clay, and the correlations are high (> 90%) with different clays (Petre, 2012; Mukhopadhyay et al., 2013). The methylene test is simple and much cheaper than XRD or DTA, which can be used to identify the type and quantity of the clay in a short time.

Alaska DOT’s ATM 313 Degradation Value, Georgia DOT’s GDT 75 Durability Index, Oregon DOT’s TM 208 Air Aggregate Degradation Test, and Washington’s T 113 Degradation Value are all based on the sand equivalent test with some modifications to rank different aggregates on the potential of degradation (Alaska DOT2022, GDT, 2010; ODOT, 2023).

- In GDT 75, the aggregates are oven-dried at 110°C (230°F) and are sieved through No. 10 Screen. The material passing the No. 10 sieve is then shaken in water inside a washing vessel for 10 minutes using a sieve shaker. The material is then washed through a No. 200 sieve, and the passing No. 200 material is discarded. The retained material on the No. 200 sieve is then dried at 110°C (230°C). The material is then evaluated for the SE following the Reference Method in AASHTO T 176, except changing the shaking time in the mechanical shaker to 10 mins. instead of 45 seconds. The durability index D_f is equal to the SE reading. This is the same definition of D_f in the Caltrans CTM 229 California Degradation Test.

- Alaska DOT’s ATM 113 and WSDOT T 113, with some differences in the procedures of preparing the samples, have the same testing procedure for calculating the Degradation Values. Alaska DOT is in the process of replacing ATM 313 with the Micro-Deval Test, which means the ATM 313 will no longer be the standard test for Degradation in Alaska. WSDOT T 113 uses a similar apparatus for shaking the aggregate as the agitator in AASHTO T 210 and Caltrans CTM 229 (Figure 1.7). WSDOT T 113 only tests one blended gradation for each aggregate sample versus two for AASHTO T 210. It takes less time than AASHTO T 210 to finish, and the results produced one of the best correlations with field performance compared with other degradation tests (Geitz, 2006). Since AASHTO or ASTM does not accept WSDOT T 113, other states hesitate to use this test.

- The Aggregate Degradation Test used in Oregon is also referred to as the "Oregon Air Test” because the particles are agitated in water by compressed air jets (Pressure: 20 psi) instead of a mechanical shaker (ODOT, 2023). The aggregate sample for testing is the material retained between No.10 and No. 20 sieves. The specimen is agitated in water with compressed air for 20 minutes. Two factors measure the degradation of the aggregate: 1) the sediment height test for materials passing the No. 140 sieve after agitation, and 2) the percentage of aggregate passing the No. 20 sieve. Although the results from the Oregon Aggregate Degradation test showed satisfactory correlations with field performance ratings, the test became an underperformer

when it was compared to the correlation obtained by other degradation tests (Clemmons, 1979; Geitz, 2006).

Ranking of Test Methods of Aggregate Degradation

Eleven states have ranked these test methods based on their efficiencies (Table 2.6). Nine of these eleven states selected L.A. Abrasion as the most efficient method for aggregate degradation tests. Alaska selected the Micro-Deval test (AASHTO T 327) over L.A. Abrasion, while Oklahoma selected the Durability Index Test (AASHTO T 210) as the most efficient test. Five States ranked the Micro-Deval test as the second choice.

Table 2.6: Ranking of Degradation Tests

States	Rank 1	Rank 2	Rank 3	Rank 4
Alaska	Micro-Deval	L.A. Abrasion		
Arkansas	L.A. Abrasion			
Louisiana	L.A. Abrasion	Micro-Deval (Coarse)		
Montana	L.A. Abrasion	Micro-Deval (Coarse)		
Nevada	L.A. Abrasion	Durability Index		
New Jersey	L.A. Abrasion	Petrographic Analysis	Micro-Deval (Fine)	British Wheel
North Dakota	L.A. Abrasion			
Oklahoma	Durability Index	Micro-Deval (Coarse)	L.A. Abrasion	
Oregon	L.A. Abrasion	Oregon Air		
Texas	L.A. Abrasion	Micro-Deval (Coarse)	Micro-Deval (Fine)	
Wyoming	L.A. Abrasion	Micro-Deval (Coarse)	Micro-Deval (Fine)	

Selection of Possible Supplemental Testing Methods

A successful test method for evaluating should have the following characteristics:

1. an easy-to-perform and widely acceptable testing procedure;
2. readily available and relatively uncomplicated pieces of equipment;
3. an acceptable testing time frame;
4. a range of results with a reasonable span to differentiate between materials;
5. a reasonable correlation to the observed performance in service.

Degradation Tests

Of the test methods examined above, the Aggregate Degradation Index (AASHTO T 210), the Micro-Deval Tests for Coarse Aggregate (AASHTO T 327), and for Fine Aggregate (ASTM D7428) fulfill these criteria:

1. All three tests are wet abrasion tests like the Idaho Degradation Test. They all use standardized AASHTO and ASTM procedures, which practitioners have fine-tuned multiple times.
2. All three tests use economical standard equipment, which can be purchased readily through multiple manufacturers.
3. The three tests can all be finished in two working days.
4. The variations between the test data have a spread of test results in a reasonable range.
5. Multiple studies above showed that all test methods can perform satisfactorily.

Furthermore, both the Micro-Deval test and the Aggregate Durability Index test have been studied by ITD before, with research goals closely associated with the current study (Allum and Ebrahimpour, 2014; Howard, 1966). Selecting these methods can help ITD to close some unfinished research initiatives.

3. Materials

Aggregate Sources

For this research project, sixteen different aggregates for all six districts were collected. These aggregates were excavated directly from borrow areas, rock quarries, or gravel pits and delivered without crushing. ITD district personnel throughout Idaho obtained these samples, as shown graphically in Figure 3.1. Numbers 1 to 6 represent the districts in ITD.

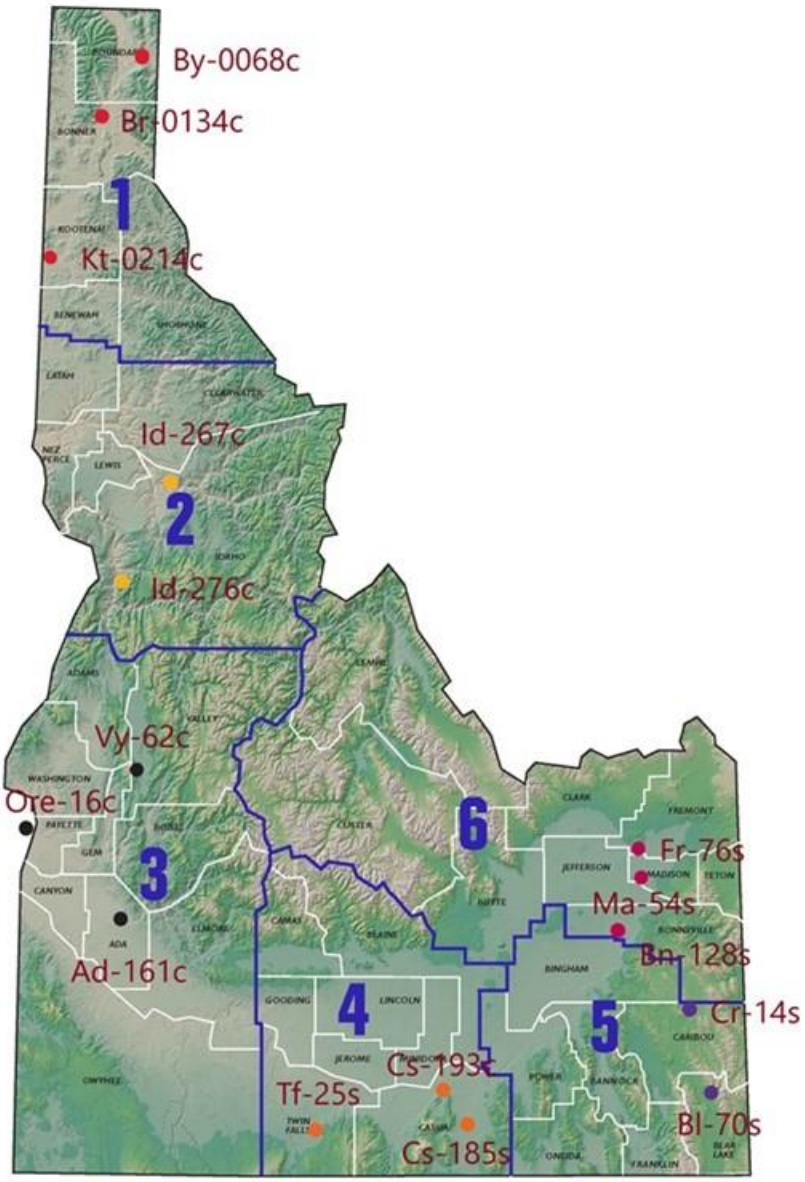

Figure 3.1: Locations of Aggregate Sources

A complete list of the locations of these aggregate sources is provided in Table 3.1. The aggregates are identified using ITD's Material Source Codes, designated by a two-letter abbreviation of the county followed by a sequentially determined number and a lower-case letter indicating ownership (s for the State and c for commercial). For example, Kt-214c refers to Material Source No. 214 in Kootenai County, which is commercially owned. Source Cs-135s is No. 135, owned by the State, in Cassia County. Idaho's diverse geology provides significant structure differences and heterogeneity in aggregate composition for road construction throughout all districts. The durability of aggregate is closely related to mineral composition, rock type, and geologic history. To better understand these sources' geological properties, Table 3.1 also lists the geological information of each source that is obtained from the Interactive map from the Idaho Geological Survey (Idaho Geological Survey, 2023). The details of the geological descriptions are listed in Appendix I.

Table 3.1: Locations of Aggregates Sources

District	ITD Code	Latitude	Longitude	County	Geology
District 1	Br-134c	48°22'31.94" N	116°30'49.98" W	Bonner	Prichard Formation (Mesoproterozoic)
District 1	By-0068c	48°41'36.58" N	116°13'43.91" W	Boundary	Alluvial deposits (Quaternary)
District 1	Kt-214c	47°43'55.96" N	117°1'2.03" W	Kootenai	Missoula Flood deposits (Pleistocene)
District 2	Id-267c	45°56'31.56" N	116°5'56.40" W	Idaho	Columbia River Basalt Group (Miocene)
District 2	Id-276c	45°34'54.79" N	116°14'32.18" W	Idaho	Riggins Group, Orofino series, and related rocks (Cretaceous to Permian)
District 3	Ad-161c	43°30'7.90" N	116°12'47.80" W	Ada	Sediments and sedimentary rocks (Pleistocene and Pliocene)
District 3	Ore-16c	44°1'11.73" N	116°56'20.55" W	State of Oregon	Alluvial deposits (Quaternary)
District 3	Vy-62c	44°52'11.21" N	116°10'9.42" W	Valley	Columbia River Basalt Group (Miocene)
District 4	Cs-185s	42°23'29.45" N	113°24'29.04" W	Cassia	Alluvial-fan deposits (Quaternary)
District 4	Cs-193s	42°34'11.03" N	113°30'22.02" W	Cassia	Basalt (Pleistocene and Pliocene)
District 4	Tf-25s	42°18'20.93" N	114°30'22.00" W	Twin Falls	Alluvial deposits (Quaternary)
District 5	Bl-70s	42°29'20.40" N	111°24'50.40" W	Bear Lake	Alluvial deposits (Quaternary)
District 5	Cr-14s	43°0'43.20" N	111°30'57.60" W	Caribou	Sedimentary rocks (Permian and Pennsylvanian)
District 6	Bn-128s	43°26'55.36" N	112°6'1.51" W	Bonneville	Alluvial deposits (Quaternary)
District 6	Fr-76s	43°54'29.09" N	111°44'7.53" W	Fremont	Alluvial deposits (Quaternary)
District 6	Ma-54s	43°46'44.73" N	111°50'13.25" W	Madison	Alluvial deposits (Quaternary)

Sample Preparation

Of these sixteen sources, nine aggregates contained natural fines and could be directly fractionated and combined into the gradation used in the aggregate tests. These nine aggregates were evaluated under both crushed and uncrushed conditions, which resulted in eighteen samples in total. The other seven aggregates were made of quarry rocks and must be crushed into the gradation needed. Twenty-five samples were obtained with both uncrushed and crushed conditions.

- Uncrushed and Crushed (19 samples): By-68c, Id-276c, Ore-16c, Ad-161c, Cs-185s, Bl-70s, Fr-76s, Ma-54s, and Bn-128s.
- Crushed only (7 samples): Kt-214c, Br-0134c, Id-267c, Vy-62c, Cs-193s, Tf-25s, Cr-14s.

Size Reducing

All samples were reduced to a workable size/weight first following Method B - Quartering in AASHTO T 248 (AASHTO, 2022). For aggregates that need to be evaluated as both crushed and uncrushed, after combining diagonally opposite quarters of the material into two samples, one sample was evaluated as the uncrushed sample directly, and the other was crushed through a jaw crusher and evaluated as the crushed sample. During quartering, the samples were processed in the delivered status without drying. For the aggregates evaluated for crushed samples only, one of these two halves was stored as a backup, and the other was crushed for testing.

Aggregate Crushing

Before crushing, all aggregate samples were dried at 110 ± 5°C (230 ± 9°F) in an oven to allow for clean separation of fines from the surfaces of coarse aggregates. The selection of 110°C will be explained in Chapter 5. A jaw crusher was employed for the crushing process. The crush jaws were set at ¾ inch (19 mm) apart. When crushing the materials with fines, the whole sample was poured into the open of the crusher continuously. The process might be repeated up to three times to gain enough crushed particles for each sieve. The jaw crusher was thoroughly cleaned with pressurized air and a wire brush between each run.

4. Test Methods

In this project, the laboratory tests conducted by the researchers can be categorized into two groups:

1. Clay Identification: Petrographic analysis (ASTM C295), X-ray diffraction (XRD), and the Methylene Blue Test (AASHTO T 330)
2. Degradation Tests: Aggregate Degradation Index (AASHTO T 210/Caltrans CTM 229), Micro-Deval Tests for Coarse Aggregate (AASHTO T 327) and for Fine Aggregate (ASTM D7428), and the Modified Idaho Degradation Test

Chapter 5 will discuss the modified Idaho Degradation Test (MIDT). This chapter introduces the rest of the test methods.

Clay Identification

In this study, the X-ray diffraction (XRD) method was selected as the main method used to identify the relative percentage and mineral components of different clays inside these aggregates. The petrographic analysis (ASTM C295) was used to understand the texture and the components of the coarse aggregates on the results of the degradation tests. The Methylene Blue Test (AASHTO T 330) was used to measure the reactivity of the clay components. These tests were used only to identify the type of clay and to understand the effects of different clays on the results of the MIDT. These methods should not be considered as supplemental tests for MIDT.

X-Ray Diffraction (XRD) Test

Identifying and characterizing the clay minerals accurately is challenging due to their fine grain size and the potential for mixed-layer compositions. X-ray diffraction (XRD) has emerged as a suitable technique in the analysis and identification of clay minerals due to its small sample size, quick testing speed, and nondestructive analytical technology. It can be used to determine the lattice parameters, the arrangement of individual atoms in a single crystal, or the phase analysis in the case of polycrystalline materials and compounds.

Principle of XRD Test

XRD identifies the geometry or shape of material structure using X-rays. When a focused X-ray beam is directed onto the structure of a mineral, part of the beam is diffracted. X-rays are diffracted differently depending on the atomic composition and arrangement within the structure. XRD technique is divided into two categories based on the morphology and size of the sample:

1. If a material sample has a large enough crystal structure, it can be analyzed using X-ray Single Crystal diffraction**,** which solves for the complete structure ranging from simple inorganic solids to complex polymers.

2. If a material does not form large enough crystals, then the sample is analyzed by using the X-ray Powder diffraction (XRPD) technique. Powders of crystalline materials inside the sample diffract X-rays. A beam of X-rays passing through a sample with randomly oriented microcrystal powders produces a pattern of rings on a distant screen. XRPD provides less information than X-ray single crystal diffraction; however, it is much simpler and faster. XRPD is useful for confirming the identity of a solid material since clay materials do not have a large three-dimensional crystal structure. The XRPD is used to analyze clay minerals.

When a focused X-ray beam is directed onto the crystal structure of a mineral, part of the beam is diffracted. The pattern of the diffraction is dependent on the mineral composition and atomic arrangement within the crystal structure. Each mineral has a unique fingerprint determined based on a characteristic set of d-spacings (space between adjacent planes of atoms in the structure). This is a fundamental characteristic of minerals that allows clay identification through XRD.

In the XRPD test, X-rays are generated in a vacuum tube and directed to a powdered sample. The wavelength (λ) of the X-ray beam is a constant, which is based on the material generating the X-rays. When the beam of X-rays hits the sample, they are diffracted onto a detector following Bragg's law (Figure 4.1).

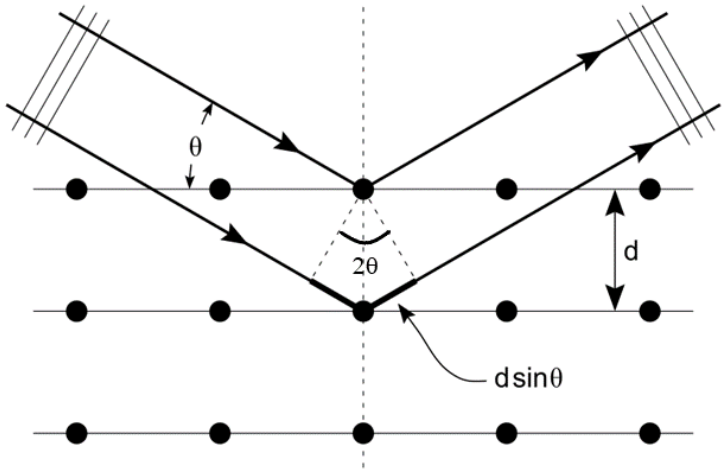

Figure 4.1: Bragg's Law

The X-ray detector then converts the signal to a count rate. The diffraction angle (2θ) between the X-ray tube, sample, and detector varies during measurement to produce a scan of the X-ray reading. Using the

angle (2θ, which can be measured) and the wavelength of a generated X-ray beam (λ, which is known based on the material generating the X-rays), the d-spacing can be determined by using Bragg's Equation (Equation 4).

$$n(\lambda) = 2d\sin\theta \qquad (4)$$

n = order of the diffracted beam (1, 2, 3, …n)
λ = the wavelength of the X-ray beam
d = spacing between adjacent planes of particles (d-spacings)
θ = the angle of incidence of the X-ray beam

Sample Preparations

For the aggregate sources that contain natural fines, the samples were obtained from P200 materials out of the uncrushed samples. For the aggregate sources that need to be crushed before testing, the samples were collected from P200 materials after the aggregates were crushed. Sixteen samples, with one sample for each source, were evaluated. To avoid any damage to the clay structure, all clay samples used in this test did not go through the acetic acid treatment for the removal of carbonate and the hydrogen peroxide treatment for the removal of organic.

For bulk rock analysis, the sample was usually crushed to a passable size through a 400-mesh sieve. These P200 samples were determined to need further pulverization by a McCron Micronizing Mill. The powder was then packed into a standard XRD sample well, and an X-ray diffraction pattern was collected using a Rigaku Miniflex 600 X-ray diffraction equipment (Figure 4.2). The XRD data was collected using an automated sample changer and a step scan at 0.02 degrees two-theta angle per second, scanning the range between 2 and 75 2θ angles.

In this project, the identification of mineral components of clays was completed following the flow diagram suggested by the U.S. Geological Survey (Poppe, L. J., etc., 2001). The full diagram is listed in Appendix J. For clay analysis, the sample was usually crushed to a size that could pass through a 60-mesh sieve. For the case of samples in this study, no further crushing was necessary, and the samples, in their as-received condition, were placed into centrifuge tubes, and distilled water with a small amount of deflocculant solution was added. This material was placed in a sonic bath to dislocate the clay from the framework grains. After sonic dismemberment, each sample was centrifuged to separate the less than two-micron clay-sized particles from the framework grains. The clay particles were subsequently caught on a cellulose filter using vacuum filtration. The clays were then transferred to a zero background XRD holder and dried in the desiccator for at least 30 minutes before XRD analysis.

These oriented clays were scanned by XRD in three states of air dried, glycolated, and heat-treated to aid in the identification of any swelling clays and chlorite/kaolinite overlap, which may occur in these samples. After the air-dried sample was evaluated, ethylene glycol was utilized as an auxiliary agent to induce the expansion of swelling clay minerals, which serves as a pivotal supplementary technique for

the identification of clays. The degree of expansion observed provided critical insights into the mineralogical composition, particularly distinguishing between smectite group minerals like montmorillonite, nontronite, and beidellite, as well as certain mixed-layer clays and vermiculite. In this study, a swift application method was used. A single drop of ethylene glycol was applied onto the surface of the oriented aggregate mount using a glass rod. Since the effect of the ethylene glycol could only last for more than 4 hours, once the ethylene glycol was fully absorbed, the sample was ready for testing. Any extra ethylene glycol was delicately blotted away with laboratory tissue. Several clays have intensity peaks at very similar angles, making it difficult to distinguish one clay from another.

Figure 4.2: Rigaku Miniflex 600 X-Ray Diffractometer

Thermal treatment was a pivotal step in differentiating these clay minerals. By applying controlled high temperatures for some time (at least 30 minutes), an alteration of mineralogical compositions may occur (Figure 4.3). Different clay minerals react to heat differently. Certain clays may undergo structural collapse because of dehydration, while others may experience complete destruction of their crystalline framework. The samples were placed at a sustained temperature of 400°C or 500°C for at least half an hour. After the heat treatment, the samples were left in the furnace to cool down. The samples were removed from the furnace when the temperature inside reached 100° and 200°C. The samples were placed in the desiccator immediately to cool. Once the samples reached room temperature, they were run in the XRD.

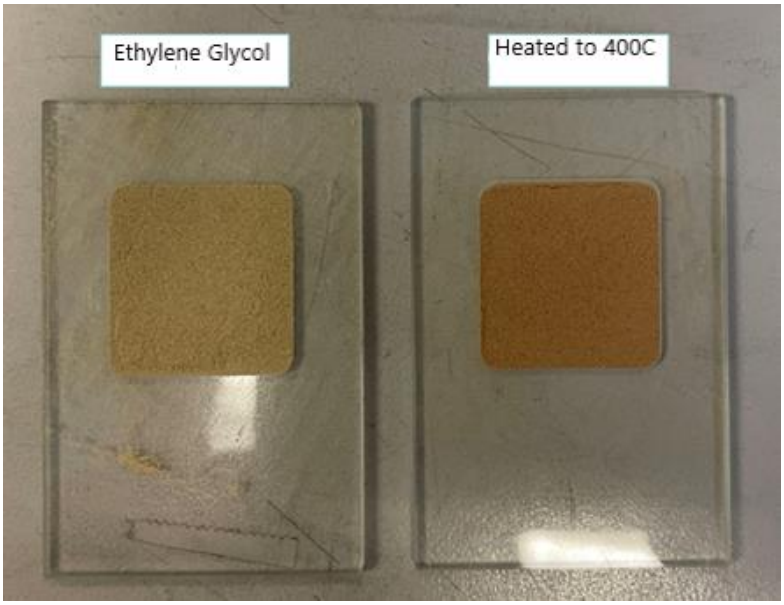

Figure 4.3: Clay Samples for XRD Tests

For the clay test, the instrument was set to initiate the diffraction angle (2θ) at 5 degrees and conclude the scan at 80 degrees using Copper K-α radiation, which corresponded to an x-ray wavelength of 1.5406 Å, at a scanning rate of 2 degrees per minute. Figure 4.4 shows an example of the test plot.

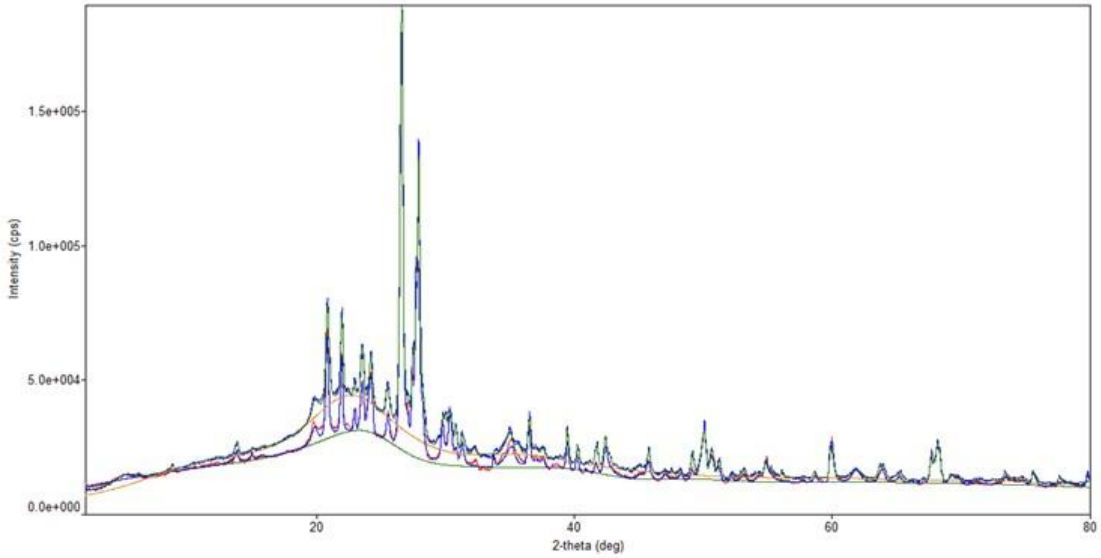

Figure 4.4: XRD Test Results for Ad-161c

The identification of the minerals in the samples was performed by comparison with reference patterns provided by the International Center for Diffraction Data (ICDD). Quantification of the phases was performed using the MDI's Jade® analytical data interpretation software, which includes Rietveld Refinement. The minerals inside samples were grouped into quartz, potassium feldspars (also known as

k-spar), plagioclase feldspar, calcite, Fe dolomite, siderite, mica, and total clay. Clays were divided into illite, kaolinite, chlorite, and smectite/montmorillonite.

Petrographic Analysis (ASTM C295)

Petrography is a branch of geology that specializes in the detailed analysis of rocks. It involves the examination of the mineral composition, texture, structure, and other critical features of rocks, primarily through petrographic microscopic study of thin sections. Through petrography, the mineralogy of a rock, the specific minerals it contains, relative proportions, and alteration characteristics can be determined. The textural features of rocks, such as grain size, shape, and the interrelationships between mineral grains, are vital clues in rock identification. These features offer insights into the conditions under which the rock formed. There are three main categories of rocks: Sedimentary, Igneous, and Metamorphic (Mackenzie, Adams, and Brodie, 2017).

Thin Sections Preparation

In this study, thin sections of the coarse aggregates/rocks were studied under the petrographic microscope. The minerals inside the rocks were analyzed. After determining the minerals, the identification of a rock was determined based on the relative abundance of the minerals and the textural relationships between them. The analysis began with sample collection, where a representative specimen was retrieved from a geologically relevant location. In this project, ITD representatives collected aggregates/rocks from the sites indicated in Table 3.1. After the samples were delivered to the researchers, a preliminary examination was conducted to observe and select a representative rock sample based on the rock's macroscopic features, such as color, grain size, and composition (Figure 4.5).

(a) (b)

Figure 4.5: Raw Rock Samples Selected after Preliminary Examination (a) Ore-16c; (b) Vy-62c

Next, the rock was sliced into translucent specimens, typically 30 micrometers thick (Figure 4.6). The process began with the precision cutting of the rock sample, followed by the embedding of the cut specimen onto a glass slide with a blue-dyed resin under a pressure of 200 psi. The blue color would aid

in visualizing the porosity in different structural features. The sample was then ground into a uniform 30-micron thickness, a key step for proper light transmission during microscopic analysis. Selective staining techniques were employed to distinguish various minerals: a calcite stain for carbonates, a K-spar stain for potassium feldspar, and a plagioclase stain to differentiate feldspar species. A cover glass was subsequently applied to protect the stained sections, and each was labeled with a unique identifier correlating to the sample data.

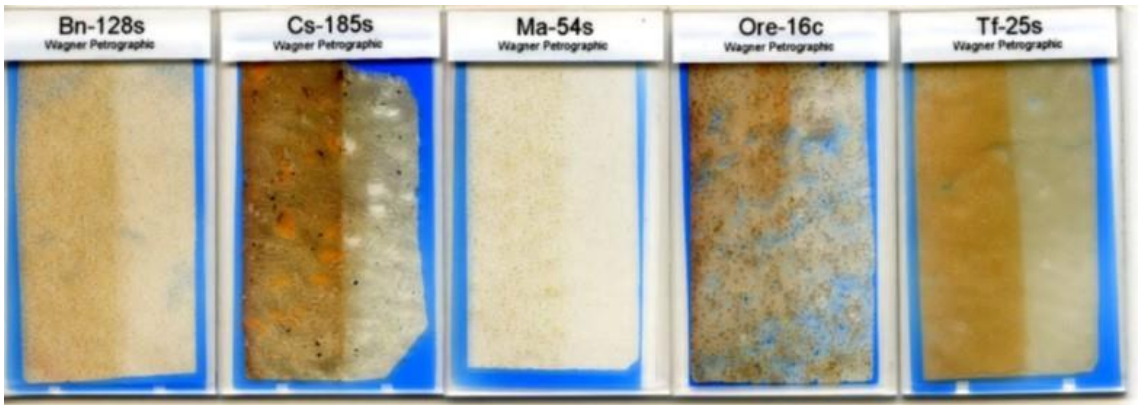

Figure 4.6: Thin Sections of Different Sources

Sample Observation

The thin sections were observed under a petrographic microscope (Figure 4.7).

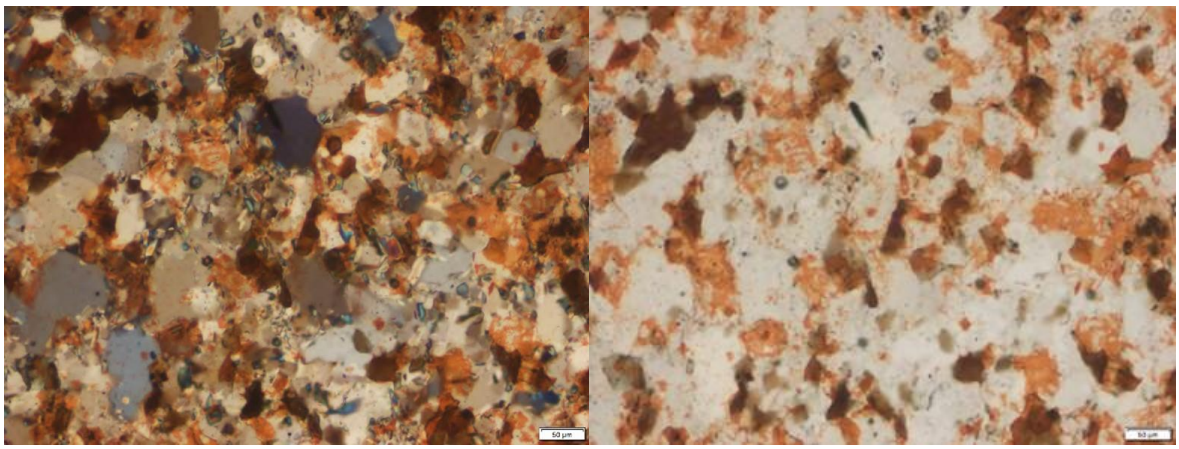

Image A: 20X, 2.0 mm XPL

Image B: 120X, 50 microns PPL

Figure 4.7: Example of Petrographic Analysis (Br-0143c)

Each thin section was first observed under Plane-Polarized Light (PPL) to identify individual minerals and structures. It was then examined under Cross-Polarized Light (XPL) to reveal optical properties and crystallographic details unique to each mineral. The images provide a direct measurement of the texture of the aggregates: the distribution, size, shape, clay alterations, and reaction boundaries. These

measurements provide clues to the rock's fundamental properties, such as chemical composition, permeability, or porosity, which may directly relate to the behavior of aggregates during the Idaho Degradation Test. In this project, thin sections of representative rocks from all sixteen locations were prepared and examined to identify the composition of each source.

Methylene Blue Test (AASHTO T 330)

The Methylene Blue test was developed in France and originally used to determine clay content in the granular material (Turkoz, M. and Tosun, H., 2011). Methylene Blue (Chemical Formula: $C_{16}H_{18}N_3SCl$) behaves like a cationic dye when mixed with water. When the solution is mixed with clay slurry, chloride ions in the Methylene Blue (MB) solution change places with cations in the clay minerals and let the Methylene Blue be adsorbed onto the surface of the clay minerals. The amount of adsorbed Methylene Blue solution varies according to the amount of clay minerals in the slurry, the clay type, the cation exchange capacity, and the specific surface area (SSA) of clay particles.

Sample Preparation

For the aggregate source that contained natural fines, the P200 samples were collected from both crushed and uncrushed materials. For the aggregate source that needed to be crushed before testing, the samples were collected from P200 material after the aggregates were crushed through a Jaw crusher. A total of twenty-five samples with one sample for each source were evaluated.

Test Procedure

The procedures in AASHTO T 330 were followed. The MB solution (5 mg/ml) was prepared by dissolving one gram of reagent-grade MB with 200 ml of distilled water. Ten grams of P200 material was then mixed with 30 ml of distilled water. The MB solution was added to this clay slurry in 0.5 ml increments. The clay slurry was mixed with a magnetic stirrer for one minute after each 0.5 ml MB solution was added. After mixing for one minute, a small drop of slurry was removed using a glass rod and placed onto filter paper. When the excess MB formed a blue-green tint that radiated from the darker spot, like a halo, this indicated that the endpoint (V: ml of MB solution used for titration) where MB had coated the entire available clay surface was reached (Figure 4.8).

The Methylene Blue Value (MBV) (mg/g) was calculated as (Equation 5):

$$MBV = 0.5V \qquad (5)$$

V = ml of MB solution used for titration

The MBV expresses the quantity of MB required to cover the total surface of the clay fraction of the sample with a mono-molecular layer of the MB. Therefore, the MBV is proportional to the product of

the clay content times the specific surface area of the clay. AASHTO T 330 also lists the expected performance between the Methylene Blue Value and the moisture susceptibility of hot mix asphalt pavement (Table 4.1) (AASHTO, 2022).

Table 4.1: Expected Performance of MB

MBV (mg/g)	Expected Performance
≤6	Excellent
7-12	Marginal Acceptable
13-19	Problems/Possible Failure
≥20	Failure

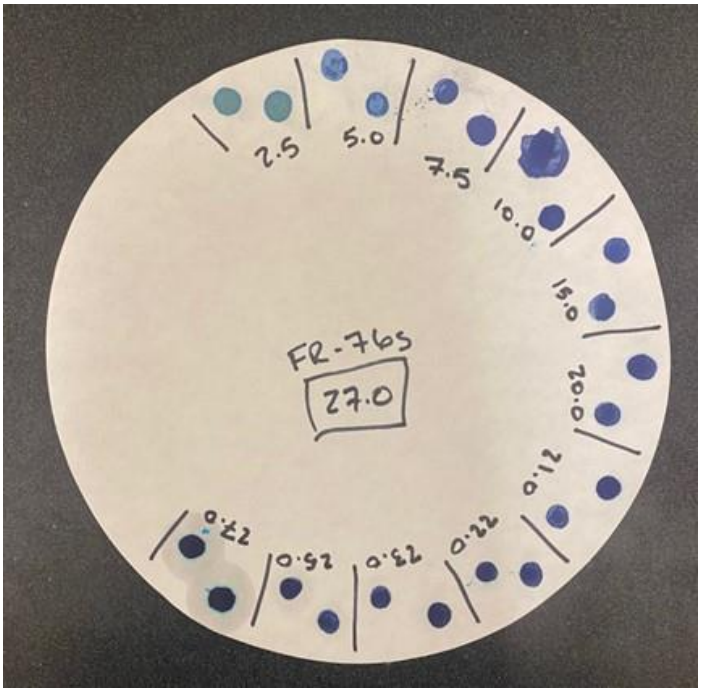

Figure 4.8: Methylene Blue Test

Aggregate Degradation Tests

Durability Index (AASHTO T 210 and CTM 229)

The test procedures of both AASHTO T 210 and CTM 29 are identical in sample preparation and result calculation. The Aggregate Durability Index was designed to measure an aggregate's resistance to generating fines when shaken in the water. For coarse (materials retained on #4 sieve) and fine (materials passing #4 sieve) aggregates, separate and different procedures were used. In this project, all twenty-five samples were evaluated for both coarse and fine durability indices.

The Aggregate Durability Index test for coarse aggregate was summarized as follows: a sample of coarse aggregate of a specific grading was agitated in water using a mechanical washing vessel (Durability Index Agitator) for a period of 2 minutes. After discarding the minus No. 4 material, the washed sample was dried at 110°C (230°F) and recombined to the final grading (Table 4.2). This washed and dried coarse aggregate sample was agitated in water using a mechanical washing vessel for a period of 10 minutes. The resulting wash water and minus 75 µm (No. 200) size fines were collected and mixed with stock calcium chloride solution and placed in a plastic sand equivalent cylinder. After a 20-minute sedimentation time, the level of the sediment column was read. The height of the sediment was then used to calculate the durability index of the coarse aggregate (D_C).

Table 4.2: Coarse Aggregate Grading Used for Durability Index Test

Aggregate Size	Preliminary Weight, g	Test Weight, g
19.0 to 12.5 mm (¾ to ½ in.)	1070 ± 10	1050 ± 10
12.5 to 9.5 mm (1/2 to 3/8 in.)	570 ± 10	550 ± 10
9.5 to 4.75 mm (3/8in. to No.4)	910 ± 5	900 ± 5
Total	2550 ± 25	2500 ± 25

For the fine aggregate sample, 500 ± 25 g of fine aggregate was agitated in water using a mechanical washing vessel for a period of 2 minutes. The gradation of the fine aggregate is blended from the passing #4 sieves materials based on the weight in Table 2.5, except the passing #200 material. As a result, the total weight is 495 g. The resulting wash water and minus 75 µm (No. 200) size fines were discarded. The rest retained on No. 200 material was dried at 110°C. The fine aggregate sample was then evaluated by AASHTO T 176 under the reference method using a mechanical shaker with only one modification to the shaking time: a shaking time of 10 minutes instead of 45 s. The SE reading became the durability index of the fine aggregate (D_f).

Micro-Deval Tests (Coarse Aggregate AASHTO T 327 and Fine Aggregate ASTM D7428)

The Micro-Deval test measures the abrasion resistance and durability of mineral aggregates resulting from a combination of actions, including abrasion and grinding, between aggregate particles and steel balls in the presence of water. Coarse and fine aggregates have different test procedures. In this project, all twenty-five samples were evaluated as both coarse aggregates following AASHTO T 327 and fine aggregates following ASTM D7428.

For coarse aggregate, a washed and dried sample with standard grading was initially soaked in water for no less than 1 hour. The sample weighed 1500 ± 5 g (Table 4.3). It was then placed in a stainless-steel jar with 2000 ± 50 ml of tap water and an abrasive charge of 5000 g of 9.5 mm diameter steel balls. The jar, aggregate, water, and charge were revolved at 100 rpm for 2 hrs depending on the particle size. The sample was then washed and oven-dried. The loss was determined as the amount of material passing the 1.18 mm (#16) sieve, expressed as a percent by mass of the original sample. AASHTO T 327 lists %

loss limits that have been found to separate coarse aggregates with satisfactory performance from those of fair or poor performance (Table 4.4) (AASHTO, 2022).

Table 4.3: Coarse Aggregate Grading for Micro-Deval Test (AASHTO T 327)

Aggregate Size	Test Weight, g
19.0 to 16.0 mm (¾ to 5/8 in.)	375
16.0 to 12.5 mm (5/8 in. to 1/2 in.)	375
12.5 to 9.5 mm (1/2 in. to 3/8 in)	750
Total	1500 ± 5

Table 4.4: Satisfactory Loss Limits for Coarse Aggregate (AASHTO T 327)

Application	Maximum Micro-Deval Abrasion Loss, %
Granular subbase	30
Granular base	25
Open-graded base course	17
Asphalt concrete base course and secondary surface course	21
Asphalt concrete surface course	17, 18

For fine aggregates, a 500 ± 5 g sample of washed and oven-dried fines with standard grading was initially soaked in water for no less than one hour (Table 4.5). The sample was then placed in a stainless-steel jar with 750 ± 50 ml of water and an abrasive charge of 1250 g of 9.5 mm diameter steel balls. The jar, aggregate, water, and charge were revolved at 100 rpm for 15 minutes. The sample was then washed and oven-dried. The loss was the amount of material passing the 75 µm (#200) sieve expressed as a percent by mass of the original sample. ASTM D7428 also lists % loss limits that have been found to separate fine aggregates with satisfactory performance from those with fair or poor performance (Table 4.6) (AASHTO, 2022).

Table 4.5: Fine Aggregate Grading for Micro-Deval Test (ASTM D7428)

Aggregate Size	Test Weight, g
No.4 to No.8	50
No. 8 to No. 16	125
No. 16 to No. 30	125
No. 30 to No. 50	100
No. 50 to No. 100	75
No. 100 to No. 200	25
Total	500 ± 5 g

Table 4.6: Satisfactory Loss Limits for Fine Aggregate (ASTM D7428)

Application	Maximum Micro-Deval Abrasion Loss, %
Granular subbase	35
Granular base	30
Open graded base course	25
Structural Concrete	20
Concrete Pavement	20
Asphalt concrete base course and secondary surface course	25
Asphalt concrete surface course	15
Asphaltic concrete—all traffic levels	15 for manufactured sand, 20 for natural sand
Bedding and Joint sands for interlocking concrete pavements in vehicular applications with greater than 1.5 million lifetime equivalent standard axle loads (ESALS) of 11 000 kg	8

5. The Modified Idaho Degradation Test (MIDT)

Appendix K lists the modified test procedure for the Idaho Degradation Test (IT-15). This procedure was used to conduct all Idaho Degradation Tests in this project (Figure 5.1). This chapter explains some of the major modifications in the suggested procedure compared to the current ITD's IT-15.

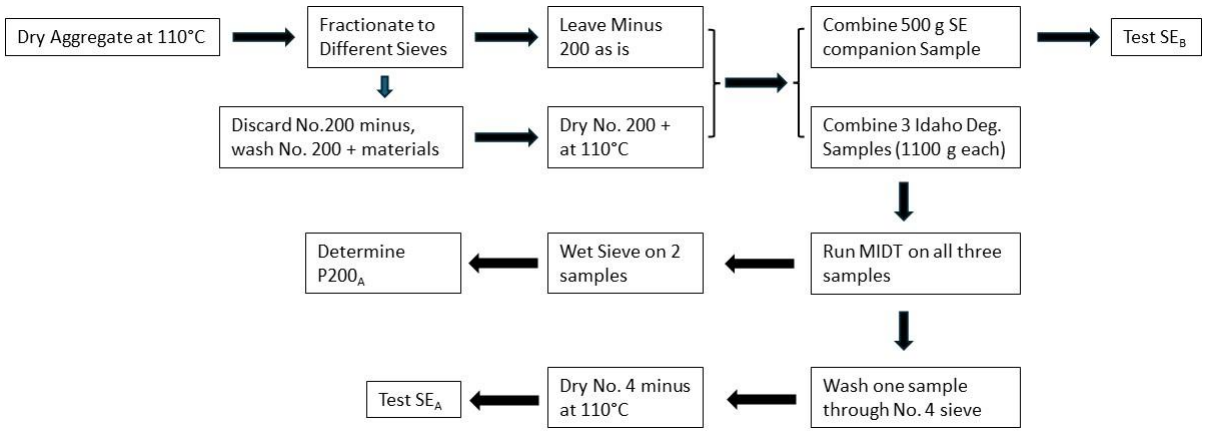

Figure 5.1: Flow Chart of the Modified Idaho Degradation Test

Modifications of Testing Apparatus

The Container

After reviewing the practice of running the Idaho Degradation Test, all Idaho laboratories are currently using plastic containers when running the Idaho Degradation Test. The TAC for this project has agreed to use plastic containers as the Container and discontinue using glass jars in the future. The researchers then selected a one-gallon, round, wide-mouth plastic jar made by Uline (www.uline.com) (Product No. S-17077) as the Container for this study (Figure 5.2). The lid has a 4 in. diameter with a foamed polyethylene liner (Product Number: S-18108).

Table 5.1 lists the requirements for the materials and dimensions of the Container to standardize it and provide abundant choices. Plastic jars from manufacturers other than Uline fit these dimensions. Practitioners can select other companies' products if they meet these requirements. These containers are not one-time items and can be used repeatedly.

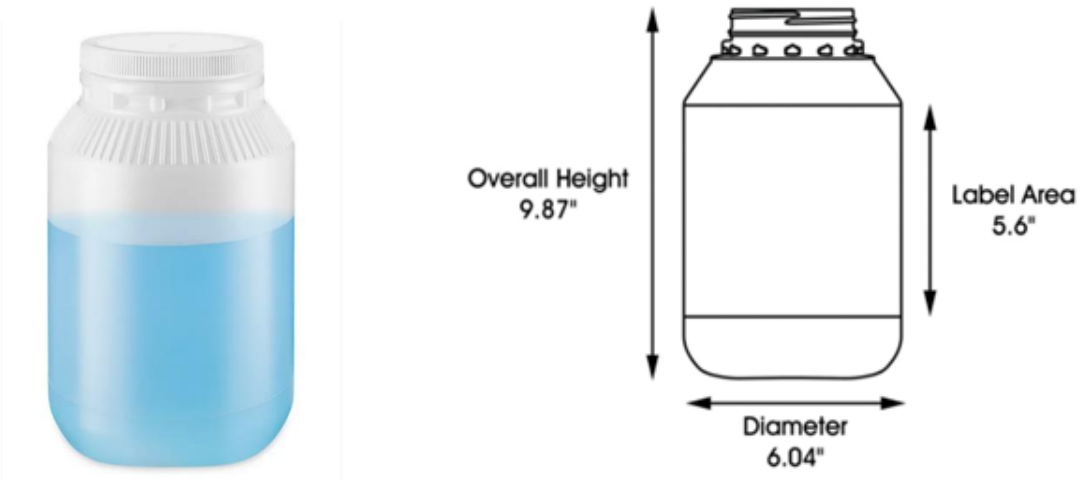

Figure 5.2: The Container for the Idaho Degradation Test

Table 5.1: The Requirements of the Container

Items	Requirements
Materials	Plastic (Polyethylene or Polypropylene)
Size	1 gallon
Height with the Cap	10 ± ¼ in.
Diameter of the Jar	6 ± ¼ in.
Diameter of the Mouth (Opening)	4 ± ¼ in.
Height of the Cap	4 3/8 ± 1/8 in.
Liner Material	Plastic (Polyethylene or Polypropylene) or Rubber
Thickness of the Liner	3/64 ± 1/64 in.

The Testing Machine

No equipment manufacturer makes a special testing machine for the Idaho Degradation Test. Every lab in Idaho that tests the Idaho Degradation has made its own apparatus. In this study, the researcher first conducted a search to locate a commercial testing machine that could be used for this test. Based on the search, Glas-Col® (www.glascol.com) makes a Dry Powder Rotator (Item Number: 099A RD9912) that can be used as the testing machine for the Idaho Degradation Test (Figure 5.3). The machine has a control box to adjust the rotation speed from 2 to 83 rpm, which covers the 31±2 rpm required by the proposed Idaho Degradation Test. It has an adjustable rack that can hold jars up to 10 inches tall and 7 inches in diameter, which adjusts to allow the axis of rotation to pass through the center of the container. A magnet counter is added to accurately determine the number of rotations.

Figure 5.3: Glas-Col's Dry Powder Rotator for the Idaho Degradation Test

The problem with Glas-Col's device is only one container can fit into the rack, which means only one test can be run at a time. To expedite the test, another apparatus was made (Figure 5.4). This device has one rating speed of 31 rpm, and two samples can be run simultaneously. It also has a magnet counter to accurately determine the number of rotations. These two devices were used interchangeably throughout the project. No significant difference in the results was observed based on the repeatability evaluation in Chapter 6.

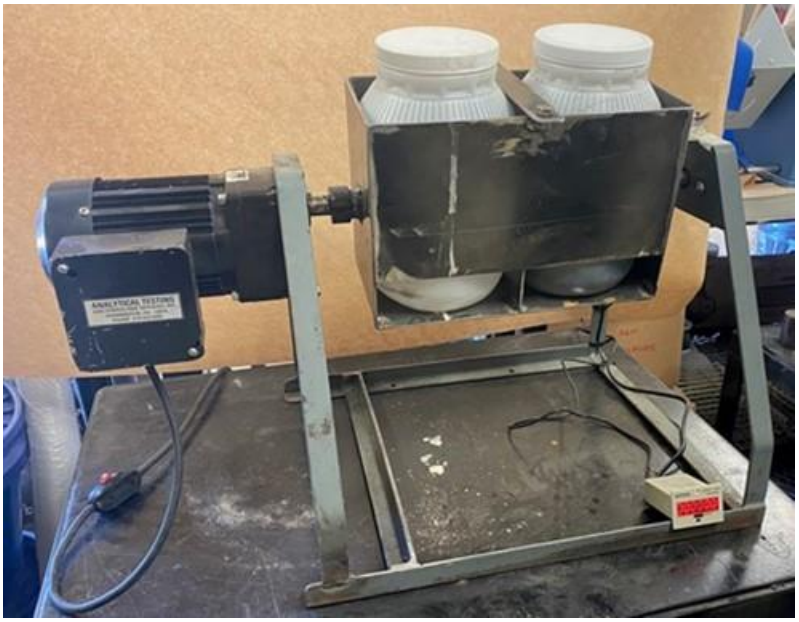

Figure 5.4: The Idaho Degradation Testing Apparatus

The description of the machine was listed in the modified IT-15 procedure (Section 3.2 in Appendix K):

> The apparatus is equipped with an electric motor that shall maintain a substantially uniform speed of 31±2 rotation per minute (rpm). It shall be equipped with spring tension or other suitable apparatus to securely hold the container(s) in section 3.1 in place and can be inserted and removed without binding. The container(s) shall be positioned so that the rotating axis passes at the center of the container(s), and the container(s) shall rotate in an end-over-end motion. The apparatus should also have a counter device to record the number of rotations.

Modifications of Sample Preparation

Sample Make-up

To limit the variances in aggregate gradations in the Idaho Degradation Test, a uniform gradation was suggested to prepare samples (Table 5.2). This gradation used in this research (Listed as MIDT) slightly differs from the proposed gradation by ITD (ITD, undated) listed previously in Table 2.5. The MIDT gradation also meets both ¾ inch B Plant Mix Aggregate specification in Table 703.04-1 – Nominal Maximum Size of Section 703.04 Aggregate for Untreated Base, Treated Base, and Road Mix and ¾ inch aggregate for HMA Table 703-0.5-2 (ITD, 2023). This gradation is also within the range listed in RP029 and the current IT-15.

Table 5.2: Idaho Degradation Test Uniform Gradation

Sample Make up	Sieve	ITD Weight (g)	ITD % Passing	MIDT Weight (g)	MIDT % Passing
	¾ in	**0**	**100**	**0**	**100**
16.6% passing the 3/4 in. and retained on the 1/2 in	½ in	**183**	**83**	**183**	**83**
16.6% passing the 1/2 in. and retained on the 3/8 in	3/8 in	**183**	**67**	**183**	**67**
16.7% passing the 3/8 in. and retained on the No. 4	No.4	**184**	**50**	**184**	**50**
19.1% passing the No.4 and retained on the No. 8	No. 8	**210**	**31**	**110**	**40**
10.5% passing the No.8 and retained on the No. 16	No. 16	**115**	**20**	**110**	**30**
5.9% passing the No.16 and retained on the No. 30	No. 30	**65**	**15**	**75**	**23**
3.6% passing the No.30 and retained on the No. 50	No. 50	**40**	**11**	**75**	**16**
3.2% passing the No.50 and retained on the No. 100	No. 100	**35**	**8**	**65**	**10**
2.7% passing the No.100 and retained on the No. 200	No. 200	**30**	**5.0**	**60**	**5.0**
5.0% passing No. 200	Pan	**55**		**55**	
	Total	1100		1100	

The 0.45 power chart of both gradations is shown in Figure 5.5. Although both gradations have the same % pass numbers on coarse aggregates (larger than #4), the MIDT gradation is much finer than the one proposed by ITD in the minus #4 portion. The MIDT gradation is located above the restricted zone, while the ITD-suggested gradation is located under the zone. The finer gradation of the MIDT has a larger number of fine aggregates. This gradation was selected for this project, if the higher number of fines

would create larger changes in % of P200 before and after the degradation test. The larger difference would expand the range of variances of the possible testing results of aggregate, which can easily distinguish the degradation resistances of different sources.

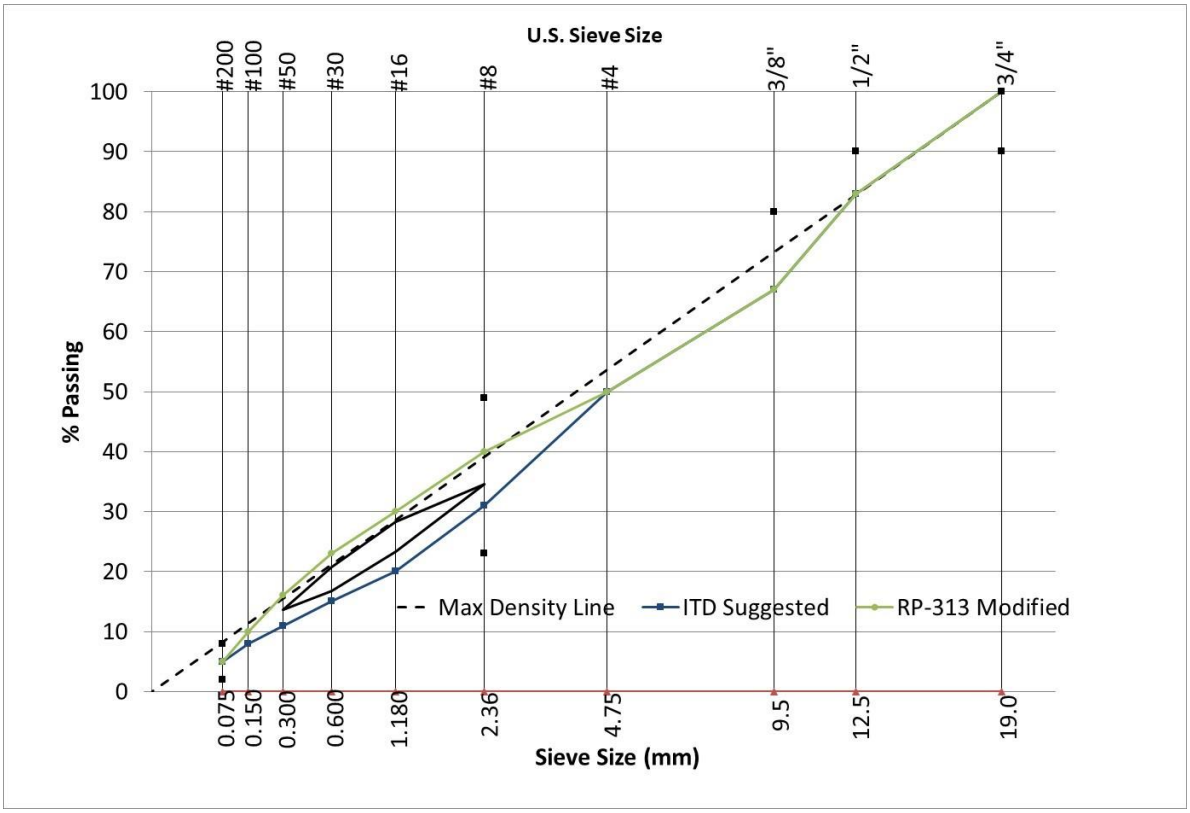

Figure 5.5: Uniform Gradations for the Idaho Degradation Test

Sample preparation

Aggregate Crushing and Blending

The current IT-15 procedure allows the blending of crushed aggregates with the original (uncrushed) sample to achieve the testing gradation. In the modified procedure used in this project, the samples for testing can only be uncrushed original samples or 100% crushed aggregates. For materials with original portions that can be fractioned into the gradation as intended for use, the original (uncrushed) sample was used without crushing. For materials with original portions that cannot be fractioned into the gradation as intended, the entire material was crushed to pass the ¾ in (19.0 mm) sieve to gain enough fractioned aggregates for testing.

Water Amount for Aggregate Soaking

In Section 5.1 of current IT-15 (Appendix B), it is required to add "enough water to cover the aggregate to a depth of approximately ½ inch." In Section 5.3, the specification mentions adjusting the water level so that "the aggregate is barely covered." This language caused some confusion among the technicians. After measuring the amount of water needed to cover the aggregates with the uniform gradation to ½ inch, 350 g of water was selected as the amount needed to fill the Container, and the step of adjusting the water level was deleted (Figure 5.6).

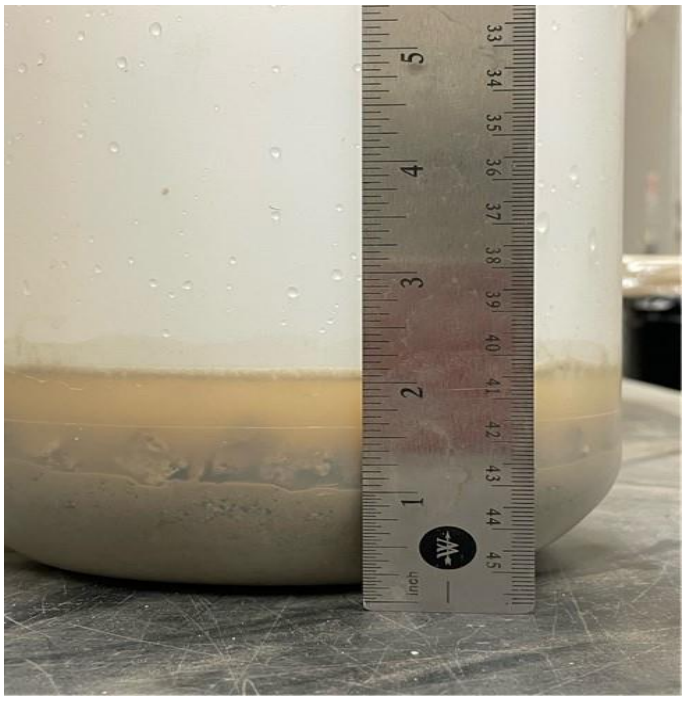

Figure 5.6: Water Amount (350 g) to achieve ½ in. coverage

Subtask for Determining Requirements for Aggregate Conditioning

The current IT-15 specification only allows the aggregates to be oven-dried at 60°C (140°F). The other tests involved in the project (AASHTO T 210 Durability Index, AASHTO T 327 Micro-Deval Test on Coarse Aggregate, and ASTM D7428 Micro-Deval Test on Fine Aggregate) all dry the test sample to a constant weight at 110°C (230°F). Furthermore, drying aggregate at 110°C (230°F) has been the practice for preparing testing samples for all other ITD tests on aggregates. If the Idaho Degradation Test allows 110°C (230°F) drying temperature, the technicians would not be forced to dry aggregate for the same source or project under two different conditions.

The current IT-15 specification requires a soaking time of more than 16 hours. However, the soaking time for the AASHTO T 327 Micro-Deval Test on Coarse Aggregate and ASTM D7428 Micro-Deval Test on Fine Aggregate is only 1-hour minimum, while the time of soaking for AASHTO T 210 is 1 minute for

coarse aggregate and 10 minutes for fine aggregate. By allowing a 1-hour conditioning time, the testing will be significantly shortened.

The TAC was concerned that allowing higher drying temperature and shorter conditioning time would a) alter the structure and reactivity of the clay inside the aggregate and b) limit the development of the swell due to insufficient soaking time. To understand the feasibility of conditioning the samples under these conditions, a subtask to understand the effects of different drying temperatures and soaking times was conducted.

Test Variables

Six different aggregates were selected for this subtask. Commercial Blend wasn't one of the twenty-five aggregates in this research. It was an aggregate used in a construction project by ITD. It was selected to expand the scope to include currently commercially processed aggregates.

- Ad-161c (Crushed and Uncrushed)
- Ore-16c (Uncrushed)
- Fr-76s (Uncrushed)
- By-68c (Uncrushed)
- Commercial Blend (Crushed)

Two drying temperatures were included: 60°C (140°F) and 110°C (230°F). Two soaking times were selected: 1 hour and 16 hours before testing. In the Modified Idaho Degradation Test (MIDT), three results were reported: SE_B, SE_A, and D_{P200}. SE_B is the SE value on the aggregate before the MIDT. SE_A is the SE value on the aggregate after the MIDT. D_{P200} is the difference in % P200 values of the aggregate before and after the MIDT.

Test Results

The test results of the subtask were organized based on the effects of temperature and soaking time and were listed in Tables 5.3 and 5.4, respectively. UC stands for Uncrushed, and C stands for Crushed. For example, Ad-161c UC 1hr stands for Uncrushed Ad-161c after 1 hour soaking. Ad-161c UC 60 stands for Uncrushed Ad-161c after 60°C drying.

Table 5.3: MIDT Results under Different Drying Temperatures

Aggregate Sample	D_{P200} (%)	D_{P200} (%)	SE_B (%)	SE_B (%)	SE_A (%)	SE_A (%)
	60°C	110°C	60°C	110°C	60°C	110°C
Ad-161c UC 1 hr.	7.2	6.0	46	47	35	36
Ad-161c C1 hr.	6.2	6.7	44	45	34	35
Ad-161c UC 16 hrs.	7.1	6.4	46	47	35	37
Ad-161c C 16 hrs.	6.9	7.0	44	45	34	36
Ore-16c UC 1 hr.	3.5	3.5	63	62	49	50
Ore-16c UC 16 hrs.	3.5	3.2	64	63	50	52
Fr-76s UC 1 hr.	3.6	4.3	44	44	35	36
Fr-76s UC 16 hrs.	4.6	3.8	44	44	35	34
By-0068c UC 1 hr.	11.8	11.6	69	69	35	34
By-0068c UC 16 hrs.	11.4	11.6	69	69	35	33
Blend C 1 hr.	5.0	5.1	67	69	45	47
Blend C 16 hrs.	5.0	5.2	67	69	46	46

Table 5.4: Idaho Degradation Test Results under Different Drying Time

Aggregate Sample	D_{P200} (%)	D_{P200} (%)	SE_B (%)	SE_B (%)	SE_A (%)	SE_A (%)
	1hr	16 hrs	1hr	16 hrs	1hr	16 hrs
Ad-161c UC 60	7.2	7.1	46	46	35	35
Ad-161c C 60	6.2	6.9	44	44	34	34
Ad-161c UC 110	6.0	6.4	47	47	36	37
Ad-161c C 110	6.7	7.0	45	45	35	36
Ore-16c UC 60	3.5	3.5	63	64	49	50
Ore-16c UC 110	3.5	3.2	62	63	50	52
Fr-76s UC 60	3.6	4.6	44	44	35	35
Fr-76s UC 110	4.3	3.8	44	44	36	34
By-0068c UC60	11.8	11.4	69	69	35	35
By-0068c UC 110	11.6	11.6	69	69	34	33
Blend C 60	5.0	5.0	67	67	45	46
Blend C 110	5.1	5.2	69	69	47	46

Effects of Drying Temperatures

Figure 5.7 shows the correlation between the D_{P200} values under 60°C drying versus those under 110°C drying. The correlations between the results of SE_B and SE_A are shown in Figures 5.8 and 5.9, respectively. In all three graphs, the data was forced to be fitted along the line of equality (y=x). The R^2 values indicated strong fits for all three tests (0.945 for D_{P200}, 0.993 for SE_B, and 0.938 for SE_A).

Paired two-tail t-tests were also conducted with this data (60°C versus 110°C) (Table 5.5). Based on the results of these t-tests, these two conditions created no statistically significant differences in the results of MIDT at a 95% confidence level.

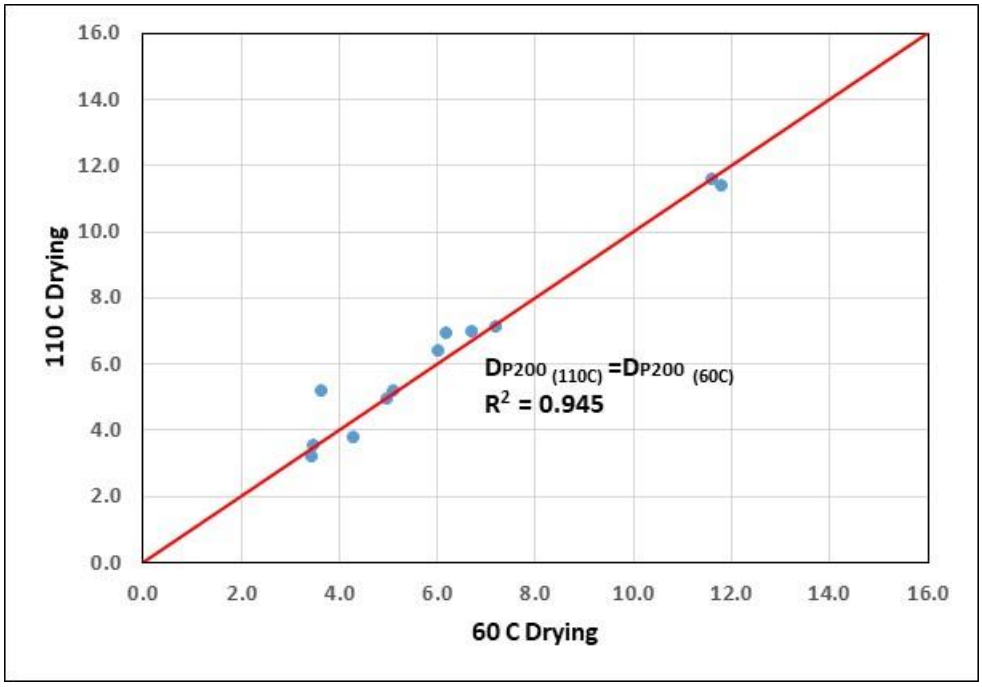

Figure 5.7: Effect of Drying Temperatures on D_{P200}

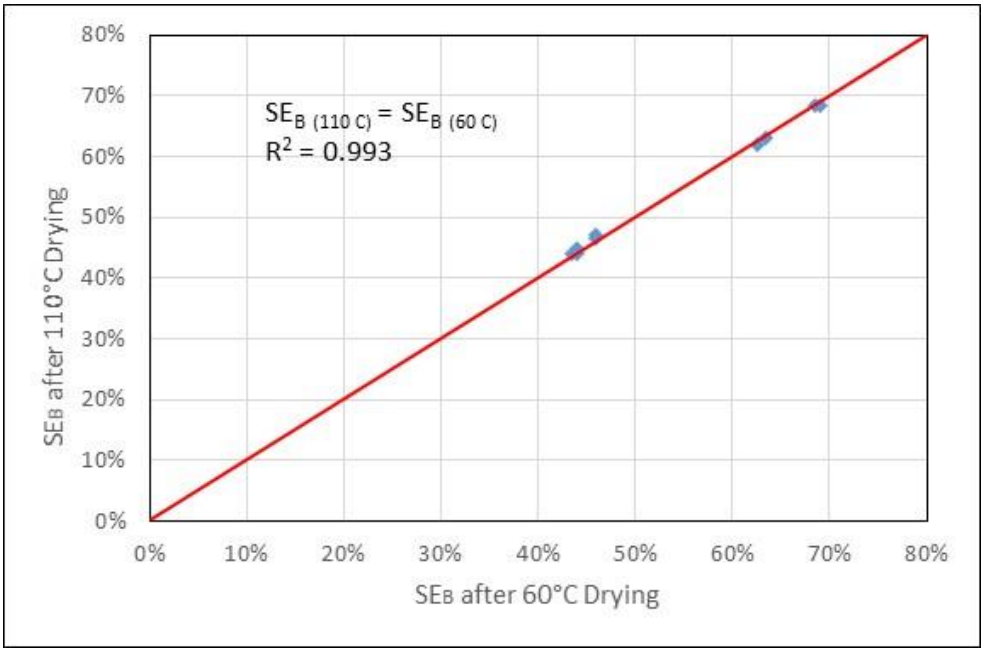

Figure 5.8: Effect of Drying Temperatures on SE_B

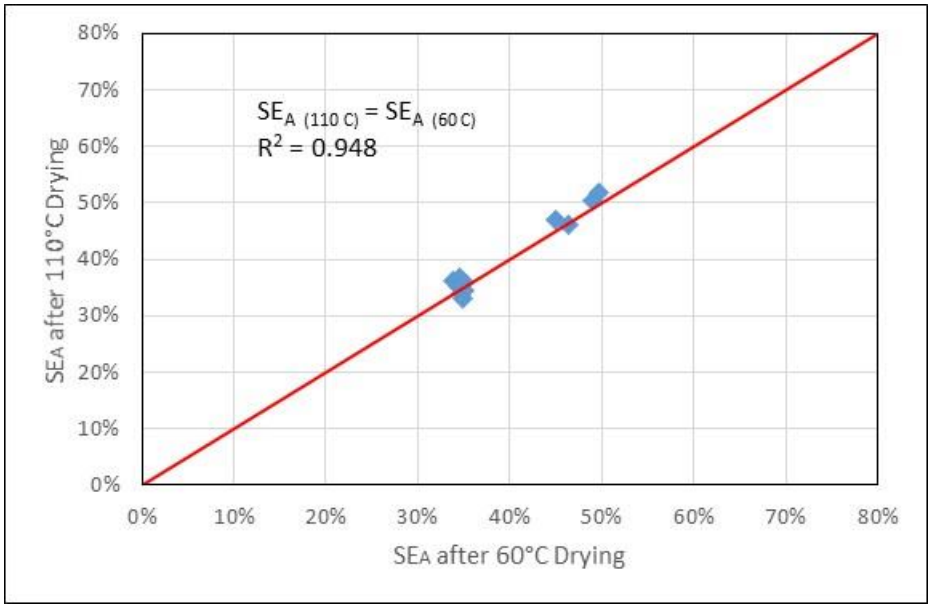

Figure 5.9: Effect of Drying Temperatures on SE_A

Table 5.5: T-tests on Idaho Degradation Test Results under Different Drying Temperatures

	Difference 60°C - 110°C	Difference 60°C - 110°C	Difference 60°C - 110°C
	D_{P200}	SE_B	SE_A
Degree of Freedom	11	11	11
t stat	1.179	-1.958	-2.073
t Critical two-tail	2.201	2.201	2.201
p-value	0.486	0.08	0.06
α	0.05	0.05	0.05

XRD tests were also run on the P200 materials from 60°C drying versus those from 110°C drying (Table 5.6). Both air-dry and Ethylene glycol-treated samples were included (Figure 5.10). A t-test was run on the data in Table 5.6. The t-value was -0.196, which was smaller than the t-critical of 2.262. The p-value was 0.848, which was more than 0.05. At a 95% confidence level, these two conditions (60°C and 110°C) created no statistically significant differences in the results of XRD tests of P200 materials. The data in Table 5.6 also indicate that there were no significant differences in the XRD results between crushed and uncrushed aggregates from the same source. Figure 5.11 shows the XRD data for crushed and uncrushed Ad-161c aggregates under 110°C drying conditions. There were no significant shifts among peak locations and intensities of the peaks. This means that the crushing action does not alter the mineralogy at each sieve size, and the breakdown of the aggregates was proportional to the component of the mineral structure of the source rocks. In the rest of the XRD tests in this research, crushed and uncrushed samples were considered identical for determining mineral and clay contents.

Table 5.6: Effect of Drying Temperature on XRD results

Aggregate Sample	d (Å) (60°C)	d (Å) (110°C)
Ad-161c UC AD	14.653	14.752
Ad-161c C AD	14.685	13.952
Fr-76s UC AD	6.528	7.127
By-0068c UC AD	14.227	14.312
Ore-16c UC AD	14.417	14.227
Ad-161c UC EG	17.583	17.583
Ad-161c C EG	17.498	17.98
Fr-76s UC EG	17.444	16.87
By-0068c UC EG	14.424	14.478
Ore-16c UC EG	17.148	17.596

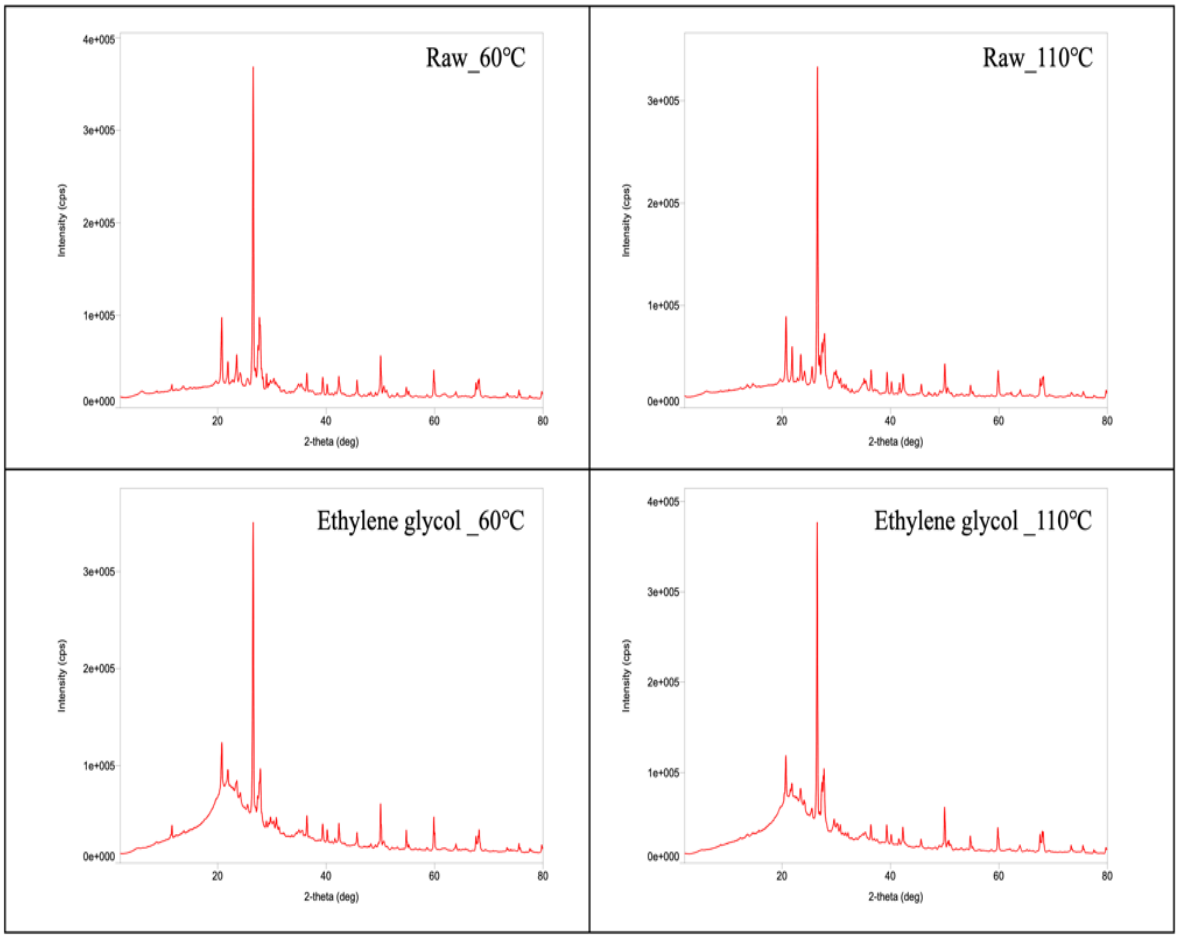

Figure 5.10: XRD results for By-0068c UC under Different Drying Temperatures

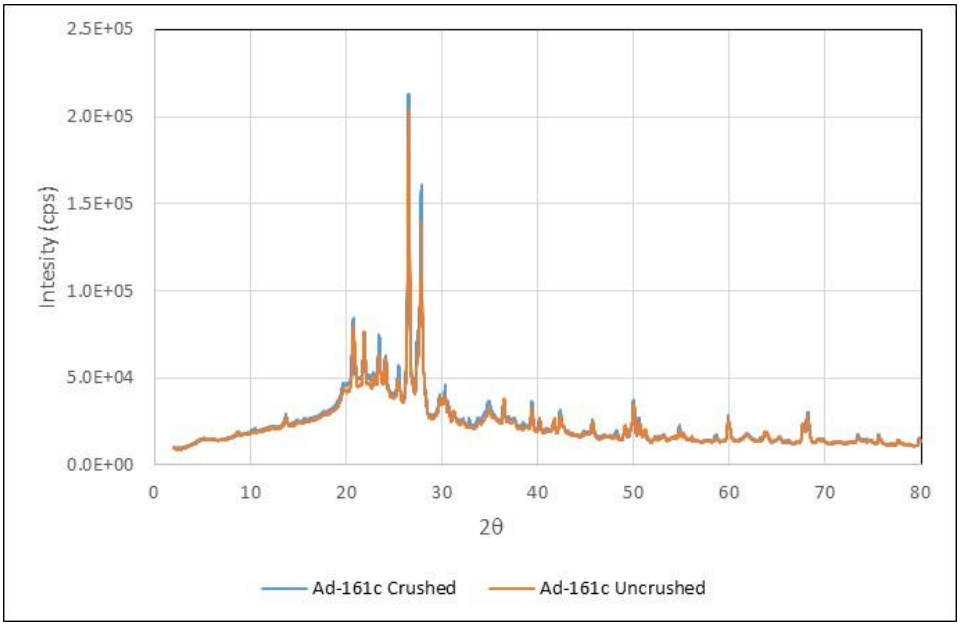

Figure 5.11: XRD results for Ad-161c (Crushed versus Uncrushed)

Effects of Soaking Time

Figure 5.12 shows the correlation between the D_{P200} values under 1 hour soaking versus those under 16 hours soaking.

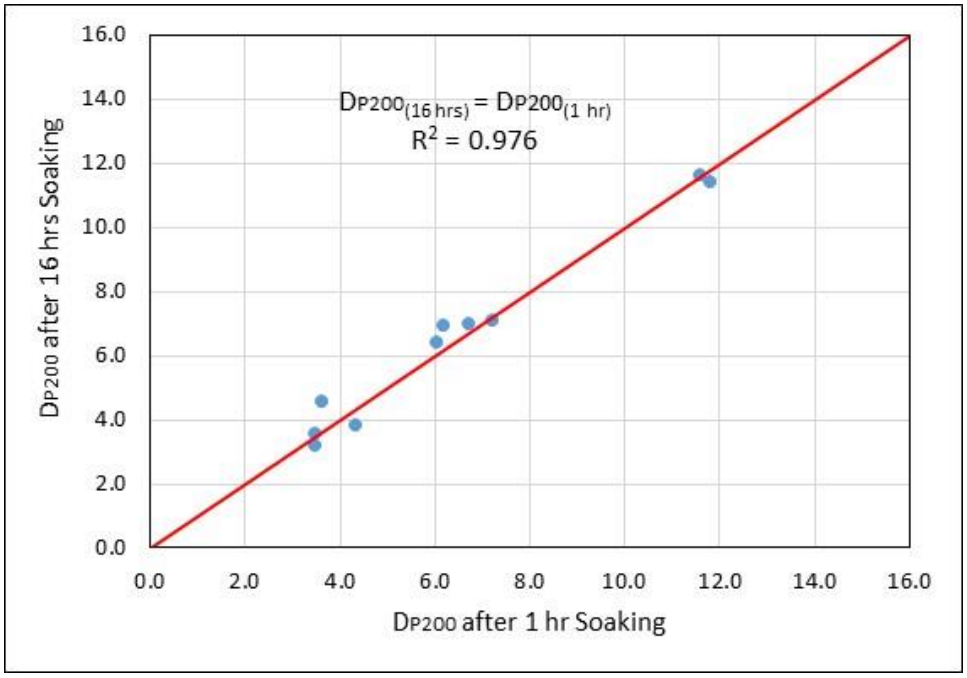

Figure 5.12: Effect of Soaking Times on D_{P200}

Figures 5.13 and 5.14 show the correlations between SE_B and SE_A results, respectively. In all three graphs, the data was forced to be fitted along the line of equality (y=x). The R^2 values indicated strong fits for all three tests (0.976 for D_{P200}, 0.998 for SE_B, and 0.984 for SE_A).

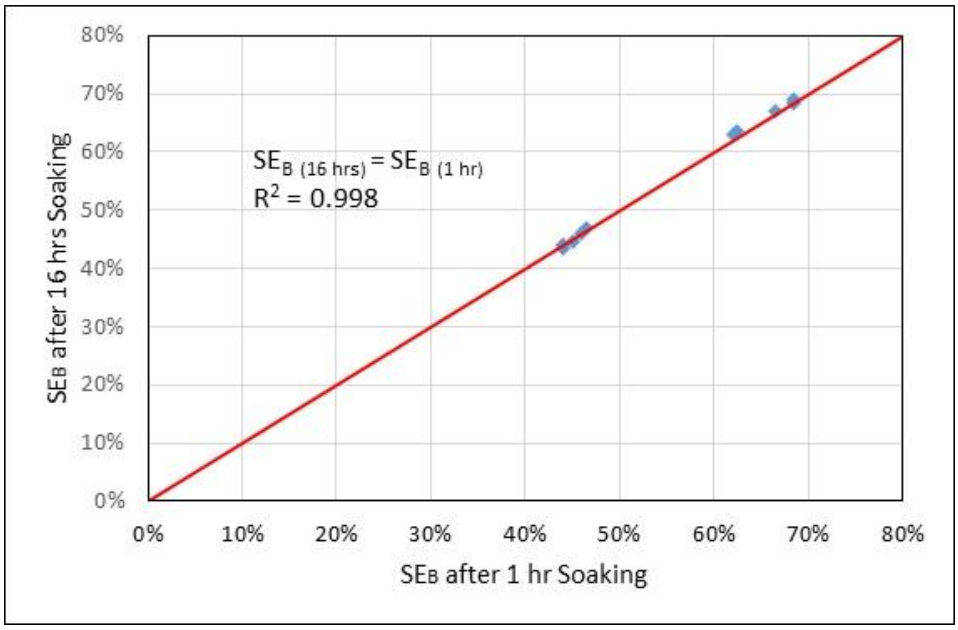

Figure 5.13: Effect of Soaking Times on SE_B

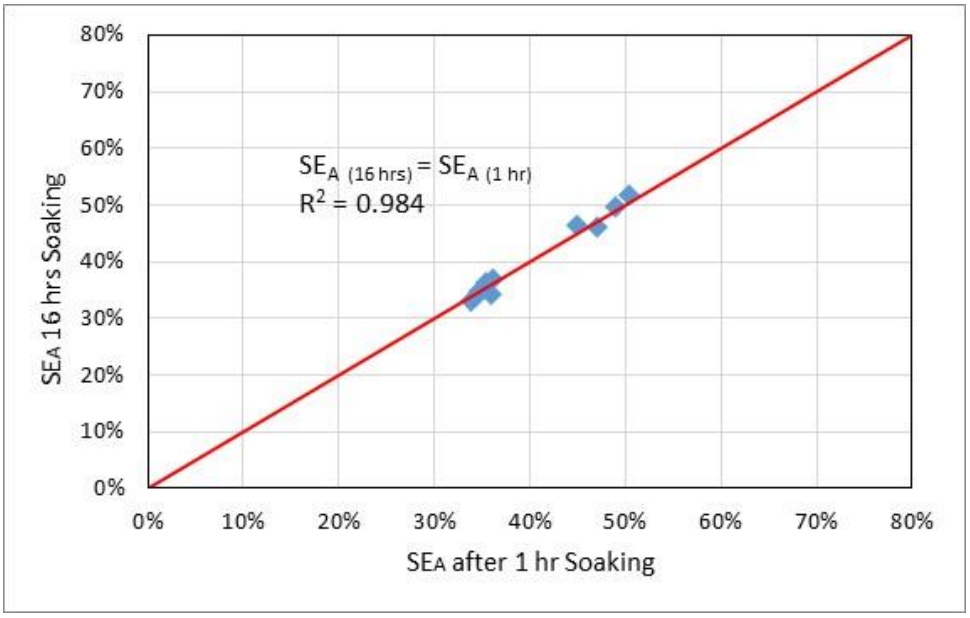

Figure 5.14: Effect of Soaking Time on SE_A

Paired two-tail t-tests were also conducted with this data (1 hour versus 16 hours) (Table 5.7). Based on the results of these t-tests, these two conditions created no statistically significant differences in the results of the MIDT at a 95% confidence level.

Table 5.7: T-tests on Idaho Degradation Test Results under Different Soaking Times

	Difference 1 hour – to 16 hrs.	Difference 1 hour – to 16 hrs.	Difference 1 hour – to 16 hrs.
	D_{P200}	SE_B	SE_A
Degree of Freedom	11	11	11
t stat	-0.745	-1.449	-0.376
t Critical two-tail	2.201	2.201	2.201
p-value	0.472	0.175	0.714
α	0.05	0.05	0.05

Review of Testing Results

The TAC for this project reviewed the results from the subtask and decided to proceed with a 110°C drying temperature for the rest of the project, partially based on the acceptance of this drying condition in other AASHTO tests. Also, it was decided that the P200 fines could only be completely separated from the coarse aggregate surface so that the accurate amount of P200 fines could be determined with an oven-dried sample at 110°C. Due to the limited number of evaluated samples, the minimum soaking time was kept at 16 hours. To provide a reasonable range of the soaking time, a maximum of 20 hours was added to the procedure.

6. Results and Discussions

Clay Identification

Results of XRD Tests

Table 6.1 shows the mineralogy test results of the P200 materials for different aggregates used in this research. The ND in the table stands for Not Detected. The results indicated significant variances in mineral structures, especially the clay content, among these aggregates. For example, there are three different basalts involved in this research: Id-267c, Vy-62c, and Cs-193s. Both Id-267c and Cs-193s contained a large amount of Calcite, while Vy-62c had no Calcite in it. Although these results were obtained only from the P200 materials, these results can be used to identify the structural differences among different aggregates and to understand the effect of clay on the degradation of the aggregates.

Table 6.1: Bulk Mineralogy (%) of Different Sources

Source	Quartz	K-Feldspars	Plagioclase	Calcite	Dolomite	Siderite	Mica	Total Clay	Total
By-0068c	39.7	1.1	10.3	14.7	3.1	ND	17.9	13.3	100
Br-0134c	50.0	0.6	9.5	6.4	2.1	1.3	16.8	13.3	100
Kt-0214c	46.5	5.3	18.2	10.1	0.4	ND	12.1	7.4	100
Id-267c	3.4	ND	59.9	17.2	0.6	ND	ND	18.9	100
Id-276c	1.3	0.2	0.7	88.9	4.0	ND	2.2	2.7	100
Ad-161c	25.1	10.3	50.7	ND	ND	ND	ND	13.9	100
Ore-16c	44.6	33.0	12.6	ND	ND	ND	ND	9.9	100
Vy-62c	2.2	ND	76.2	ND	ND	ND	ND	21.7	100
Cs-185s	51.5	14.2	9.7	8.7	1.2	ND	ND	14.6	100
Cs-193s	14.6	ND	62.6	18.3	ND	ND	ND	4.4	100
Tf-25s	12.7	0.7	1.1	10.8	72.2	ND	ND	2.5	100
Bl-70s	43.8	2.0	3.6	38.5	3.9	ND	ND	8.1	100
Cr-14s	2.9	0.5	0.2	94.4	0.4	ND	ND	1.7	100
Bn-128s	60.6	3.7	5.9	17.2	2.3	ND	ND	10.4	100
Fr-76s	26.6	2.5	36.8	ND	17.0	ND	ND	17.2	100
Ma-54s	61.2	3.6	3.5	21.6	4.9	ND	ND	5.2	100

Table 6.2 lists the components of clays inside the aggregates evaluated in this project. The clay components were divided into four groups: Illite, Kaolinite, Chlorite, and Smectite/Montmorillonite for the rest of the report, montmorillonite is used to represent smectite. No mixed-layered illite-smectite clay was detected through XRD. Illite, Kaolinite, and Chlorite are all non-expanding clay materials. Montmorillonite can expand to several times its original volume by taking in water between the sheet structure (the TOT layers: tetrahedral (T) and octahedral (O)). The swelling or shrinking of the clays inside the aggregates is directly related to the amount of montmorillonite. The montmorillonite clay is derived by weathering volcanic ash. This means that volcanic rock and basalt should contain large amounts of montmorillonite. The clays in the three different basalts rocks, Id-267c, Vy-62c and Cs-193s,

were all primarily montmorillonite. Id-267c and Vy-62c contained 100% montmorillonite clay, while the clays in Cs-193s were made of more than 70% montmorillonite.

Table 6.2: Clay Content (%) of Different Sources

Source	Illite	Kaolinite	Chlorite	Montmorillonite	Total
By-0068c	0.8	0	83.1	16.0	100
Br-0134c	0.8	82.6	10.0	6.6	100
Kt-0214c	60.0	0	21.4	18.6	100
Id-267c	0	0	0	100.0	100
Id-276c	11.5	20.3	5.9	62.4	100
Ad-161c	20.5	13.3	0	66.2	100
Ore-16c	3.4	0.5	96.1	0	100
Vy-62c	0	0	0	100.0	100
Cs-185s	15.6	3.8	1.5	79.1	100
Cs-193s	17.2	10.2	0	72.6	100
Tf-25s	100.0	0	0	0	100
Bl-70s	27.3	13.9	8.0	50.8	100
Cr-14s	97.4	2.6	0	0	100
Bn-128s	24.5	5.2	3.8	66.4	100
Fr-76s	36.4	8.0	2.4	53.3	100
Ma-54s	42.4	8.8	5.1	43.7	100

Petrographic Analysis

The petrographic analysis results are listed in Appendix L. Table 6.3 indicates the rock type determined based on the XRD data in Table 6.1, the geological info in Appendix I, RP-212 Report (Gillerman and Weppner, 2014), and the petrographic analysis results. The rock type of the aggregates varied among the districts. The rocks from District 1 for this research were all with a high amount (>10%) of mica minerals between the grains. The high mica minerals reduced the contact area between the grains. The reduced contact area between the grains could cause weak bonding and low durability, which results in poor MIDT results. The aggregates provided by District 6 were all sedimentary rocks. Although they were all sandstones, the textures and the structures of these rocks were quite different. Both Bn-128s and Ma-54s had a high amount of calcite, while Fr-76s contained none of it.

The petrographic images also provide in-depth information about the clay formation inside the aggregate. For example, in the petrographic analysis of Cs-185s, the images indicated that some of the small volcanic glass shards were altered into smectite/montmorillonite clay minerals with their characteristic honeycomb structure. A scanning electron microscope (SEM) image shows the montmorillonite clay inside Cs-185s (Figure 6.1). This means that Cs-185s might produce a high amount of montmorillonite when it is being processed.

Most rock sources in Idaho are combinations of multiple different rocks (Gillerman and Weppner, 2014). The petrographic thin slides were prepared using one rock. Due to the constraints of sampling (one

rock), the petrographic analysis alone cannot identify the “true” cause. Information from other technologies, such as XRD and MBV, should supplement the petrographic analysis.

Table 6.3: Rock Forms Determined Based on Petrographic Analysis

Source	Rock Description	Rock Classification
By-0068c	Micaceous, Quartz-Rich Granitoid	Metamorphic
Br-0134c	Greywacke	Sedimentary
Kt-0214c	Micaceous, Quartz-Rich Granitoid	Metamorphic
Id-267c	Calcareous Basalt	Igneous
Id-276c	Marble	Metamorphic
Ad-161c	Micaceous Syenogranite	Igneous
Ore-16c	Quartz Syenite	Igneous
Vy-62c	Basalt	Igneous
Cs-185s	Quartz-Rich Granitoid	Igneous
Cs-193s	Basalt	Igneous
Tf-25s	Dolomite	Sedimentary
Bl-70s	Very Calcareous, Silty Sandstone	Sedimentary
Cr-14s	Very Fossiliferous Limestone	Sedimentary
Bn-128s	Calcite cemented sandstone	Sedimentary
Fr-76s	Porous, quartz-rich sandstone	Sedimentary
Ma-54s	Fine-grained, calcite cemented sandstone	Sedimentary

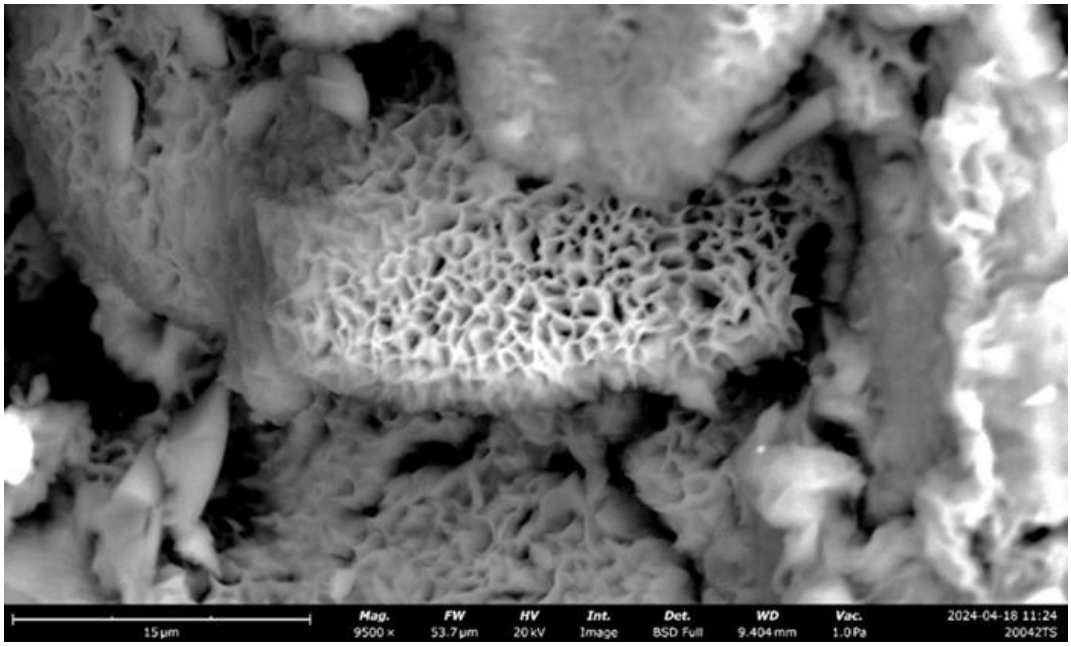

Figure 6.1: Scanning Electron Microscope Images of montmorillonite (Cs-185s)

Methylene Blue

Table 6.4 lists the MBV values versus clay contents for different aggregates in this study. The total clay content and the total montmorillonite content for different aggregates were also included in the table. The total montmorillonite content was calculated by multiplying the total clay content in Table 6.1 with the montmorillonite content in Table 6.2. From the table, Cs-185s had the highest MBV value (27.5) and a lower total montmorillonite % (11.5). This phenomenon could be explained by the alternation of glass shards to montmorillonite, which is shown in petrographic analysis (Figure 6.1). Because these montmorillonite particles were still attached to the rock surface, they were not identified through XRD as part of the clay in P200 material. The MBV test could react with all exposed montmorillonites, including those still attached to the rocks. The MBV is proportional to the product of the clay content times the specific surface of the clay. Both the "true" clay content and the "true" specific surface area of the clay were all higher than the numbers indicated in Table 6.4.

Table 6.4: The MBV Values and the Clay Contents of Different Sources

Source	Total Clay (%)	Montmorillonite Content of the Clay (%)	Total Montmorillonite (%)	MBV (mg/g)
By-0068c	13.3	16.0	2.1	3.5
Br-0134c	13.3	6.6	0.9	3.3
Kt-0214c	7.4	18.6	1.4	2.8
Id-267c	18.9	100.0	18.9	22.5
Id-276c	2.7	62.4	1.7	4.8
Ad-161c	13.9	66.2	9.2	16.2
Ore-16c	9.9	0	0.0	8.5
Vy-62c	21.7	100.0	21.7	17.0
Cs-185s	14.6	79.1	11.5	27.5
Cs-193s	4.4	72.6	3.2	2.3
Tf-25s	2.5	0	0.0	1.3
Bl-70s	8.1	50.8	4.1	3.3
Cr-14s	1.7	0	0.0	2.5
Bn-128s	10.4	66.4	6.9	15.0
Fr-76s	17.2	53.3	9.2	13.5
Ma-54s	5.2	43.7	2.3	6.5

Figure 6.2 shows the relationship between the total clay contents versus the MBV values. The correlation between the total montmorillonite content with the MBV values is demonstrated in Figure 6.3. Although both plots showed positive correlations, the R^2 values were not high (0.5175 and 0.6638). The less-than-strong correlations between the MBV and the two contents (Total Clay Content and Total Montmorillonite) were caused by the variances in the clay component. The MBV values were obtained by testing the amount of methylene blue needed to cover the surface area of the clay. It does not differentiate the types of clay. Different types of clay absorb different amounts of methylene blue. Although the correlations between individual clay type to the methylene blend amount were all strong

positive linear, the rates of the increase between the clay content to the MBV were different (Pitre, 2012). Even though the total clay content is the same, the MBV will be different when the components inside the clay are different. This will cause the spread of the data and weaken the correlation.

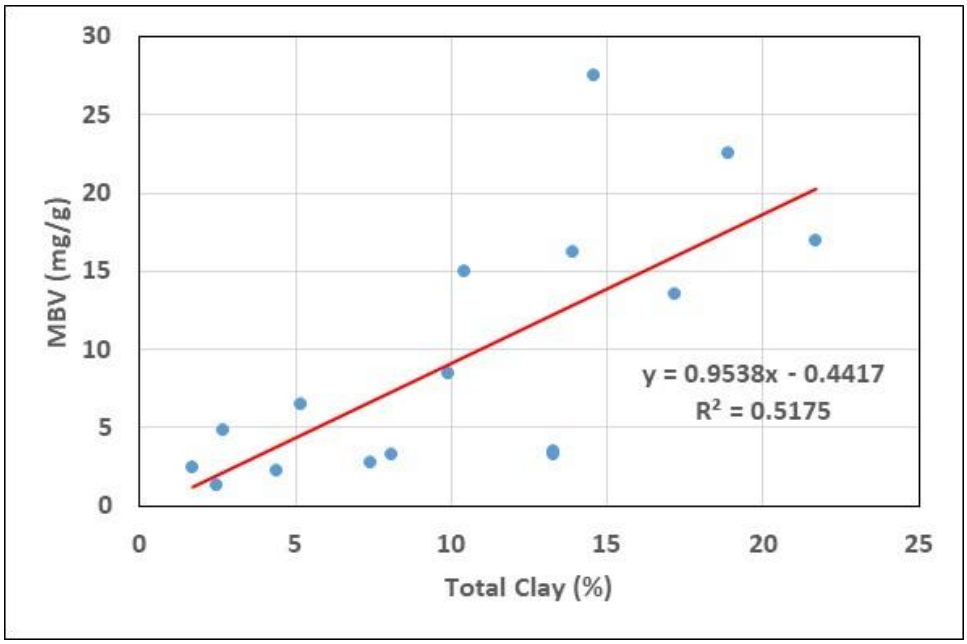

Figure 6.2: The Total Clay Content versus the MBV

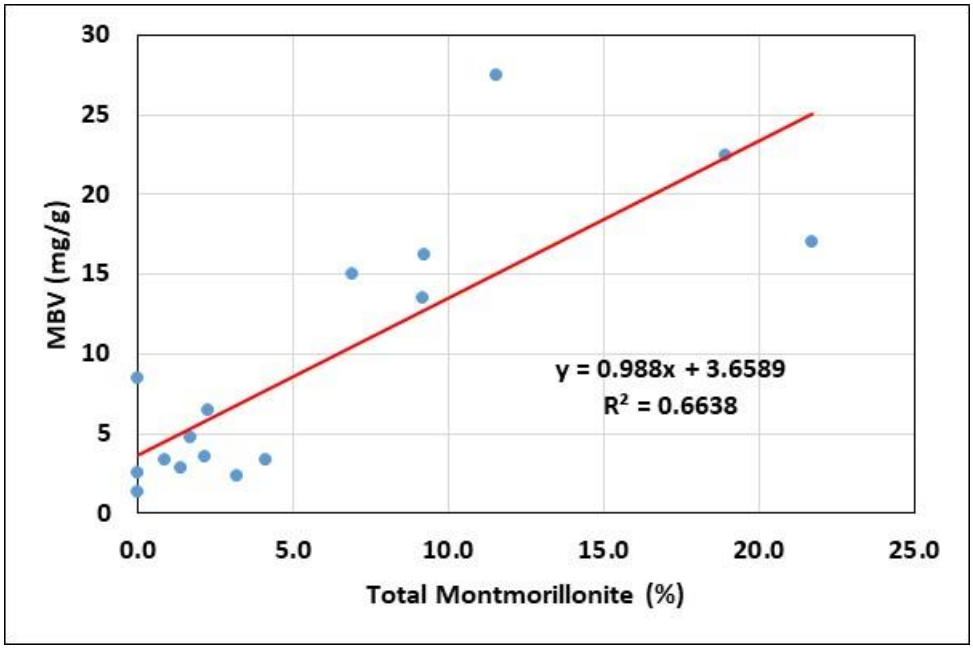

Figure 6.3: The Total Montmorillonite Content versus the MBV

The MBV values between crushed and uncrushed aggregates were also compared (Table 6.5). There was no significant difference in MBV results between crushed and uncrushed aggregates from the same source. This indicated that the crushing action in the preparation of the samples did not significantly change the percentages of the components inside the clay, the total clay content, and the total montmorillonite content inside the P200 materials. This finding correlated to the observations in XRD results of both uncrushed and crushed aggregates (Table 5.6 and Figure 5.11).

Table 6.5: The MBV Values (Crushed versus Uncrushed)

	MBV (%) Uncrushed	MBV (%) Crushed
By-0068c	3.5	3.5
Id-276c	4.8	4.8
Ad-161c	16.2	16.2
Ore-16c	8.5	8.5
Cs-185s	27.3	27.5
Bl-70s	3.3	3.3
Bn-128s	15.0	15.0
Fr-76s	13.5	13.5
Ma-54s	6.5	6.7

Test Results of the Degradation Tests

Table 6.6 lists all the degradation test results on the twenty-five aggregate samples in this project. The tests include the Modified Idaho Degradation Test (MIDT), the Durability Index Test (Coarse and Fine Aggregates), the Micro-Deval Tests (Coarse and Fine Aggregates), and the Methylene Blue Test. In this Chapter, the data was analyzed to determine the proper usage of these tests in evaluating the aggregates in Idaho.

Table 6.6: Summary of Test Results of Different Degradation Tests

District	Aggregate	Micro-Deval Abrasion Loss (%) Coarse	Micro-Deval Abrasion Loss (%) Fine	Durability Index Coarse (D_c)	Durability Index Fine (D_f)	MIDT $P200_A$ (%)	MIDT SE_B (%)	MIDT SE_A (%)	MIDT D_{P200} (%)	MBV (mg/g)
Dist. 1	**By-0068c UC**	10.8	27.0	93	69	16.6	69	33	11.6	3.5
Dist. 1	**By-0068c C**	9.1	27.8	87	69	16.4	58	32	11.4	3.5
Dist. 1	**Br-0134c C**	14.1	32.1	80	59	18.4	61	27	13.4	3.3
Dist. 1	**Kt-0214c C**	5.1	16.6	90	76	12.2	72	48	7.2	2.8
Dist. 2	**Id-267c C**	16.2	30.2	65	27	18.6	50	22	13.6	22.5
Dist. 2	**Id-276c UC**	16.1	17.1	82	80	12.8	73	50	7.8	4.8
Dist. 2	**Id-276c C**	18.8	22.6	80	79	15.9	63	31	10.9	4.8
Dist. 3	**Ad-161c UC**	15.4	11.0	89	56	11.0	47	37	6.0	16.2
Dist. 3	**Ad-161c C**	19.0	12.2	93	51	11.7	45	36	6.7	16.2
Dist. 3	**Ore-16c UC**	3.5	6.1	93	76	8.2	62	53	3.2	8.5
Dist. 3	**Ore-16c C**	4.3	10.8	96	74	9.4	67	44	4.4	8.5
Dist. 3	**Vy-62c C**	9.1	20.2	80	62	14.0	67	44	9.0	17.0
Dist. 4	**Cs-185s UC**	9.2	19.2	87	48	13.4	51	26	8.4	27.3
Dist. 4	**Cs-185s C**	7.7	22.0	87	42	15.6	44	23	10.6	27.5
Dist. 4	**Cs-193s C**	12.2	14.6	93	77	11.6	75	59	6.6	2.3
Dist. 4	**Tf-25s C**	10.1	21.4	90	75	15.6	79	53	10.6	1.3
Dist. 5	**Bl-70s UC**	10.8	12.4	80	58	9.5	48	29	4.5	3.3
Dist. 5	**Bl-70s C**	10.6	14.7	90	72	11.1	69	36	6.1	3.3
Dist. 5	**Cr-14s C**	11.5	16.6	87	76	13.4	70	36	8.4	2.5
Dist. 6	**Bn-128s UC**	2.3	9.6	96	65	8.5	82	40	3.5	15.0
Dist. 6	**Bn-128s C**	3.5	9.9	93	71	9.2	63	31	4.2	15.0
Dist. 6	**Fr-76s UC**	3.8	7.7	93	55	8.8	44	34	3.8	13.5
Dist. 6	**Fr-76s C**	5.9	14.7	93	62	10.1	62	32	5.1	13.5
Dist. 6	**Ma-54s UC**	2.1	10.2	96	70	8.5	65	49	3.5	6.5
Dist. 6	**Ma-54s C**	3.5	9.8	96	74	8.4	69	55	3.4	6.7

The Modified Idaho Degradation Test (MIDT)

D_{P200}, SE_B, and SE_A

As listed in Section 8.2 of Appendix K, the amount of degradation is indicated by the difference in the passing of the No. 200 sieves (D_{P200}) (Equation 6):

$$D_{P200} = P200_A - 5.0 \qquad (6)$$

Where $P200_A$ is the % of Passing #200 after the degradation test; 5.0 represented the % of Passing #200 of the blended sample before the degradation test (Table 5.2).

Figure 6.4 indicates the distribution of D_{P200} values in this project. The majority of the D_{P200} results (72%) are less than 9%, and no sample has a D_{P200} value higher than 14%. In the current ITD's specification (Table 2.6), 5% and 8% are used as the test criteria for D_{P200} (ITD, 2023). At the 5% limit, 32% (eight samples) of the samples in this research would have passed the specification. At the 8% limit, 60% (15 samples) of samples would have passed the specification. To allow a higher number of aggregate resources with passing test values, a higher number of D_{P200} (> 8%) should be considered to establish acceptance criteria for the Modified Idaho Degradation Test.

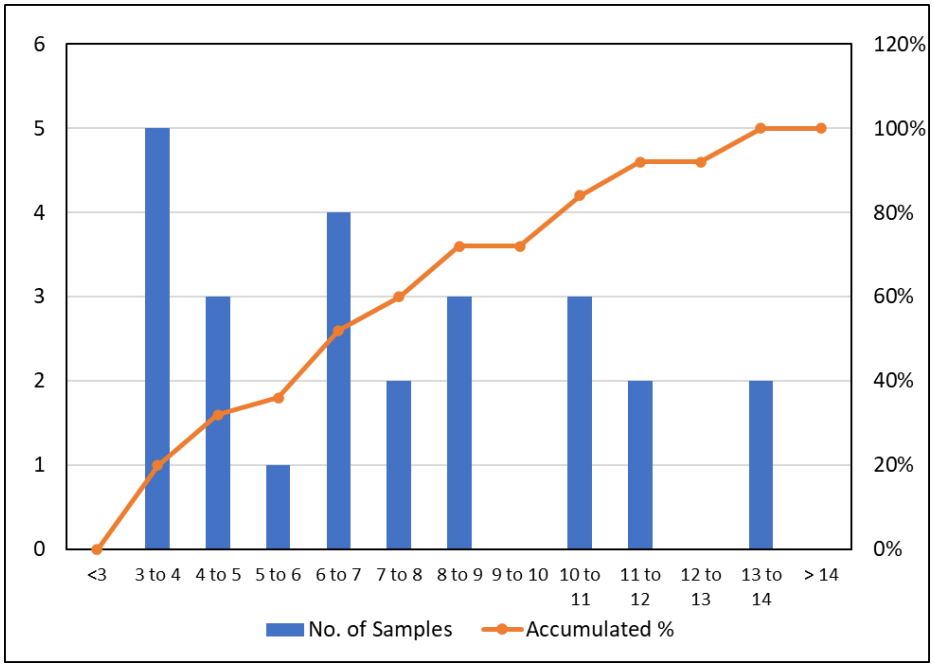

Figure 6.4: Distribution of D_{P200} values

For the SE values before the Degradation Test (SE_B), the values vary from 44% to 82%. These values pass the SE requirement of 30% listed in Table 703.04-2 – Aggregate Criteria of Section 703.04 Aggregate for Untreated Base, Treated Base, and Road Mix (ITD, 2023). These values are also higher than the SE requirements for aggregates in SP2 (30%) and SP3 (40%) Superpave mixtures (ITD, 2023). The SE_A is the SE after the MIDT. The values of SE_A ranged from 22% to 59%. The distribution of SE_A is shown in Figure 6.5. Based on the previous SE_A requirement of 30% (Table 2.3), out of the twenty-five samples, a total of five (20%) samples in this project have failed results. Two samples (8%) have SE_A values less than 25%. These two samples, Cs-185s and ID267c, also had high D_{P200} values (10.6% and 13.6%, respectively). The other three samples (12%) have SE_A values between 25% to 30%. Among these three samples, the crushed Br-0134c also has a high D_{P200} value (13.4%) and the uncrushed Cs-185s has one of the highest MBV values (27.3 mg/g), which indicates that it contains a large amount of highly reactive clay. The uncrushed BL-70s' result is borderline (29%) and has an initial SE_B value of 48%.

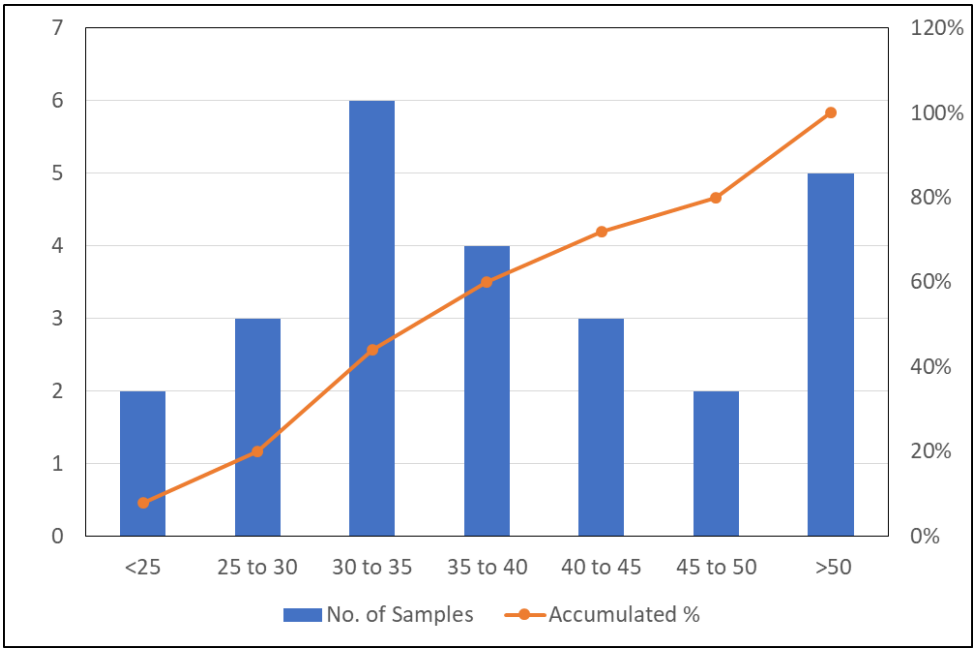

Figure 6.5: Distribution of SE_A values

Repeatability of the MIDT

One of the complaints about the current Idaho Degradation Test is that the test is highly technician dependent. By using the uniform gradation, the variance between replicates and among technicians should decrease. In the MIDT, two duplicates were run for each sample, and the average was used to calculate the results listed in Table 6.6. To compare the repeatability of the test, the results of these duplicated samples are analyzed in Table 6.7. Based on these results, the average difference in D_{P200} between the two duplicated tests was 0.09 or 0.1. This is within the accepted precision value 0.24 for a single laboratory fine aggregate test following AASHTO T11 (AASHTO, 2023). The average difference in the SE values after the Degradation Test (SE_A) was 0.3%. Although there are no precision and bias values in AASHTO T176, the ASTM standard on the SE test (ASTM D2419) lists the difference between two properly conducted tests by the same operator on similar material should not differ by more than 4.2% (ASTM, 2022). The average difference of 0.4% is well within the allowable variation. The narrow differences in D_{P200} and SE_A results of duplicates demonstrated the repeatability of the MIDT. The acceptable ranges for D_{P200} and SE_A can be calculated from the standard deviation (SD) results in Table 6.6. If the differences in D_{P200} and SE_A results followed a normal distribution, the acceptable range of the test results was ±1.96SD at the 95% confidence interval. For D_{P200}, the range was 0.52 – (-0.35), which was 0.87. For SE_A, the range was 2.4% – (-1.8%), which was 4.2%. To standardize the MIDT procedure, both ranges were rounded to a whole number: 1.0 for D_{P200} and 4% for SE_A. If the test results between duplicates are out of these ranges, a third test should be run. The two results within these ranges will be used to calculate the average of the results.

Table 6.7: Summary of Test Results of Duplicates

	D_{P200} (%)	D_{P200} (%)	D_{P200} (%)	D_{P200} (%)	SE_A (%)	SE_A(%)	SE_A (%)	SE_A (%)
	Test 1	**Test 2**	**Average**	**Difference**	**Test 1**	**Test 2**	**Average**	**Difference**
By-0068c UC	11.6	11.6	11.6	0.0	33	32	33	-1
By-0068c C	11.4	11.3	11.4	0.0	32	32	32	0
Br-0134c C	13.4	13.4	13.4	0.1	27	27	27	0
Kt-0214c C	7.3	7.1	7.2	-0.1	47	49	48	2
Id-267c C	13.5	13.6	13.6	0.1	22	22	22	0
Id-276c UC	7.7	8.0	7.8	0.2	49	50	50	1
Id-276c C	10.9	11.0	10.9	0.1	31	31	31	0
Ad-161c UC	6.2	5.9	6.0	-0.4	37	36	37	-1
Ad-161c C	6.5	6.9	6.7	0.4	35	37	36	2
Ore-16c Un	3.2	3.2	3.2	0.0	51	52	52	1
Ore-16c C	4.3	4.5	4.4	0.2	44	43	44	-
Vy-62c C	9.2	8.7	9.0	-0.4	44	44	44	0
Cs-185s UC	8.3	8.4	8.4	0.1	26	26	26	0
Cs-185s C	10.4	10.7	10.6	0.3	22	24	23	2
Cs-193s C	6.5	6.6	6.6	0.1	59	59	59	0
Tf-25s C	10.6	10.5	10.6	0.0	52	54	53	2
Bl-70s UC	4.5	4.6	4.5	0.1	29	29	29	0
Bl-70s C	6.1	6.2	6.1	0.1	36	36	36	0
Cr-14s C	8.4	8.4	8.4	0.0	35	37	36	2
Bn-128s UC	3.3	3.7	3.5	0.4	40	40	40	0
Bn-128s C	4.1	4.4	4.2	0.3	31	31	31	0
Fr-76s UC	3.9	3.7	3.8	-0.2	34	34	34	0
Fr-76s C	5.1	5.2	5.1	0.1	32	32	32	0
Ma-54s UC	3.2	3.8	3.5	0.5	50	48	49	-2
Ma-54s C	3.2	3.5	3.4	0.2	55	55	55	0
Average				0.09				0.3
Standard Deviation (SD)				0.22				1.1
Average + 1.96SD				0.52				2.4
Average - 1.96SD				-0.35				-1.8

Figures 6.6 and 6.7 show the correlations between the D_{P200} and SE_A values between the duplicates. In both graphs, the data was fitted along the line of equality (y=x), where Test 1 and Test 2 are exactly the same. The high R^2 values indicated good fits or high repeatability for both results (0.995 for D_{P200} and 0.998 for SE_A). Paired two-tail t-tests were also conducted for both the D_{P200} and SE_A values between the duplicates (Table 6.8). Based on the results of these t-test results (t stat < t critical and p-value > α), there were no statistical differences between the duplicates in the MIDT at a 95% confidence level.

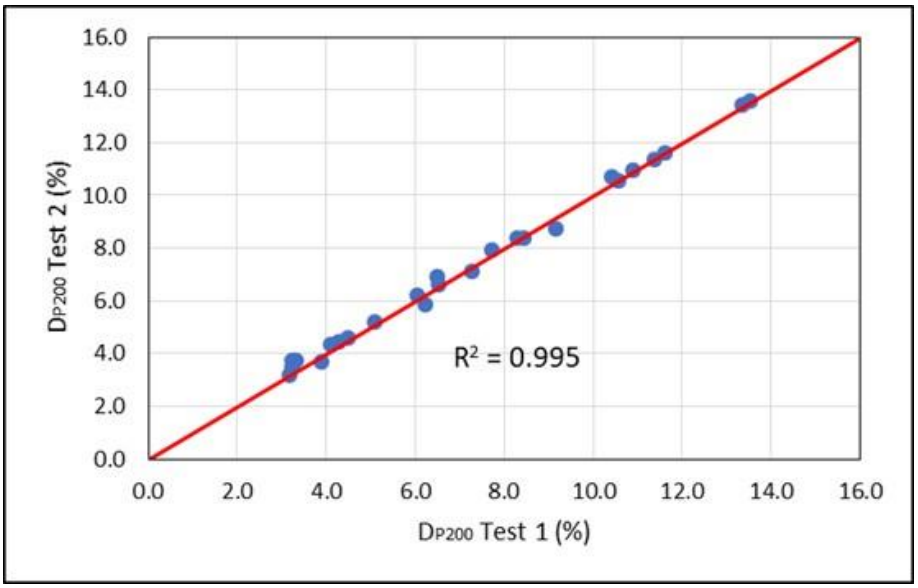

Figure 6.6: D_{P200} between Duplicates

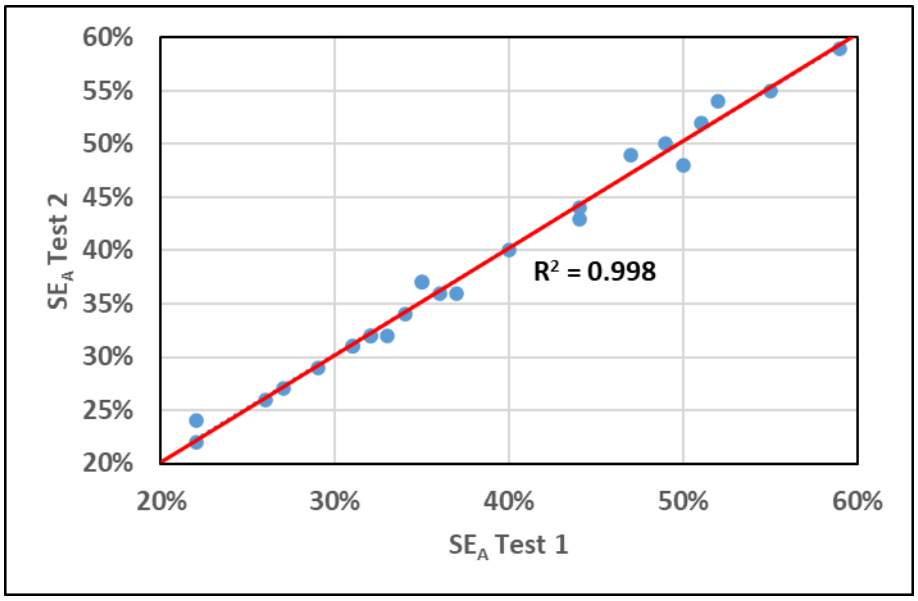

Figure 6.7: SE_A between Duplicates

Table 6.8: T-tests on the MIDT Test Results between Duplicates

	D_{P200}	SE_A
Degree of Freedom	24	24
t stat	-1.971	-1.319
t Critical two-tail	2.064	2.064
p-value	0.060	0.200
α	0.05	0.05

Correlations of the MIDT Measurements

The correlations between D_{P200} and SE values are shown in Figures 6.8 (SE_B) and 6.9 (SE_A). Based on the low R^2 values, there were no direct correlations between D_{P200} values and the SE values. The results from RP029 research also indicated the same observations (Howard, T.R., 1966).

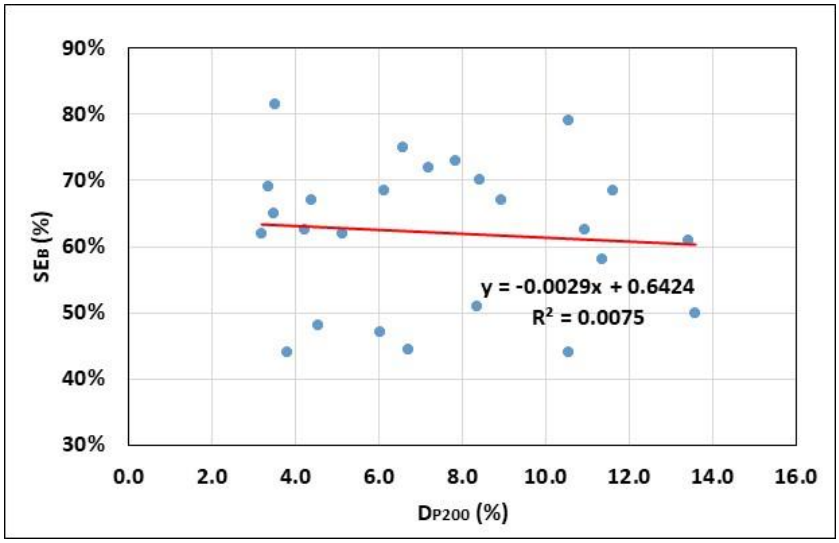

Figure 6.8: D_{P200} versus SE_B

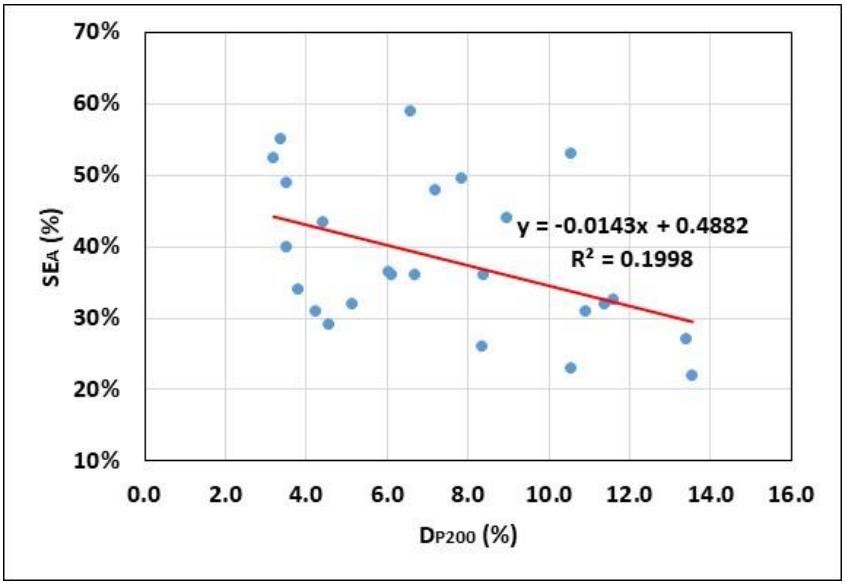

Figure 6.9: D_{P200} versus SE_A

The data indicated significant variances in SE values at the same D_{P200} results and vice versa. For example, Ad-161c and Cs-193s had almost identical D_{P200} values (6.7% versus 6.6%). And yet, the SE values showed enormous differences (SE_B: 45% versus 75%; SE_A: 46% versus 59%). Ore-16c and Vy-62c had identical SEB (67%) and SEA (44%), but their D_{P200} values were quite different (4.4% versus 9.0%).

The lack of correlation between the D_{P200} and SE values demonstrated the complexity of the results of MIDT. The changes in the results could be related to the type of aggregates, the differences in surface texture, porosity, and angularity, the clay or plastic fine content, and the particle interactions. D_{P200} measures the increase of fine particles in the material and relates more with the mechanical impact and surface abrasion brought by the rotating actions. The SE test was designed to determine the relative volume of clay-like materials to the sand or granular particles in passing #4 portion. The degradation of each aggregate is not controlled by one factor. It is a compounded effect of the aggregate mineralogy and the interaction with water.

Based on the information on rock types from Table 6.3, several aggregates are from the same type of rock. ID-267c, Vy-62c and Cs-193s are all Basalt, while Bn-128s, Fr-76s, and Ma-54s are all sandstone. Figure 6.10 shows the correlation between D_{P200} and SE for these two aggregate groups (Basalt and Sandstone). Both groups of aggregates exhibited a strong correlation between D_{P200} and SE. However, there were significant differences between the correlations between these two groups. This indicated that the relationships between SE values are dependent on the types of minerals inside the aggregates. For the same type of rock, there were strong correlations between D_{P200} and SE values if the materials were crushed and prepared in the same way.

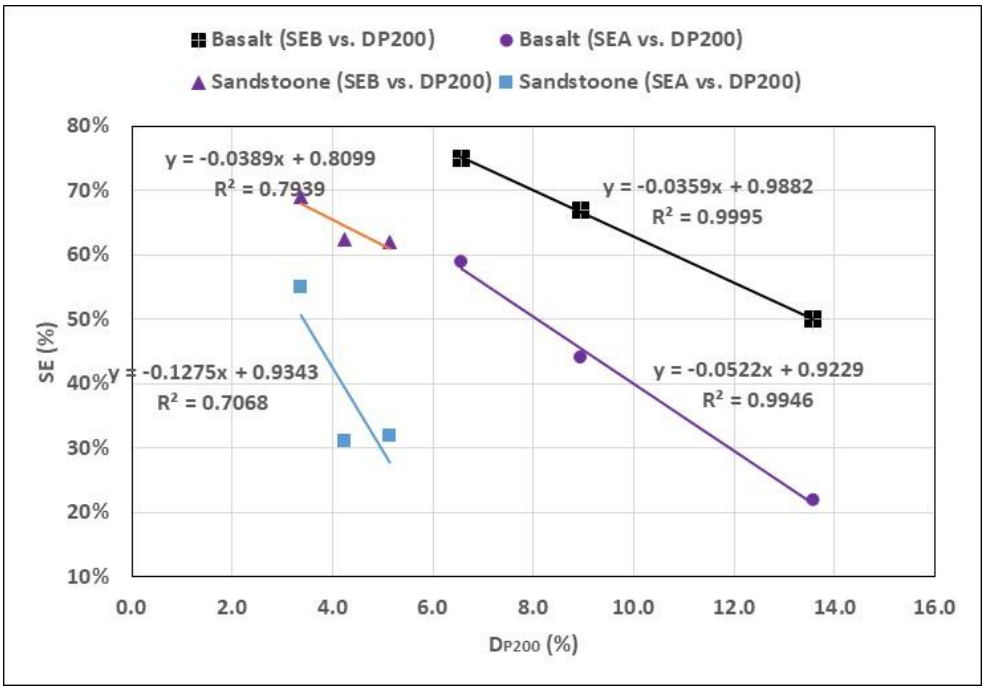

Figure 6.10: D_{P200} versus SE (Basalt and Sandstone)

Figure 6.11 indicates the correlation between SE_B and SE_A. With an R^2 of 0.4191, there was a weak linear positive correlation between SE_B and SE_A. This correlation is weaker than the results from RP029 (R^2 0.85), which indicates that the change in SE values was also influenced by multiple factors. Besides the clay content, SE values are related to the composition of the clay/plastic fine, the angularity/shape of granular particles, and the absorption of the aggregates (Clough and Martinez, 1961). Different clays

react differently to the working solution or flocculating agent, which contributes to the variances in the SE values (Hveem, 1953). SE values should be used as the relative indications of the cleanliness and reactivity of the aggregate, not a direct correlation to physical properties.

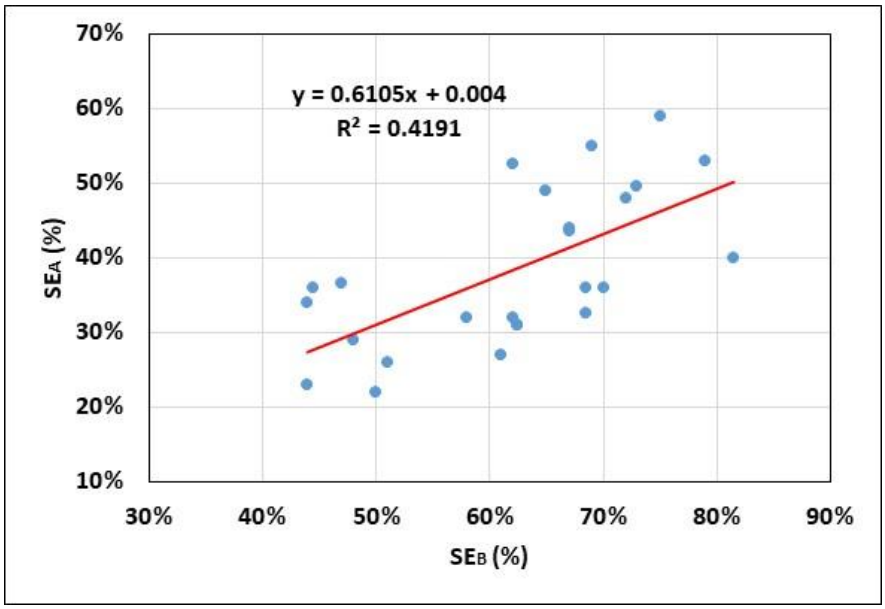

Figure 6.11: SE_B versus SE_A

Figure 6.12 indicates the correlation between SE_B and SE_A for Basalt and Sandstone aggregates.

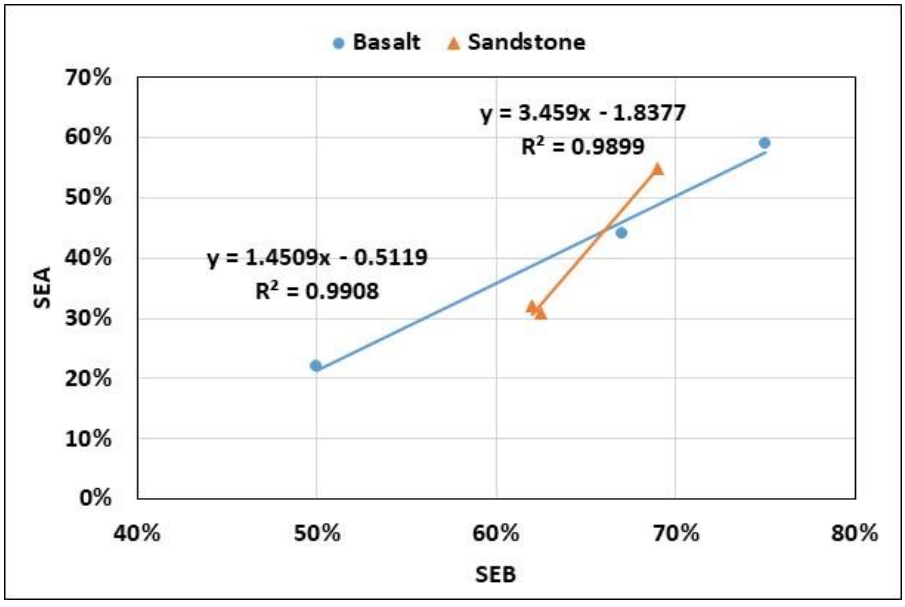

Figure 6.12: SE_B versus SE_A (Basalt and Sand Stones)

With an R^2 close to 1, there was a strong linear positive correlation between SE_B and SE_A for both aggregates groups. This indicated that the change in SE values was also influenced by rock types and the

mechanical process that the samples were put through. Combined with the information from Figure 6.11, different rocks react differently to the same mechanical process. With the same type of rock, the changes in MIDT results seem to move proportionally.

Effect of Crushing on the MIDT Results

Table 6.9 compares the MIDT results between crushed (C) and uncrushed (UC) aggregates from the same source. Figures 6.13, 6.14, and 6.15 show the correlations between crushed and uncrushed aggregates on SE_B, SE_A and D_{P200}, respectively. Based on the trends shown in Figures 6.13 and 6.14, there was no correlation between SE values before and after the crushing, which indicated that the crushing had no contribution or influence on the SE results from the MIDT. The aggregates in the basalt group were all big rocks and must be crushed for testing. The sandstones did not show a strong correlation between crushed and uncrushed samples on both SE values either.

Table 6.9: The MIDT Test Results (Crushed versus Uncrushed)

	D_{P200} (%)	D_{P200} (%)	D_{P200} (%)	SE_B (%)	SE_B (%)	SE_B (%)	SE_A(%)	SE_A(%)	SE_A(%)
	UC	**C**	**Difference**	**UC**	**C**	**Difference**	**UC**	**C**	**Difference**
By-0068c	11.6	11.4	0.2	69	58	11	33	32	1
Id-276c	7.8	10.9	-3.1	73	62	11	50	32	18
Ad-161c	6.0	6.7	-0.7	47	69	-22	37	33	4
Ore-16c	3.2	4.4	-1.2	62	44	18	53	34	19
Cs-185s	8.4	10.6	-2.2	51	45	6	26	36	-10
Bl-70s	4.5	6.1	-1.6	48	69	-21	29	36	-7
Bn-128s	3.5	4.2	-0.7	82	70	12	40	36	4
Fr-76s	3.8	5.1	-1.3	44	47	11	34	37	1
Ma-54s	3.5	3.4	-0.1	65	82	11	49	40	18

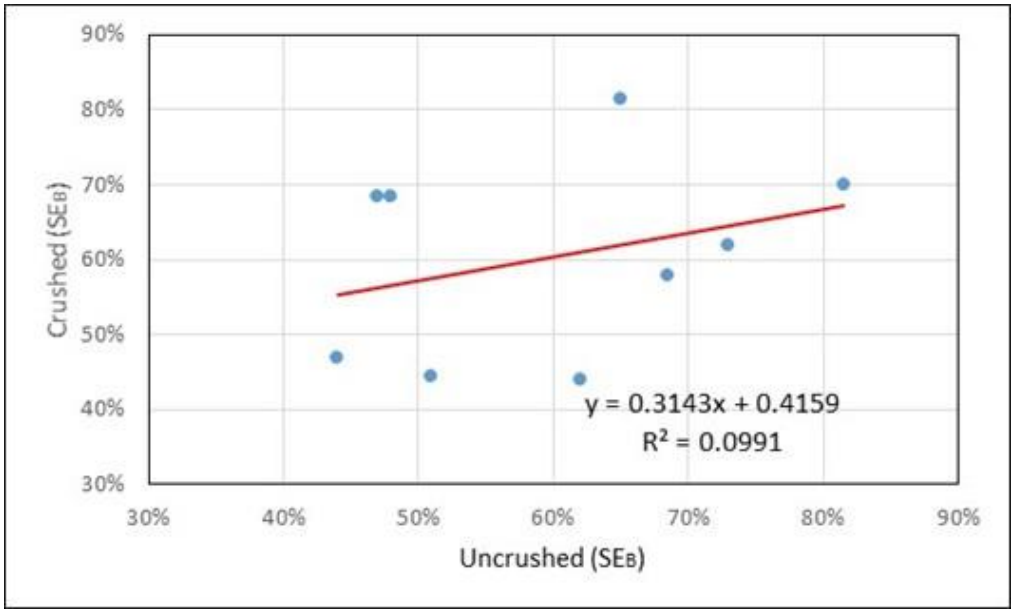

Figure 6.13: Crushed versus Uncrushed (SE_B)

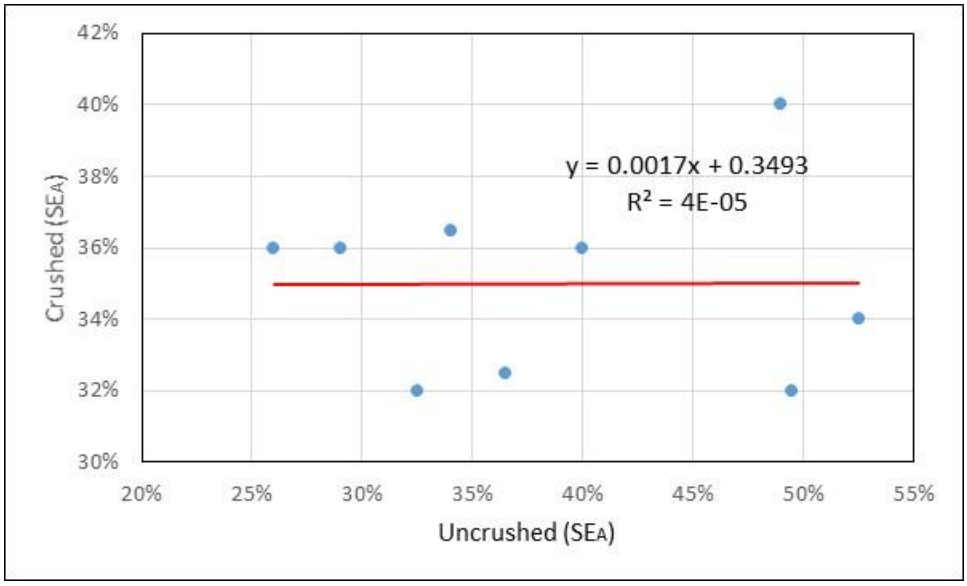

Figure 6.14: Crushed versus Uncrushed (SE_A)

In Figure 6.15, there was a strong positive linear correlation between uncrushed and crushed aggregates on D_{P200} values (R^2: 0.8851). The correlation showed that the slope of the fitting line was close to 1, while the interception on the crushed (D_{P200}) was 1.01. This indicated that, on average, the D_{P200} values from the crushed aggregate were 1% higher than the D_{P200} values of the uncrushed aggregates from the same source. The higher values might be caused by the higher angularity and rougher surface that was created through crushing (Figure 6.16).

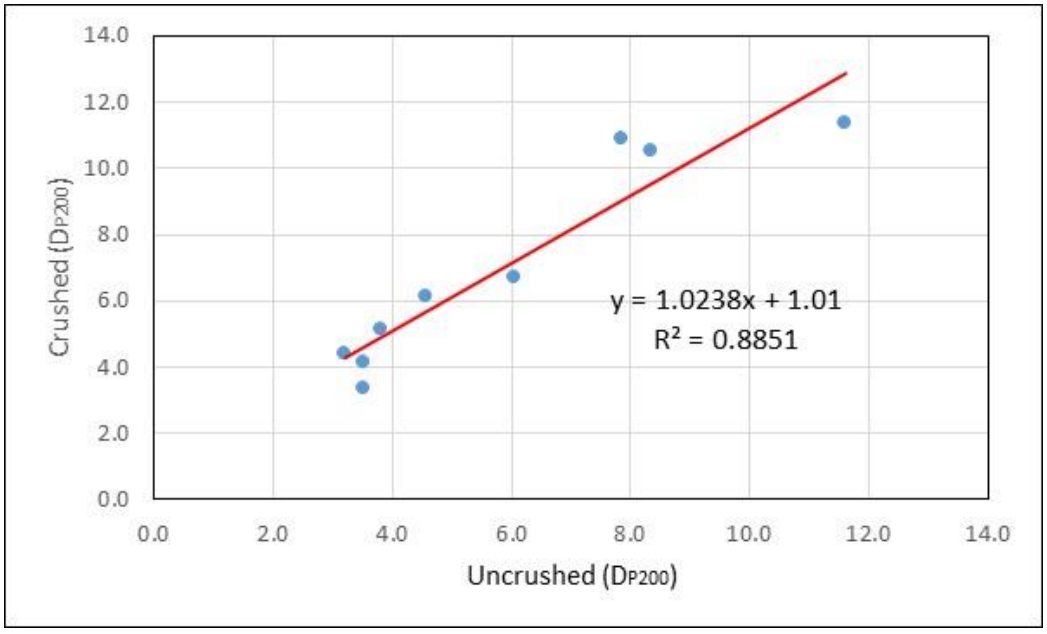

Figure 6.15: Crushed versus Uncrushed (D_{P200})

Figure 6.16: Crushed and Uncrushed Aggregates (Fr-76s)

The uncrushed aggregates were made of rocks that have been through thousands, if not millions, of years of weathering, abrading, and polishing by the environment. These uncrushed aggregates were round in shape and smooth in texture. When they were rotated in the container for the MIDT, the aggregate particles rolled over each other with relative ease. As a result, there were fewer fractures or breakdowns of large particles after the MIDT, which lowered the increase in P200. After the aggregates were processed through the jaw crusher, more fractured faces and sharp edges were created for the crushed aggregates. There were more rough surfaces and sharp edges in these aggregates than those in the uncrushed aggregates. When the particles were rolling over each other, the higher roughness caused more friction, abrasions, and impacts among the particles and created more fines during the rotations (Fournari and Inannis, 2019). To avoid the variances in the MIDT results, the practice of blending uncrushed and crushed aggregates in the current IT-15 should be avoided. The samples for the MIDT should be eight field crushed samples or must be put through the lab crusher as a whole to achieve consistency in the test. Since the crushed samples, on average, produced higher or worse D_{P200} numbers, selecting crushed samples provided a tougher testing condition. Different crushers might have different impacts on the sample. Further tests are needed.

Effect of Clay Content (MBV) on the MIDT Results

As indicated in the previous section, the MBV value correlates to the product of the total clay content and the specific surface area of the clay particles. It is used as an indicator of the amount of plastic fines inside the aggregate. Figure 6.17 shows the relationship between the DP200 values and the MBV. Figure 6.18 indicates the correlation between MBV and the SE values.

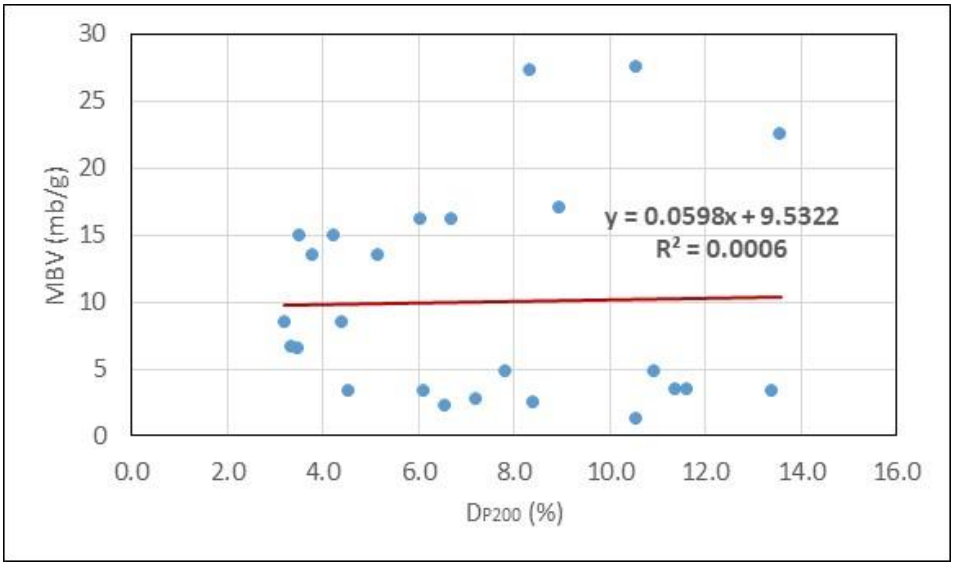

Figure 6.17: D_{P200} versus MBV (All Aggregates)

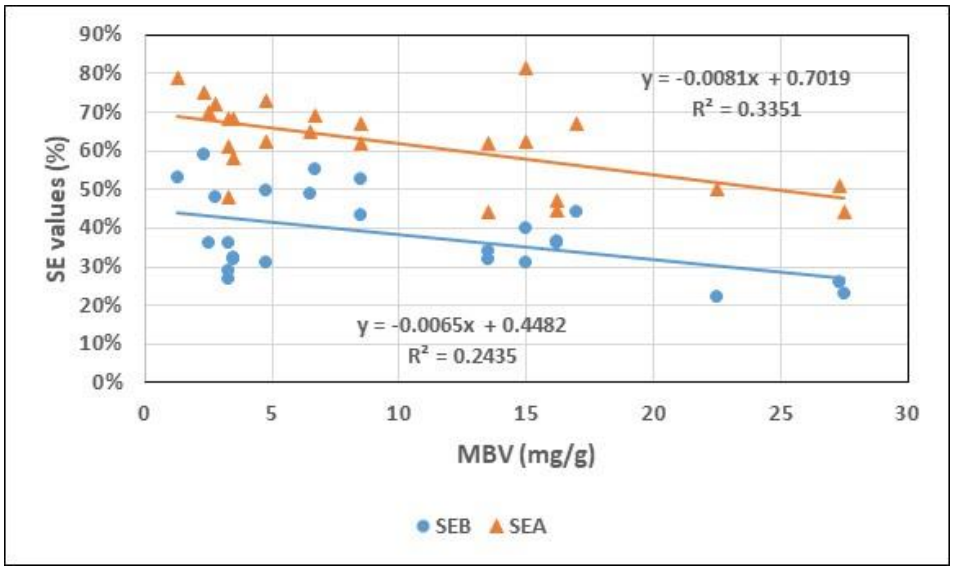

Figure 6.18: SE values versus MBV (All Aggregates)

No strong correlation was observed between these two sets of test results versus MBV values, which implied that the clay content had no effect on the degradation results. This is against the initial assumption for the degradation test that the increase in the number of plastic fines under repeated traffic loading was one of the key causes of degradation failures (Minor, 1960; Day, 1962). However, the degradation failures in the 1950's were all on basalt aggregates (Erickson, 1958).

Figure 6.19 illustrates the relationship between D_{P200} and MBV of the three basalt aggregates (Id-267c, Vy-62c, and Cs-193s). The basalt group had the largest variance in MBV value (from 4.4 to 22.5 mg/g). There was a strong positive linear correlation between the D_{P200} values and the MBV values. This

indicated that for basalt aggregates, the higher clay content would cause more degradation in the aggregates, which correlated to the field observations in Idaho back in the 1950s. Based on the discussions in the previous sections, the strong correlation might be the results of tight control in the sample preparation conditions: gradation and crushing, which lower the sample variations.

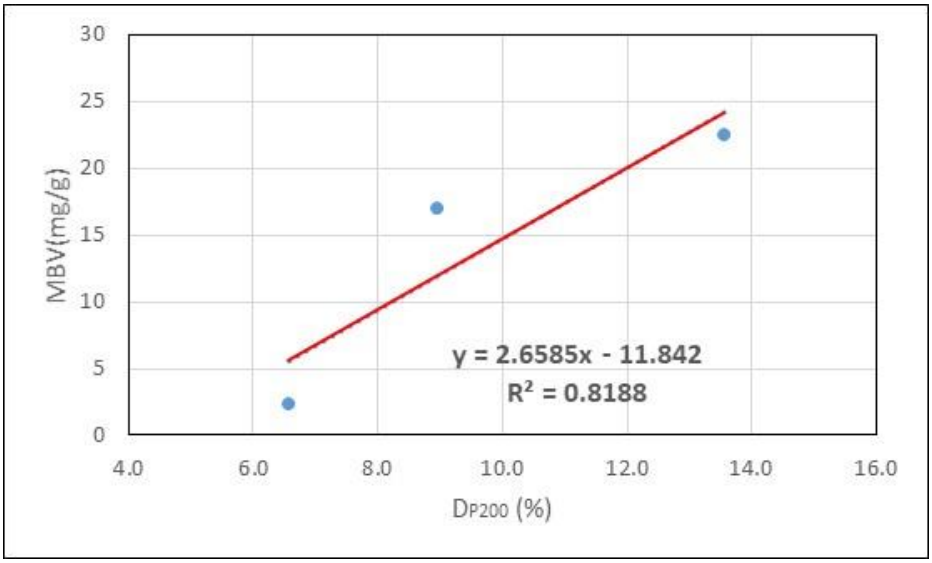

Figure 6.19: D_{P200} versus MBV (Basalt)

Figure 6.20 demonstrates the correlations between the MBV and SE values of the basalt aggregates. The data indicated strong negative linear correlations between MBV, SE_B, and SB_A. The SE test was designed initially to evaluate the montmorillonite in basalt (Hveem and Smith, 1964). Higher MBV values correlated to higher clay contents, which resulted in higher SE values.

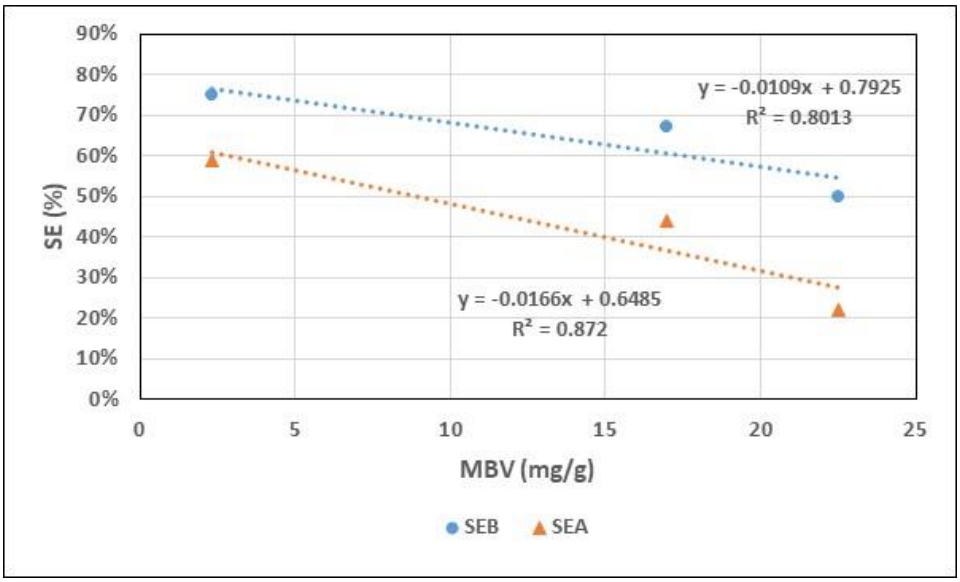

Figure 6.20: SE versus MBV (Basalt)

The effect of clay content or MBV values on the MIDT results seems to be rock-type dependent. Figures 6.21 and 6.22 show the relationships between MBV and MIDT results (D_{P200}, SE_B, and SE_A) of crushed sandstones: Bn-128s, Fr-76s, and Ma-45s. This group of rocks also had a wide range in MBV values (6.7 to 15.0). Figure 6.21 shows that the correlation between MBV and D_{P200} was not as strong as those for basalt aggregates, and the range of the D_{P200} values was too narrow to differentiate these aggregates.

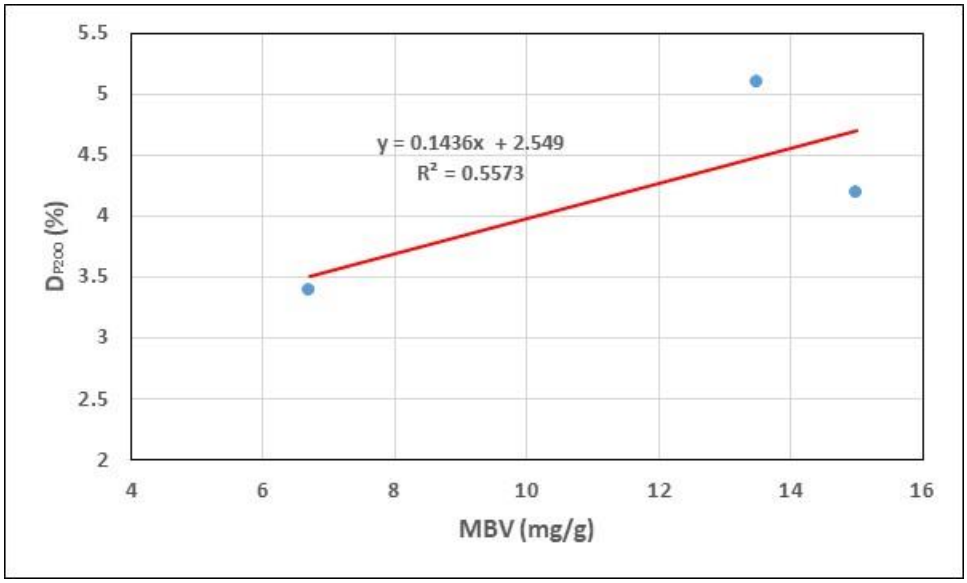

Figure 6.21: D_{P200} versus MBV (Sandstone)

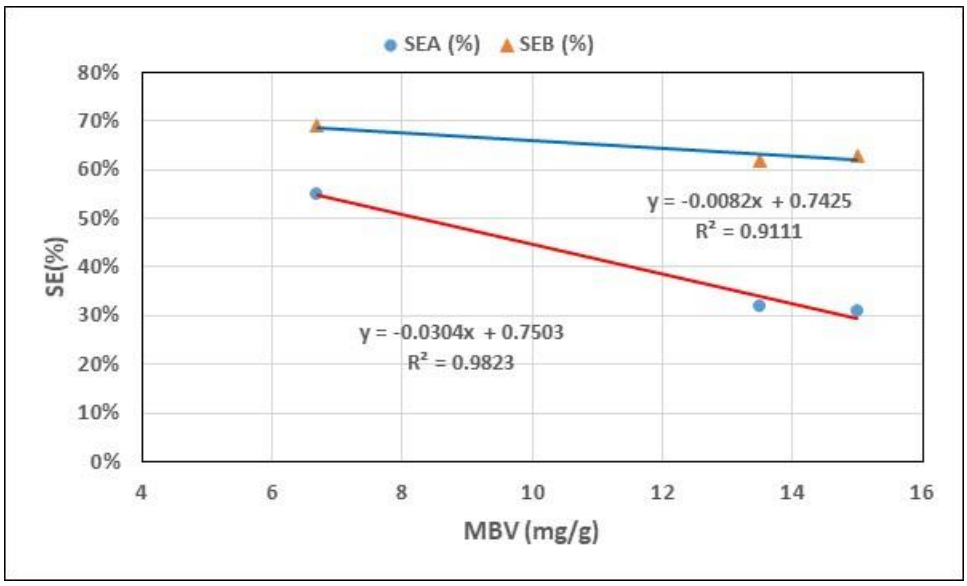

Figure 6.22: SE versus MBV (Sandstone)

However, the correlations between MBV and SE values in Figure 6.22 exhibited stronger positive relationships (R^2: 0.911 for SE_B and 0.982 for SE_A). The fitting equations obtained were also quite

different from those of basalt aggregates. The variation in clay components between the rocks might mainly contribute to these differences. Different clay has different specific surface areas. Even with the same clay content, the MBV number would be different. The clay in the Basalt aggregates in this study is almost solely the montmorillonite. In the sandstones, the amount of illite and kaolinite was also significant.

SE values in MIDT

Figures 6.18 and 6.20 also indicate the dependency of SE value on the rock type. The SE values were also influenced by the angularity, surface texture, and grain size of the rock (O'harra, 1953). Since the SE values change not only with the amount of the clay but also the type of the clay and the rock, setting a minimum SE value for all aggregates, although could ensure the quality of the aggregate, may exclude a large amount of useful aggregate (Clough and Martinez, 1961).

For the SEs in the MIDT, the SE_B values relate to the makeup of the sample. The graduation of the sieves passes ¾ inch B Plant Mix Aggregate specification in Table 703.04-1 – Nominal Maximum Size of Section 703.04 Aggregate for Untreated Base, Treated Base, and Road Mix (ITD, 2023). For Aggregate for Untreated Base, Treated Base, and Road Mix, the SE requirement is a minimum of 30%, if 5.0% or more of the material passes the No. 200 sieve. Hveem suggested 35% as the minimum requirement for the same application (Hveem, 1953). For SE_B, a minimum of 30% is selected to correlate with ITD's current specification.

For the after-test SE (SE_A), using 30% as the minimum requirement excludes 20% of the sample (5 out of 25). Since the P200 % range in Table 703.04-01 is 3.0 to 9.0% and the initial gradation contains 5% P200, when the D_{P200} value is larger than 4%, the gradation of the aggregate after the MIDT will be out of the specification in 703.04-1. Based on the data in Table 6.6, only 20% (five samples) produced a D_{P200} value of less than 4%. Due to the high P200 numbers after the MIDT, 30% might not be a suitable requirement. Based on the range suggested by O'Harra, a SE value of 25% to 34% showed "Doubtful but usually satisfactory" performance for aggregates (O'Harra, 1953; Clough and Martinez, 1961). For SE_A, a minimum of 25% can be used to identify the aggregate quality after the MIDT.

The Aggregate Durability Index

The durability index indicates the relative resistance of an aggregate to produce clay-like or plastic fines when subjected to mechanical agitation in a special washing vessel. Since the test started with a washed aggregate without P200 materials, the plastic fines or the clay in the original aggregate had no effect on the results of the Durability Index. The coarse durability index (D_c) measures for particle size larger than the No. 4 sieve, and the fine durability index (D_f) is for the passing No.4 4 sieve materials.

D_c and D_f

The average of D_c values from Table 6.6 was 88 and the average of D_f values was 65. Both numbers were higher than the results obtained from ITD RP029 (Average D_c: 75; Average D_f: 49). Compared to the

values from RP029, the difference in D_c values was 17.3%. There was a 32.6% increase of D_f values. The difference in D_f values might be caused by the deviations from the standard testing procedure in RP029 mentioned in the literature review: 1) the extra 18 minutes of shaking time; and 2) the addition of P200 materials before shaking. The specification on the Durability index for aggregate base is 35% in California (Caltrans, 2023). Based on the results in Table 6.6, the only sample that failed the test was Id-267c Crushed. This large acceptance range might not be able to exclude known "poor" performance aggregates.

Figure 6.23 shows the correlation between D_c and D_f. The outlier, Id-267c, was excluded from the fitting. There was no correlation between D_c and D_f. Based on the testing procedure for the Durability Index, the calculation of D_c was based on the equation using predetermined factors from research done in the 1960s (AASHTO, 2023). The D_f values were determined using the SE test. Since the testing methods are different, the lack of correlation is reasonable. The reported Durability Index number must be the lower one of the D_c and D_f values, not an average or a combined number.

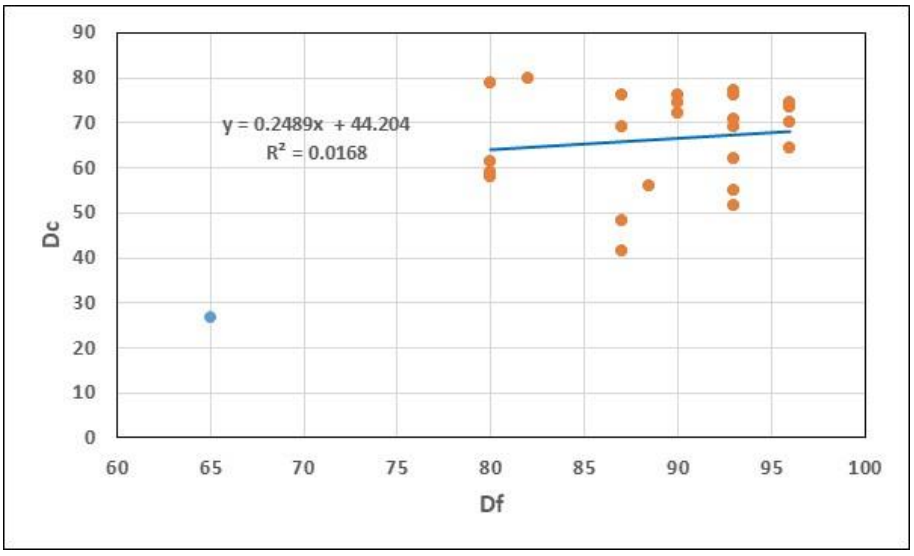

Figure 6.23: D_c versus D_f

Durability Index versus D_{P200} and SE

For every sample evaluated in this research, D_f was always lower than D_c. The reported Durability Index of the sample was D_f. Figure 6.24 illustrates the correlation between D_f and D_{P200}.

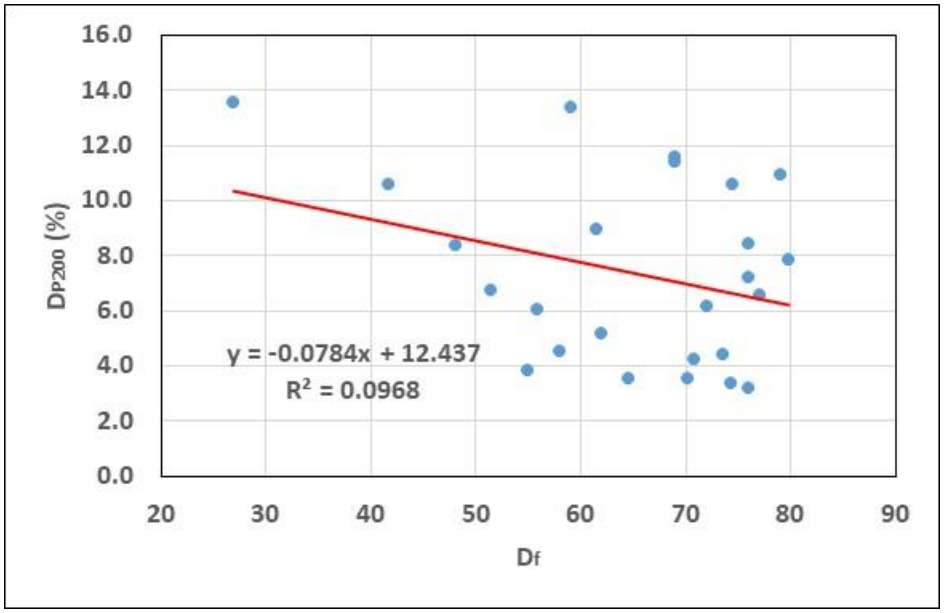

Figure 6.24: D_f versus D_{P200}

At an R^2 value of 0.0968, there was no correlation between these two test values. D_f measures the amount of newly created clay-like materials after horizontal shaking in a metal container, while D_{P200} is related to the breakdown of particles during an end-over-end rotative action in a plastic container. The difference in how the energy was applied to the aggregate might create different mechanical impacts. This might explain the lack of correlation between these test results. Figures 6.25 and 6.26 show the correlations between D_f and SE values.

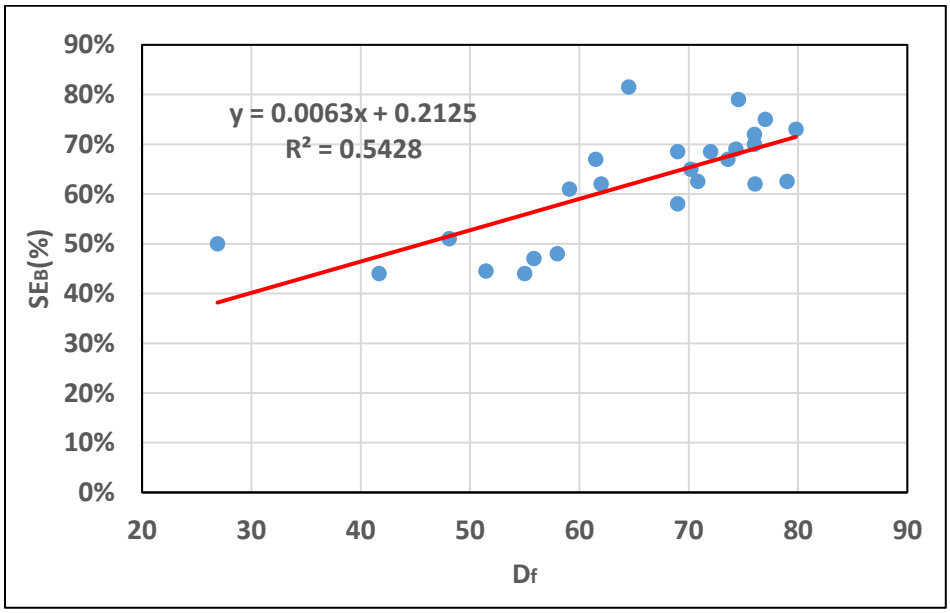

Figure 6.25: D_f versus SE_B

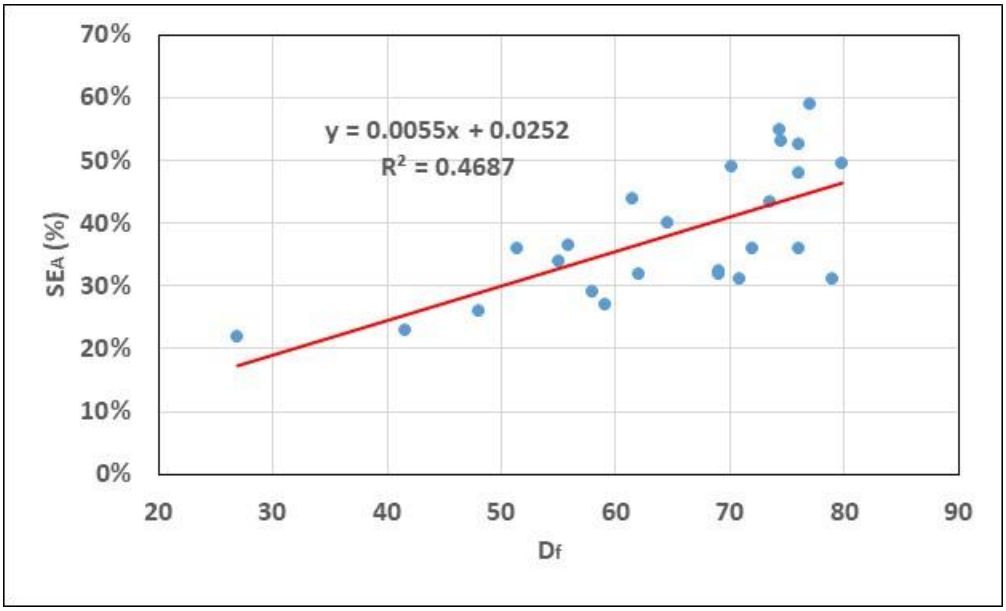

Figure 6.26: D_f versus SE_A

Although D_f values were also obtained using the SE test equipment, with a modified 10-minute shaking time, the correlations between D_f and both SE values (SE_B and SE_A) were weak. Since aggregate samples for both SE and D_f tests were batched to the same gradation listed in Table 2.5, the main cause of the lack of correlation was the difference in testing conditions. The Durability Index Test separated coarse and fine aggregate and used the sieve shaker. This would have had a different mechanical impact on the samples than the rotating actions by the MIDT.

Due to its limited correlation with MIDT, the aggregate durability test is unsuitable for replacing the Idaho Degradation Test.

Micro-Deval Abrasion Loss Tests

The Micro-Deval abrasion test evaluates the abrasion resistance and durability of aggregates by measuring the mass change in the aggregate after rotating with steel balls in the water. The abrasion loss is presented by using the percentage change in the amount of degraded material passing a 1.18mm (No. 16) sieve for coarse aggregates or 75µm (No. 200) sieve for fine aggregate after the test.

Abrasion Loss of Coarse Aggregate

Figure 6.27 shows the relationship between the % loss of coarse aggregate and D_{P200} for all aggregates. With an R^2 value of 0.3863, the correlation was weak. The differences in sample gradation were the key cause of the low correlation (Table 4.3 versus Table 5.2). The Micro-Deval test on the coarse aggregate should not be used as a supplement for the Idaho degradation test.

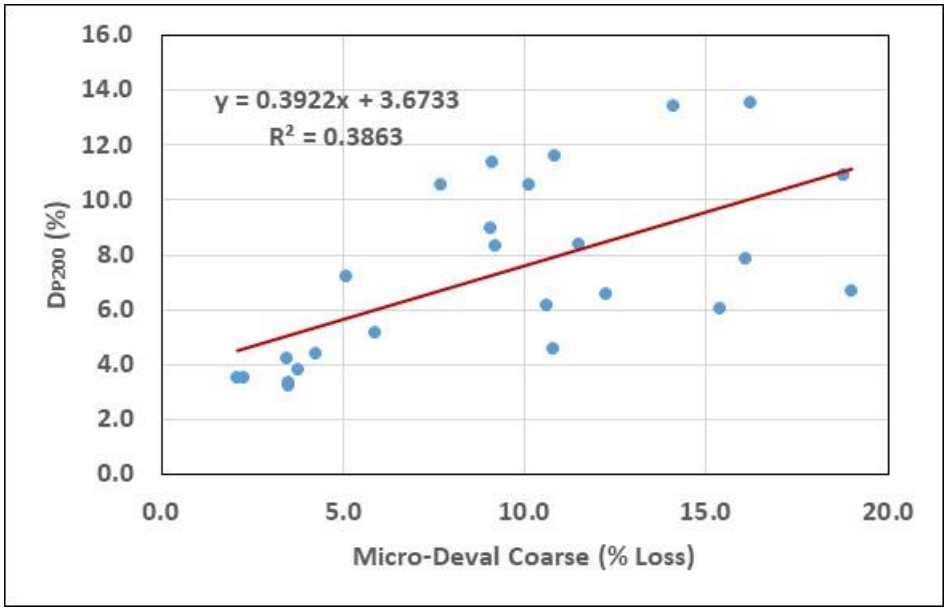

Figure 6.27: % Loss of Coarse Aggregate versus D_{P200}

Abrasion Loss of Fine Aggregate

Figure 6.28 shows the relationship between the % loss of fine aggregate and D_{P200} for all aggregates. With an R^2 value of 0.9437, the correlation between these two results indicated a strong positive linear relationship.

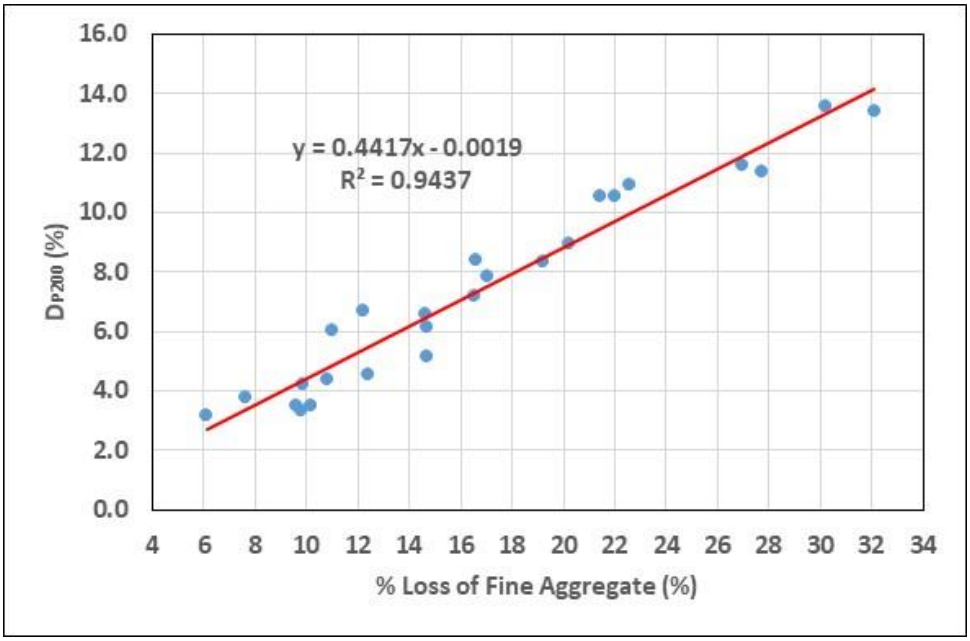

Figure 6.28: % Abrasion Loss of Fine Aggregate versus D_{P200}

Based on the fitted trendline equation, D_{P200} can be calculated from the % loss of fine aggregate using the following equation (6):

$$D_{P200}\ (\%) = 0.4417 * (\text{Abrasion loss of fine aggregate } (\%)) - 0.0019 \quad (6)$$

Figure 6.29 shows the effect of MBV on D_{P200} and Abrasion Loss of the aggregates. The data showed that the DP200 and the Abrasion Loss of the aggregates had similar trends when they were correlated with the MBV values. This indicated that the clay content or the changes in rock mineralogy had similar effects on the D_{P200} and the Abrasion Loss of fine aggregates. The correlation between D_{P200} and Abrasion loss of fine aggregate in Figure 6.28 is unrelated to differences in rocks. This means that the D_{P200} can be used as an indicator of resistance to degradation across all aggregates.

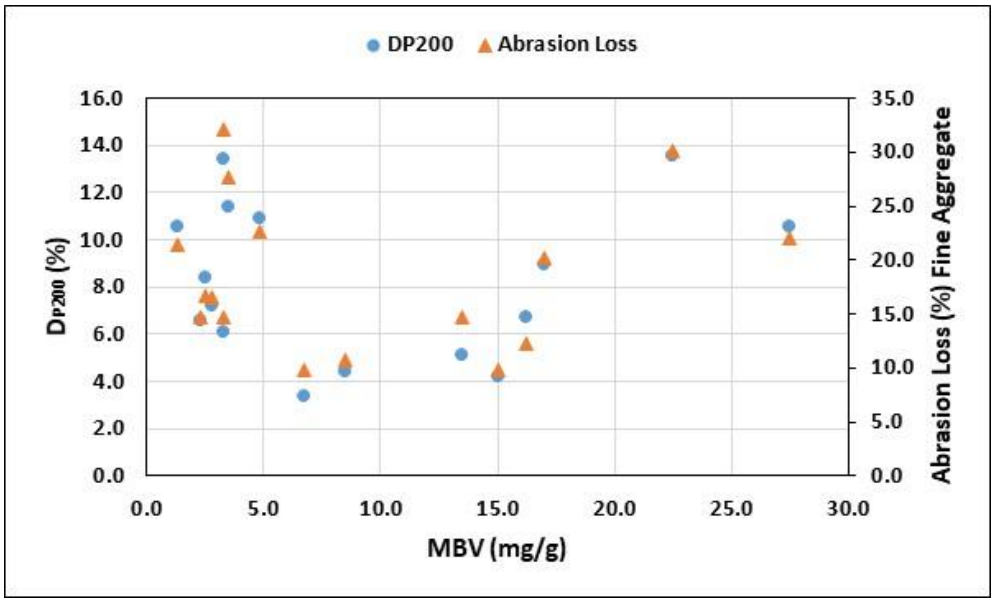

Figure 6.29: MBV versus D_{P200} and Abrasion Loss of Fine Aggregate

The difference between crushed and uncrushed aggregates on the correlation is shown in Figure 6.30. The MIDT and the Micro-Deval test on the fine aggregate had a lot of similarities in the test procedures. Although the MIDT did not use steel balls, the 50% coarse aggregates put similar mechanical abrasion forces on the fine aggregates. In other words, the coarse aggregates in the MIDT acted as the steel balls on the fine aggregates. One thing worth noting is that the soaking time for the abrasion loss is 1 hour versus 16 hours in the MIDT, which is another indicator that a one-hour soaking time should be enough for the MIDT test.

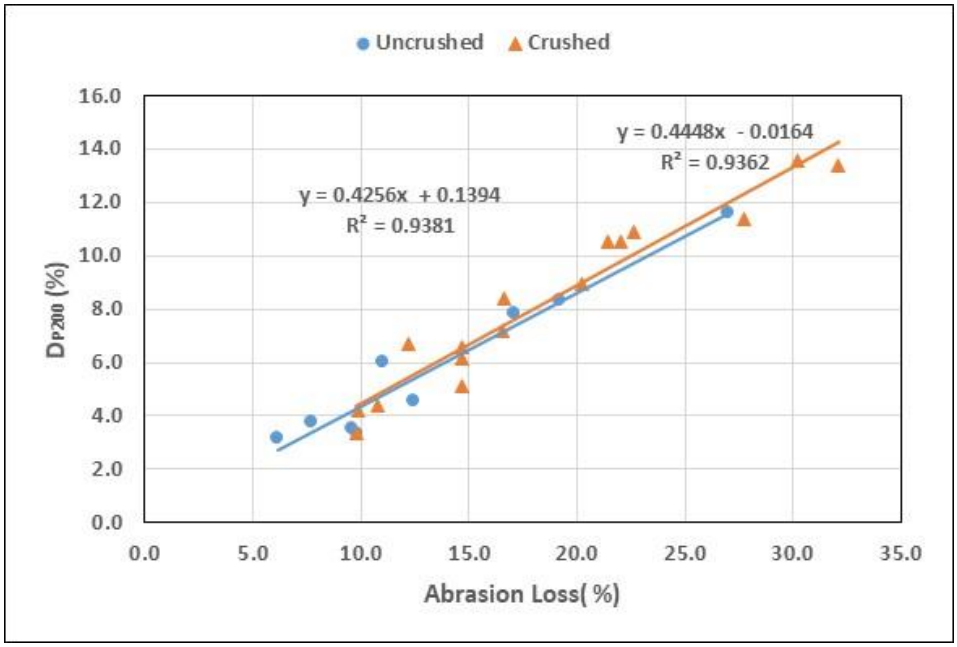

Figure 6.30: Abrasion Loss (%) of Fine Aggregate versus D_{P200} (Crushed versus Uncrushed)

Table 4.6 lists the recommended abrasion loss values on fine aggregated based on ASTM D7428. Based on these recommended satisfactory limits and equation 6, Table 6.10 shows the recommended D_{P200} values. The current ITD requirements on D_{P200} were also included. The numbers for the fitted D_{P200} were rounded up to the next higher whole number. For example, at 30% abrasion loss, D_{P200} is 13.2% based on Equation 6. The value is rounded up to 14% as the specification value. These values provide the starting points for ITD to establish the testing requirements of the MIDT for different applications. Since these numbers were obtained based on the limited number of aggregates involved in this research, they still need to be validated through more testing and evaluation of produced materials.

Table 6.10: D_{P200} Limits

Application Type	Current ITD Requirement (%)	ASTM D7428 Abrasion Loss (%)	D_{P200} (%)
Fine and Coarse Aggregate for Concrete	5	20	9
Aggregate for Untreated Base, Treated Base, and Road Mix	8	30	14
Aggregate for Superpave HMA Pavement	5	15	7
Aggregate for Cover Coat Material	5	15	7
Aggregate for Blotter and Choke Sand	Not Required	Not Required	Not Required
Aggregate for Open Graded Rock Base (Rock Cap)	8	25	11
Aggregate for Extrusions	8	20	9
Aggregate for Anti-Skid, Type 1, 3, 4, 5	Not Required	Not Required	Not Required
Aggregate for Anti-Skid, Type 2	5	15	7
Aggregate for Granular Subbase	8	35	16

7. Conclusions and Recommendations

Conclusions

Review the Idaho Degradation Test

- **The Idaho Degradation Zone Chart developed based on the data from the Idaho Degradation Test was not helpful in setting up numerical limits for the Idaho Degradation Test.**

  In Day's initial paper, the limits of different zones in the plots of SE versus P200 values were unrelated to physical properties. They were arbitrarily determined by dividing aggregate sources on the plot based on the field service records. As the field experiences changed every year, the limits were modified also.

- **There was no available research or written document on selecting the numerical limits used in the current specifications.**

  In practice, a 5% increase in No. 200 and a drop in SE to less than 30% were considered warning signs that serious degradation might occur in service. There is no current record of or research on the reasons for these selections, and such information may have been lost.

- **Research project 029 failed to develop or suggest numerical specifications for the Idaho Degradation Test due to a lack of correlation between test methods.**

  RP029 was initiated to develop a numerical value for the results of the Idaho Degradation Test. However, the lack of correlation between the number of fines in the sample and the degradation results made the task impossible to finish. The California degradation Test was determined to be inapplicable to Idaho aggregates. Further review by the research team determined the variance in the test procedures might have contributed to such a conclusion.

- **The specification of the current Idaho Degradation Test needs to be clarified and standardized.**

  The language in the Idaho Degradation Test procedure has confused practitioners who interpret the proper steps to conduct the test. This makes the test highly technician-dependent and creates variations in how the samples are prepared. Some of these variations were deliberated to achieve a passing result.

- **A Uniform Gradation is needed to increase the repeatability and reproducibility of the Idaho Degradation Test.**

  ITD has also realized that the test results from the Idaho Degradation Test showed extreme sensitivity to the graduation makeups and has suggested using a uniform gradation for passing the No. 4 portion.

- **Based on the survey conducted in this research on degradation tests across the Nation, almost all states used the L.A. Abrasion test for Aggregate Degradation.**

  Forty-nine states and Washington D.C. selected the L.A. Abrasion test (AASHTO T96/ASTM C131) as one of the tests to evaluate the degradation. The only state that does not use the L.A. Abrasion test is New York, which elects to use the soundness test as the only measurement for Aggregate Degradation.

- **There were significant variances in degradation test methods among agencies.**

  Twenty-three states use the L.A. Abrasion test as the only test for aggregate degradation. Eighteen states reported using the Micro-Deval apparatus to test coarse aggregates' resistance to degradation (AASHTO T 327/ASTM D6928) in their current specifications. Only six states used the Micro-Deval apparatus to test fine aggregates' resistance to degradation (ASTM D7428). Minnesota, Nevada, and Oklahoma are the only states using the Aggregate Durability Index (AASHTO T 210/ASHTM D3744) to evaluate aggregates' resistance to degradation (AASHTO, 2022). Seventeen States are using sixteen different other tests.

Procedure for the MIDT

- **The Research Team developed the new procedure for the Modified Idaho Degradation Test by clarifying the language in the current Idaho Degradation Test.**
  - One-gallon Plastic container was selected as the only Container for the test.
  - Detailed Description of the test apparatus was added.
  - Companion samples were used for SE tests.
  - A detailed description of sample preparation was added.
  - Three measurements were defined in the procedure: D_{P200} (Change of P200 value after the test), SE_B (SE valent before the MIDT), and SE_A (SE values after the test)

- **A uniform gradation was selected for the MIDT.**

  The selected gradation met the following ITD specifications (ITD, 2023).:

  - ¾ inch B Aggregate Base specification in Table 703.04-1 – Nominal Maximum Size of Section 703.04 Aggregate for Untreated Base, Treated Base, and Road Mix and
  - ¾ inch aggregate for HMA Table 703-0.5-2.

- **An evaluation was conducted to change the test procedure to shorten the testing time by increasing the drying temperature from 60°C to 110°C and lower the aggregate socking time from 16 hours to 1 hour**.

TAC approved the decision to increase the drying temperature for the MIDT to 110°C from 60°C. The P200 fines could only be completely separated from the coarse aggregate surface, so the accurate amount of P200 fines could be determined with an oven-dried sample at 110°C. The procedure also included the definition of dry state. Due to the limited number of samples involved in the evaluation, the soaking time in the water was kept at 16 hours.

Clay Identification

- **XRD can be used to identify the total clay content and the components of different types of clay in the P200 material.**

  XRD can scan multiple locations on the sample and multiple samples. The scan is conducted over many grains and particles, which can more accurately detect the percentages of different components.

- **Petrographic Analysis can be used as an important tool to determine the root cause of a failure.**

- **MBV provides a quick and easy method to identify the content and reactivity of the clay, which can be used to identify the total effect of different clays on the aggregate performance.**

Test Results of the MIDT

- **There were large spreads in the test results of D_{P200}, SE_B, and SE_A, which indicated that the MIDT can be used to differentiate aggregate samples.**

- **The relationship between D_{P200} and SE values is related to differences in the type of Rock.**

  Although there was no correlation between DP200 and SE values when all aggregates were included in the analysis, there were strong correlations when the results were analyzed based on the rock types.

- **The SE specifications (SE_B > 30% and SE_A > 25%) should be used as the relative indications of the suitability of the aggregate.**

  The weak correlation between SE_B and SE_A values indicated that these values were also influenced by the rock's angularity, surface texture, and grain size.

- **Crushing increased the results of D_{P200} by 1%.**

  The correlation showed that, on average, the D_{P200} values from the crushed aggregate were 1% higher than the D_{P200} values of the uncrushed aggregates from the same source.

- **The effect of clay content on the MIDT results is also rock-type dependent.**

When all aggregates were included in the analysis, there was no correlation between MBV and the MIDT results (D_{P200} and SE values). However, there were strong correlations when the results were analyzed based on the rock types.

Evaluate Supplemental Tests

- **The significant differences between the average Durability Index values (D_c and D_f) in this versus the results from RP029 indicated that the test method in RP029 was wrong.**
- **The Durability Index Test (AASHTO T 210 and CTM 229) is not a suitable replacement for the MIDT.**

  There was no meaningful correlation between the D_c and D_f values from the durability index test and the D_{P200} and SE values from the MIDT.

- **The Micro-Deval Fine Aggregate Test (ASTM D7428) is a suitable substitute test for the MIDT.**

  There was a strong positive linear correlation between the abrasion loss (%) values and the D_{P200} values from the MIDT. Based on the recommended satisfactory limits of the abrasion loss (%) in ASTM D7428 and the correlation equation between the abrasion loss and D_{P200}, the recommended D_{P200} values were established.

Recommendations

Future Research

- **Reevaluate the soaking time**

Due to the limited number of samples, TAC rejected the recommendation to use 1-hour soaking time instead of 16 hours. The initial evaluation of the soaking time showed no statistical difference between the results obtained from these two soaking times. The strong correlation between D_{P200} (16 hours soak) and Abrasion loss of Fine aggregate (1 hour soak) also suggested the shorter soaking time should not affect the degradation test results. An evaluation involving more samples should be conducted to understand the impact of soaking time on results from the MIDT. Lowering the soaking time to 1 hour would significantly shorten the testing time.

- **Test field crushed job aggregates**

The aggregates evaluated in this research were obtained directly from the pit or quarry, and all were crushed in the lab using a jaw crusher. The crushed aggregates were evaluated almost immediately without stockpiling. These aggregates may differ from the “real” job aggregates, which were crushed using different machines and went through a long period of weathering during storage and handling. Crushed aggregates, on average, had 1% higher in D_{P200} than the value from the uncrushed sample. Different crushing methods might have different influences on the results. More tests should be conducted on the job aggregates to validate the findings in this research.

- **More Tests on the Same Rock Types**

This research has indicated that the relationship between the MIDT results (D_{P200} and SE values) was rock-type specific. However, only three samples in two rock groups were evaluated. More samples from the same category of rock need to be evaluated.

- **Co-op tests to evaluate the repeatability and reproducibility of the MIDT**

In this research, all degradation tests were conducted within one lab. The data pool for evaluating repeatability was limited, and there was no data to evaluate the MIDT's reproducibility. Several labs, including ITD and commercial labs, should conduct co-op tests to evaluate the MIDT's testing procedure and establish the acceptance ranges for this test.

- **Evaluate the Micro-Deval Abrasion Loss Test on Fine Aggregate as a companion test for aggregate degradation.**

The strong correlation between D_{P200} and Abrasion Loss of Fine Aggregate indicated that the properties measured by the MIDT could be substituted by the Micro-Deval test, a widely accepted ASTM test. Multiple States and agencies have researched the Micro-Deval test for fine aggregate. The physical meaning of the measurement, the repeatability and reproducibility of the test, and the field validation for the results are well documented. ITD should consider using the Micro-Deval Test as the test for aggregate degradation.

Implementation

ITD can implement the suggested MIDT procedure listed in Appendix K. The following issues should be considered to establish the requirements for the test:

- **Crushed Aggregates for Job Mix Evaluation**

This research indicated that crushed aggregate tends to have a higher D_{P200} value than uncrushed aggregate from the same source. To cover the variance caused by this, all aggregates should be crushed before testing for job mix approval. The combination of crushed and uncrushed aggregates should not be allowed unless it is a sample from an existing, produced stockpile.

- **Aggregates Gradation for Job Mix**

The gradation in the MIDT should always be followed and stay the same as listed in Appendix K. The job mix gradation should not substitute for the MIDT gradation. When a job aggregate mix is evaluated, it should be fractionated into the different sieve sizes listed in the proposed specification and recombined into the MIDT gradation.

- **Proposed Specification Range**

The suggested SE values are 30% minimum for SE_B and 25% for SE_A.

For D_{P200}, Table 7.1 should be followed.

Table 7.1: D_{P200} Specifications

Application Type	D_{P200} (%)
Fine and Coarse Aggregate for Concrete	9
Aggregate for Untreated Base, Treated Base, and Road Mix	14
Aggregate for Superpave HMA Pavement	7
Aggregate for Cover Coat Material	7
Aggregate for Blotter and Choke Sand	Not Required
Aggregate for Open Graded Rock Base (Rock Cap)	11
Aggregate for Extrusions	9
Aggregate for Anti-Skid, Type 1, 3, 4, 5	Not Required
Aggregate for Anti-Skid, Type 2	7
Aggregate for Granular Subbase	16

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Appendix A. Idaho Degradation Test 1995 version (ITD, 1995)

IDAHO TRANSPORTATION DEPARTMENT
Boise, Idaho

Idaho T-15-95

IDAHO DEGRADATION

1. SCOPE

1.1 This test method is intended as a quantitative measure of the resistance of a graded aggregate to production of fines by abrasion in the presence of water. The test provides a means by which it is possible to evaluate how the aggregate may perform in the road.

2. APPARATUS

2.1 Idaho Degradation Machine. The Idaho Degradation Machine is equipped with an electric motor with gear reduction. The machine shall maintain a substantially uniform speed of 30 to 33 rpm. Metal cans equipped with spring tension handles to securely hold 3.8 liter jars in place are so positioned that the jars rotate end over end. Diameter of the metal cans shall be such that the jars are a snug fit, but can be inserted and removed without binding. The cans shall be deep enough so that the straight portion of the jar sidewall is completely within the can.

2.2 Wide mouth 3.8 liter jars with lids. The lids are fitted with solid 3 mm thick rubber gaskets.

2.3 Sieves. A set of U.S. Standard, 203 mm diameter sieves 19 mm through 75 µm. These sieves shall meet AASHTO M 92 specifications.

2.4 Sand Equivalent apparatus as described in AASHTO T 176.

2.5 Scoop, brush and rustproof drying container approximately 460 mm X 300 mm X 50 mm deep.

2.6 Drying Oven - 60° C maximum.

2.7 Balance with a 2000 g capacity sensitive to 0.1 g.

3. PREPARATION OF SAMPLE

3.1 Sample make-up (Oven dry at 60° C max.).

3.1.1 The sample for testing with 12.5 mm or larger size aggregate shall have the following gradation:

16.7% Passing the 19 mm and Retained on the 12.5 mm	183 g.
16.6% Passing the 12.5 mm and Retained on the 9.5 mm	183 g.
16.7% Passing the 9.5 mm and Retained on the 4.75 mm	184 g.
50% Passing the 4.75 mm	550 g.
Total	1100 g.

3.1.2 The sample for testing with 9.5 mm size aggregate shall have the following gradation:

25% Passing the 12.5 mm and Retained on the 9.5 mm	275 g.
25% Passing the 9.5 mm and Retained on the 4.75 mm	275 g.
50% Passing the 4.75 mm	550 g.
Total	1100 g.

3.1.3 The sample for testing with 4.75 mm size aggregate shall have the following gradation:

50% Passing the 9.5 mm and Retained on the 4.75 mm	550 g.
50% Passing the 4.75 mm	550 g.
Total	1100 g.

3.2 Combine oven dried original and crushed portions representative of the gradation of the material as intended for use. For material coarser than the 4.75 mm sieve, thoroughly mix original and crushed portions and weigh out exactly the specified amount. Obtain the specified amount of 4.75 mm material by the method of quartering or by the use of a sample splitter as described in AASHTO T 248.

Note: The coarse portion of the sample shall be hand shaken to refusal on each specified sieve size before make-up. Hand shaking shall continue until not more than 1% by weight of the residue passes any sieve during one minute.

4. PROCEDURE

4.1 Place the prepared oven dried material (maximum drying temperature 60° C) in a wide mouth 3.8 liter jar and enough water to cover the aggregate to a depth of approximately 13 mm.

4.2 Allow the sample to soak at least 16 hours.

4.3 If necessary, after the soaking period adjust the water in the jar so the aggregate is barely covered.

4.4 Place lid with rubber gasket on jar and seal tightly. Fit the jar into the Idaho Deg. Machine making certain that the spring tension handle is securely holding the jar.

4.5 Start the Idaho Deg. Machine and allow the jar to make 1,850 revolutions. The tumbling action of the aggregate as the jar rotates end over end produces the degradation.

4.6 At the end of the test period empty the contents of the jar over a 4.75 mm sieve placed over a container to catch all the 4.75 mm material and water.

4.7 Wash out the jar using as little water as possible. Wash the plus 4.75 mm material until all the fines sticking to the aggregate are washed into the minus 4.75 mm portion of the sample. Place the container with the minus 4.75 mm portion in the oven for drying.

4.8 Oven dry the plus 4.75 mm material and then shake to refusal over the appropriate coarse sieves. If any material passes the 4.75 mm sieve, it is to be added to the minus 4.75 mm portion.

4.9 Stir the minus 4.75 mm portion occasionally and remove from oven when a cast point is reached. A cast point is defined as that point when a portion tightly squeezed in the palm of the hand will form a cast which will bear very careful handling without breaking.

4.10 When the cast point is reached, run sand equivalent on the minus 4.75 mm material according to AASHTO T 176.

4.11 Retain the material from the sand equivalent test and return it to the minus 4.75 mm portion.

4.12 Wash entire minus 4.75 mm portion over 75 µm sieve, dry and sieve as described in AASHTO T 11.

4.13 Compute the total gradation based on initial oven dry weight of 1100 g. This becomes the gradation after degradation.

Note: Weights should be recorded to the nearest gram.

5. REPORT

5.1 The before-test gradation and sand equivalent together with the after-test gradation and sand equivalent are reported. The amount of degradation is indicated by the difference in test values.

Note: If the before-test gradation of material passing the 4.75 mm sieve is measured by sieve analysis of a representative sample for which the % Passing 4.75 mm is 50%, then the before-test percentages for 4.75 mm and finer sieves from the analysis are recorded directly in the "BEFORE TEST" column on Form ITD-895. Otherwise, all before-test percentages for 4.75 mm and finer sieves must be multiplied by an adjustment factor before recording on the form. The adjustment factor is 50 divided by the percentage of material passing 4.75 mm in the representative before-test gradation sample. For example, if the 4.75 mm and finer before-test percentages are determined on sample consisting of 100% minus 4.75 mm material, the adjustment factor is 50/100=0.50. Similarly, if the sample for determining before-test gradation has 40% minus 4.75 mm, the adjustment factor for 4.75 mm and finer sieves is 50/40=1.25.

5.2 All computations are entered on Form ITD-895.

5.3 The test results shall be reported on Form ITD-802.

6. PRECAUTIONS

6.1 Avoid baking sample during drying period prior to sand equivalent test.

6.2 Be sure to return all of the material from the sand equivalent test back into the minus 4.75 mm portion.

Appendix B. Idaho Degradation Test 2019 version (ITD, 2019)

Idaho Standard Method of Test for

Idaho Degradation

IDAHO Designation: IT-15-19

1. SCOPE

1.1. This test method is intended as a quantitative measure of the resistance of a graded aggregate to production of fines by abrasion in the presence of water. The test provides a means by which it is possible to evaluate how the aggregate may perform in the road.

1.2. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCE DOCUMENTS

2.1 *AASHTO Standards*

- M 92, Wire Cloth Sieves for Testing Purposes
- M 231, Weighing Devices Used in the Testing of Materials
- R 76, Reducing Field Samples of Aggregates to Testing Size.
- R 90, Sampling Aggregate Products
- T 176, Plastic Fines in Graded Aggregates and Soils by Use of the Sand Equivalent Test.

2.2 *ASTM Standards*

- E11, Woven Wire Test Sieve Cloth and Test Sieves

3. APPARATUS

3.1. *Idaho Degradation Machine.* The Idaho Degradation Machine is equipped with an electric motor with gear reduction. The machine shall maintain a substantially uniform speed of 30 to 33 rpm. Metal cans equipped with spring tension handles to securely hold one-gallon jars in place are so positioned that the jars rotate end over end. Diameter of the metal cans shall be such that the jars are a snug fit, but can be inserted and removed without binding. The cans shall be deep enough so that the straight portion of the jar is completely within the can.

3.2. *Containers* Wide mouth one-gallon jars with lids. The lids are fitted with solid 1/8 in. thick rubber gaskets.

3.3. *Sieves* A set of U.S. Standard, 8 in. diameter sieves 3/4 in. through No. 200. These sieves shall meet ASTM E11 specifications.

3.4. *Sand Equivalent apparatus* as described in AASHTO T 176.

3.5. Scoop, brush and rust proof drying container approximately 18 in. x 12 in. x 2 in. deep.

3.6. *Drying Oven* 140°F maximum.

3.7. *Balance*—A balance that conforms to AASHTO M 231 with a 2,000 g capacity sensitive to 0.1 g.

4. PREPARATION OF SAMPLE

4.1. Sample makeup (Oven-dry at 140°F max.)

4.1.1. The sample for testing with 1/2 in or larger size aggregate shall have the following gradation:

16.7% passing the 3/4 in. and retained on the 1/2 in	183 g.
16.6% passing the 1/2 in. and retained on the 3/8 in	183 g.
16.7% passing the 3/8 in. and retained on the No. 4	184 g.
50% passing the No. 4	550 g.
Total	1100 g.

4.1.2. The sample for testing with 3/8" size aggregate shall have the following gradation:

25% passing the ½" and retained on the 3/8 in.	275 g.
25% passing the 3/8 in. and retained on the No. 4	275 g.
50% passing the No. 4	550 g.
Total	1100 g.

4.1.3. The sample for testing with No. 4 size aggregate shall have the following gradation:

50% passing the 3/8 in. and retained on the No. 4	550 g.
50% passing the No. 4	550 g.
Total	1100 g.

4.2. Combine oven dried original and crushed portions representative of the gradation of the material as intended for use. For material coarser than the No. 4 (4.75 mm) sieve, thoroughly mix original and crushed portions and weigh out exactly the specified amount. Obtain the specified amount of No. 4 materials by the method of quartering or by the use of a sample splitter as described in AASHTO R 76.

4.3. **Note 1 –** The coarse portion of the sample shall be hand shaken to refusal on each specified sieve size before make-up. Hand shaking shall continue until not more than 1% by weight of the residue passes any sieve during one minute.

5. PROCEDURE

5.1. Place the prepared oven dried material (maximum temperature 140°F in a wide mouth jar and enough water to cover the aggregate to a depth of approximately 1/2 in.

5.2. Allow the sample to soak at least 16 hours.

5.3. If necessary, after the soaking period adjust the water in the jar so the aggregate is barely covered.

5.4. Place lid with rubber gasket on jar and seal tightly. Fit the jar into the Idaho Degradation Machine making certain that the spring tension handle is securely holding the jar.

5.5. Start the Idaho Degradation Machine and allow the jar to make 1,850 revolutions. The tumbling action of the aggregate as the jar rotates end over end produces the degradation.

5.6. At the end of the test period empty the contents of the jar over a No. 4 sieve placed over a container to catch all the No. 4 material and water.

5.7. Wash out the jar using as little water as possible. Wash the plus No. 4 material until all the fines sticking to the aggregate are washed into the minus No. 4 portion of the sample. Place the container with the minus No. 4 portion in the oven for drying.

5.8. Oven dry the plus No. 4 material and then shake to refusal over the appropriate coarse sieves. If any material passes the No. 4 sieve, it is to be added to the minus No. 4 portion.

5.9. Stir the minus No. 4 portion occasionally and remove from oven when a cast point is reached. A cast point is defined as the point when a portion tightly squeezed in the palm of the hand will form a cast which will bear very careful handling without breaking.

5.10. When the cast point is reached, run sand equivalent on the minus No. 4 material according to AASHTO T 176.

5.11. Retain the material from the sand equivalent test and return it to the minus portion.

5.12. Wash entire minus No. 4 portion over No. 200, dry and sieve as described in AASHTO T 11.

5.13. Compute the total gradation based on initial oven dry weight of 1100 g. This becomes the gradation after degradation.

Note 2— Weights should be recorded to the nearest gram.

6. REPORT

6.1. The before-test gradation and sand equivalent together with the after-test gradation and sand equivalent are reported. The amount of degradation in indicated by the difference in test values.

Note 3— If the before-test gradation of material passing the No. 4 sieve is measured by sieve analysis of a representative sample for which the % Passing No. 4 is 50%, the before test percentages for No. 4 and finer sieve from the analysis are recorded directly in the "BEFORE TEST" column on Form ITD-895. Otherwise, all before test percentages for No. 4 and finer sieves must be multiplied by an adjustment factor before recording on the form. The adjustment factor is 50 divided by the percentage of material passing No. 4 in the representative before-test gradation sample. For example, if the No. 4 and finer before-test percentages are determined on a sample consisting of 100% minus No. 4 material, the adjustment factor is 50/100 = .050. Similarly, if the sample for determining before-test gradation has 40% minus No. 4, the adjustment factor for No. 4 and finer sieves is 50/40 = 1.25.

6.2. The test results shall be reported on Form ITD-802.

7. PRECAUTIONS

7.1. Avoid baking sample during drying period prior to sand equivalent test.

7.2. Be sure to return all of the material from the sand equivalent test back into the minus No. 4 portion.

Appendix C. Aggregates Rating from RP029 (Howard, 1966)

Source	Service Report	D_c	D_f	Rating by CDT	IDT (UW) SE (B)	IDT (UW) SE (A)	IDT (UW) P200 (B)	IDT (UW) P200 (A)	Rating by IDT (UW)	Zone by IDT (UW)	IDT (W) SE (A)	IDT (W) P200 (A)	Rating by IDT (W)
Bl-94	G	80	47	G	71	53	4	7	G	B	64	4	G
Bu-58	A	78	33	P	65	40	4	8	G	B	58	5	G
Ca-57	A	78	53	G	67	50	3	7	G	B	67	4	G
Cs-84	A	67	42	G	55	29	4	14	P	A	49	6	P
Cu-39	A	73	39	P	63	39	3	8	G	B	53	6	P
Jr-2	P	73	27	P	62	35	5	13	P	B	45	9	P
Jr-38	P	72	53	G	42	25	10	18	P	B	62	10	P
TF-63	P	67	41	G	62	44	4	9	G	B	59	6	P
TF-66	A	80	65	G	70	50	3	6	G	B	65	4	G
TF-67	P	55	25	P	43	26	9	18	P	C	42	11	P
Id-93	P	59	32	P	58	33	7	14	P	B	53	9	P
Lt-102	P	62	38	P	72	45	4	12	P	B	59	7	P
Lt-126	P	78	58	G	70	53	7	12	G	B	67	7	P
NP-11	G	80	59	G	85	67	3	7	G	B	77	4	G
NP-32	G	85	77	G	88	80	3	5	G	B	88	3	G
NP-96	G	74	57	G	74	53	5	12	P	B	70	7	P
Kt-1	G	85	70	G	82	67	4	9	G	B	76	6	P
Bn-33	A	87	39	P	54	35	6	11	G	B	56	6	P
Cl-56	A	82	54	G	33	28	4	9	P	B	58	5	G
Fr-33	A	82	69	G	80	67	3	7	G	B	76	5	G

CDT: California Degradation Test; IDT: Idaho Degradation Test

UW: Unwashed; W: Washed; B: Before; A: After

Rating by IDT (UW): Increase of P200 ≤ 5%; SE After ≥ 25%

Zone by IDT (UW): Based on Equations (1) and (2)

Rating by IDT (UW): P200 after ≤ 5%; SE After ≥ 25%

G: Good; A: Acceptable; P: Poor

Appendix D. SE Tables (Original SE vs. Final SE Calculation Based on from RP029) (Howard, 1966)

Original SE (%)	Final SE (%) (Minimum)	Original SE (%)	Final SE (%) (Minimum)	Final SE (%)	Original SE (%) (Maximum)	Final SE (%)	Original SE (%) (Maximum)
19	12.7	60	33.6	10	13.7	51	94.1
20	13.2	61	34.1	11	15.7	52	96.0
21	13.7	62	34.6	12	17.6	53	98.0
22	14.2	63	35.1	13	19.6	54	100
23	14.7	64	35.7	14	21.6		
24	15.2	65	36.2	15	23.5		
25	15.8	66	36.7	16	25.5		
26	16.3	67	37.2	17	27.4		
27	16.8	68	37.7	18	29.4		
28	17.3	69	38.2	19	31.4		
29	17.8	70	38.7	20	33.3		
30	18.3	71	39.2	21	35.3		
31	18.8	72	39.7	22	37.2		
32	19.3	73	40.2	23	39.2		
33	19.8	74	40.8	24	41.2		
34	20.3	75	41.3	25	43.1		
35	20.9	76	41.8	26	45.1		
36	21.4	77	42.3	27	47.0		
37	21.9	78	42.8	28	49.0		
38	22.4	79	43.3	29	51.0		
39	22.9	80	43.8	30	52.9		
40	23.4	81	44.3	31	54.9		
41	23.9	82	44.8	32	56.8		
42	24.4	83	45.3	33	58.8		
43	24.9	84	45.9	34	60.8		
44	25.4	85	46.4	35	62.7		
45	26.0	86	46.9	36	64.7		
46	26.5	87	47.4	37	66.6		
47	27.0	88	47.9	38	68.6		
48	27.5	89	48.4	39	70.6		
49	28.0	90	48.9	40	72.5		
50	28.5	91	49.4	41	74.5		
51	29.0	92	49.9	42	76.4		
52	29.5	93	50.4	43	78.4		
53	30.0	94	51.0	44	80.4		
54	30.6	95	51.5	45	82.3		
55	31.1	96	52.0	46	84.3		
56	31.6	97	52.5	47	86.2		
57	32.1	98	53.0	48	88.2		
58	32.6	99	53.5	49	90.2		
59	33.1	100	54.0	50	92.1		

Appendix E. P200 Tables (Original P200 vs. Final P200 Calculation Based on from RP029) (Howard, 1966)

Original P200 (%)	Final P200 (%) (Maximum)	Final P200 (%)	Original P200 (%) (Minimum)
0	5.5	3	0
1	6.7	4	0
2	7.9	5	0
3	9.1	6	0.4
4	10.2	7	1.3
5	11.4	8	2.1
6	12.6	9	3.0
7	13.8	10	3.8
8	14.9	11	4.7
9	16.1	12	5.5
10	17.3	13	6.4
11	18.5	14	7.2
12	19.6	15	8.1
13	20.8	16	8.9
14	22.0	17	9.8
15	23.2	18	10.6
16	24.4	19	11.5
		20	12.3
		21	13.2
		22	14.0
		23	14.9
		24	15.7
		25	16.6
		26	17.4
		27	18.3
		28	19.1
		29	20.0
		30	20.8
		31	21.7

Appendix F. Questionnaire for State Agencies

RP313 Survey Questions

1. Please provide your contact information.

   Name:
   Agency:
   Title:
   Phone number:
   Email address:

2. What is the definition of Aggregate Degradation to Your Agency?

3. Has your agency conducted any research project on evaluating aggregate degradation? If you have, please provide the links for such studies.

4. What are the tests that your agency is using to evaluate the degradation of aggregate caused by wear, impact, and abrasion? Please Select **All** that apply.

   a) AASHTO T 96 Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine
   b) AASHTO T 327 Resistance of Coarse Aggregate to Degradation by Abrasion in the Micro-Deval Apparatus
   c) ASTM D7428 Resistance of fine Aggregate to Degradation by Abrasion in the Micro-Deval Apparatus
   d) AASHTO T 210 Aggregate Durability Index
   e) Others: **Please list the tests here**

   _____

5. If you select the multiple tests in question 4, could you please provide an efficiency ranking of the multiple tests and give a brief reason for such a ranking?

6. Has your agency conducted any research project on evaluating different test methods that you listed in question 4? If you have, please provide the links for such studies.

Appendix G. Summary of Survey from State Agencies

Agency	Definition	Test	Test	Test	Test	Test	Rank
		1	2	3	4	5	
		AASHTO T 96	AASHTO T 327	ASTM D7428	AASHTO T 210	Other	
Alaska	% Loss of mass criteria from Micro-Deval testing.	x	x			ATM 312 Nordic Abrasion Value ATM 313 Degradation Value of Aggregates	1. Micro-Deval, It is efficient, repeatable, and correlates well to aggregate surface wear 2. LA Abrasion, separates friable from more durable hard rock but does not quantify rubbing wear as well as Micro-Deval.
Arkansas	The breaking down, or deterioration, of aggregates affects the structural performance.	x				ARDOT 399 Slake Durability Index	T96 is more efficient when it comes to the time of performing the overall testing. Other than that, none are very efficient when it comes to time and expense.
Colorado	Our aggregate requirements specify the criteria necessary for the application when tested by the appropriate method.	x	x				N/A
Delaware	No	x					N/A
Idaho	The chemical and/or physical deterioration of an aggregate that will compromise the intended use.	x			X (in RipRap)	IT-15 Idaho Degradation Test	N/A
Illinois	The physical breakdown of aggregate material through attrition during transport from an aggregate producer to the incorporation of the final product.	x					N/A
Iowa	Best defined by service life in Portland cement concrete	x					N/A

Agency	Definition	Test	Test	Test	Test	Test	Rank
		1	2	3	4	5	
		AASHTO T 96	AASHTO T 327	ASTM D7428	AASHTO T 210	Other	
Louisiana	The durability of an aggregate after being subjected to test conditions that cause disintegration	x	x				1. AASHTO T96 The department uses this test to evaluate the aggregate's durability with a continuous impact 2. AASHTO T327 This test is used by the department to evaluate the aggregate's resistance to an abrasive charge in the presence of water.
Maine	None. We rely on the specification limits of the relevant tests to define adequate degradation resistance.	x	x	x		WSDOT T 113 Degradation Value (If Micro-Deval Failed)	N/A
Massachusetts	The breakdown of aggregate into smaller particle sizes when subjected to mechanical and/or chemical forces.	x					N/A
Michigan	We do not define Aggregate Degradation outside of AASHTO/ASTM definitions. More focused on measures of overall durability of the aggregates for each specific construction use using the below testing.	x	x			MTM 111 Wear Track - Aggregate Wear Index	Such a ranking is not possible, each aggregate has different test requirements based on the intended use.
Minnesota	No established definition of aggregate degradation. W we require aggregates to meet certain aggregate tests.	x			x		This question depends upon the type of aggregate used

Agency	Definition	Test	Test	Test	Test	Test	Rank
		1	2	3	4	5	
		AASHTO T96	AASHTO T327	ASTM D7428	AASHTO T210	Other	
Missouri	Aggregate degradation is the breakdown of aggregate caused by different mechanisms.	x	x				This is difficult to do. We believe each test provides insight into how the aggregate will perform in an asphalt or concrete mixture. One test by itself does not provide enough information
Montana	Aggregate breakdown due to repeated loading and/or environmental factors.	x	x				1. T96 – Short test, simplistic test to get a general idea of material durability. 2. T327 – Relatively short test, adds water to the equation.
Nebraska	Specification limits of the relevant tests to define adequate degradation resistance.	x					N/A
Nevada	A measure of an aggregate's strength properties in response to abrasion or chemical stresses	x			x		1. LAR - preferred for simplicity and believed to be a good measure of degradation 2. Durability Index
New Jersey	We define it as the breakdown of aggregate to due "normal wear and tear" in a pavement but additionally, any breakdown that occurs during manufacture, stockpile, and transport. We measure degradation in terms of percentage loss.	x		x		British Wheel, Petrographic Identification	1.T96 – Simple and quick test that gives a general indication 2.Petrographic Examination – An in-house test method designed to identify the composition of aggregate samples. 3.T327 – Did not find much success when it came to repeatability. 4. British Wheel – An oldie but a goody and only listed last because the preparation of individual samples was very time-consuming and was somewhat subjective.

Agency	Definition	Test	Test	Test	Test	Test	Rank
		1	2	3	4	5	
		AASHTO T96	AASHTO T327	ASTM D7428	AASHTO T210	Other	
New York	Any physical breakdown of particles due to weathering, traffic polishing, traffic load/impact/abrasion, or chemical reactivity.						N/A
North Carolina	The percent loss over 55% from AASHTO T96 is unacceptable.	x					N/A
North Dakota	N/A	x					We utilize AASHTO T 96 to measure coarse aggregate resistance to degrade. We require this test for all types of aggregates including base, concrete aggregates, seal coat/slurry aggregates, and hot mix.
Oklahoma	The focus of these tests is the resistance of the aggregate to physical degradation, in dry and wet conditions.	x	x		x		a. AASHTO T210 b. AASHTO T327 c. AASHTO T96 Ranking order is based on failure rate.
Oregon	Measure the quantity and quality of the material under the attrition produced in the roadway under repeated traffic loading and unloading	x	x	x		ODOT TM 208 Oregon Air Aggregate Degradation	1 - LA Abrasion is the simplest and thus the most efficient to run, but we don't consider it the best measure of durability on its own 2 – ODOT TM 208 is less efficient to run but gives us additional information for qualifying aggregates
South Dakota	N/A	x					N/A

Agency	Definition	Test	Test	Test	Test	Test	Rank
		1	2	3	4	5	
		AASHTO T96	AASHTO T327	ASTM D7428	AASHTO T210	Other	
Texas	The ability of an aggregate to resist wearing from impacts, crushing, abrasion, and weathering actions.	x	x	x			1. LA Abrasion – This is an acceptance test for aggregate used in roadways throughout the state. It adequately identifies aggregate that will begin breaking down prematurely during compaction/mixing or under roadway conditions. 2. Micro-Deval Abrasion of Aggregate – Informational Only. Due to the wide range of aggregates throughout the state, we are not able to confidently set loss limits.
Vermont	% loss of weight of aggregate as tested in AASHTO T-96.	x					N/A
Wisconsin	N/A	x					N/A
Wyoming	Aggregates capability to withstand impact/grinding and weathering	x	x	x			1, 2, 3

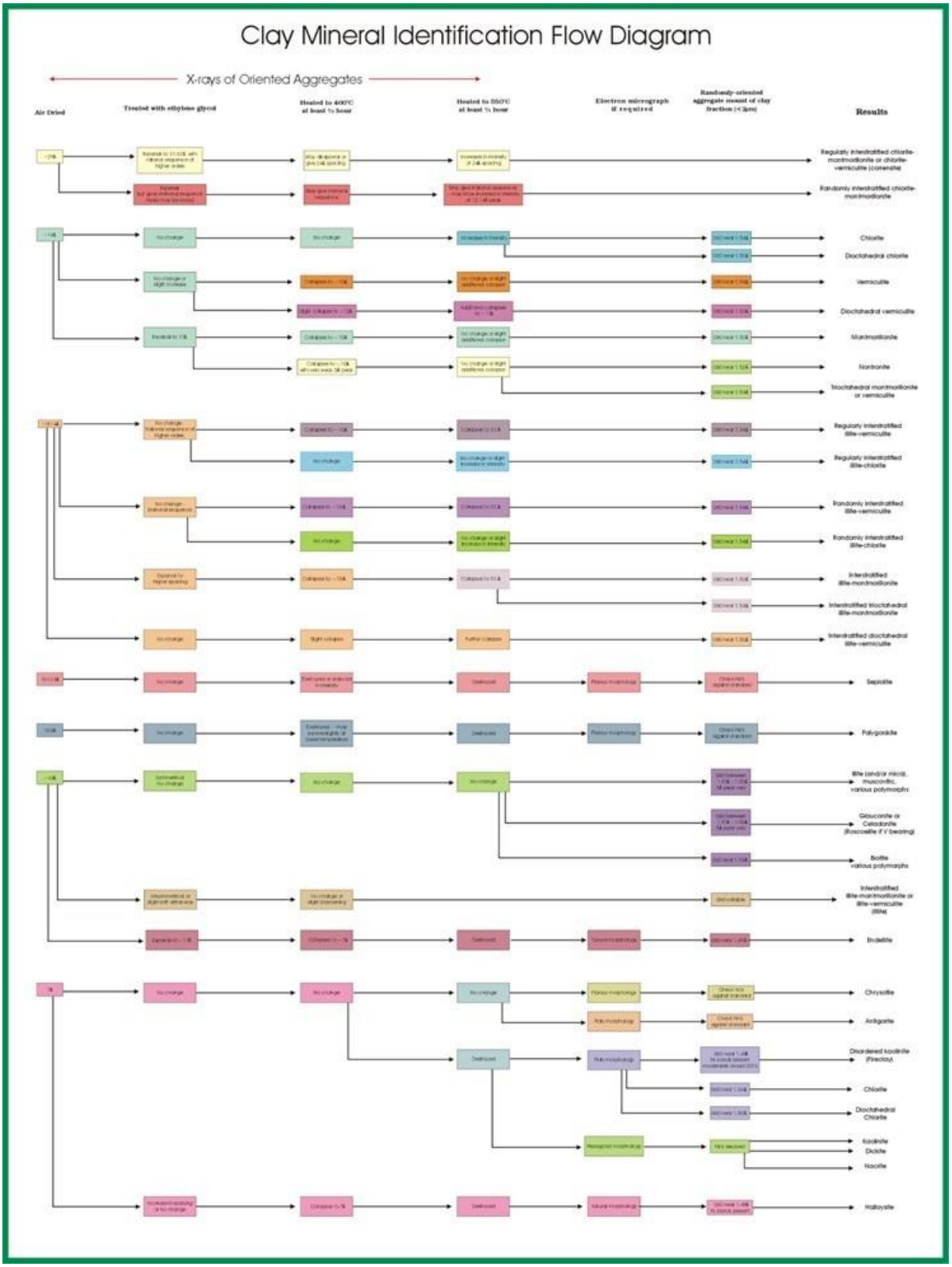
Appendix H. Review of Testing Methods from State Agencies

Agency	Test On Degradation	Test On Degradation	Test On Degradation	Test On Degradation	Test On Degradation
	1	2	3	4	5
	AASHTO T96	AASHTO T327	ASTM D7428	AASHTO T210	Other
Alabama	x				
Arizona	x				
California	x				CTM 229 Durability index
Connecticut	x				
Florida	x				
Georgia	x				GDT 75 Durability index ASTMC295 Petrographic
Hawaii	x				
Indiana	x	x			ITM 220 (Aggregate Degradation Loss)
Kansas	x	x			AASHTO T330 (Methylene Blue)
Kentucky	x				
Maryland	x				MSMT 216 Dynamic Friction Tester
Mississippi	x				
New Hampshire	x				
New Mexico	x	x			ASTMC295 Petrographic and Aggregate Index (Section 910)
Ohio	x	x			
Pennsylvania	x	x			AASHTO T330 (Methylene Blue)
Rhode Island	x				
South Carolina	x	x			
Tennessee	x				AASHTO T278/T279 British Pendulum Tester (British Wheel)
Utah	x	x			AASHTO T278/T279 British Pendulum Tester (British Wheel)
Virginia	x				
Washington	x				WSDOT 113 Degradation Factor
Washington, D.C.	x				
West Virginia	x				

Appendix I. Geological Information of Aggregates

ITD Code	Geology	Description
Br-0134c	Prichard Formation (Mesoproterozoic)	Siltite, quartzite, and argillite in northern Idaho; deposited in deep water and contains voluminous ~1470 Ma mafic sills. Includes siltite, quartzite, fine-grained schist, and carbonate rocks structurally above anorthosite near Boehls Butte, northeast of Elk River.
By-0068c	Alluvial deposits (Quaternary)	Deposits in valleys consisting of gravel, sand, and silt. Includes younger terrace deposits. May contain some glacial deposits and colluvium in uplands
Kt-214t	Missoula Flood deposits (Pleistocene)	Gravel, sand, and silt near Coeur d'Alene and Sandpoint that were carried by outburst floods from Glacial Lake Missoula (20-15 ka). Floods also flowed back up the Snake and Clearwater rivers to Kamiah. Missoula Flood slack-water deposits cover Lake Bonneville deposits in the Lewiston area.
Id-267c	Columbia River Basalt Group (Miocene)	Large-volume lava flows of tholeiitic basalt, basaltic andesite, and subordinate andesite in western Idaho; consists of Imnaha Basalt (17.5-16.5 Ma), Grande Ronde Basalt (16.5-15.6 Ma), Wanapum Basalt (15.6-14.5 Ma), and Saddle Mountains Basalt (14.5-6 Ma). Includes porphyritic basalt and basaltic andesite in western Owyhee County.
Id-276c	Riggins Group, Orofino series, and related rocks (Cretaceous to Permian)	Metasedimentary and metavolcanic schist, gneiss, amphibolite, and marble, all of uncertain age, along eastern margin of island-arc complex; typically hornblende-rich. Includes Pollock Mountain amphibolite southeast of Riggins and gneiss of Swiftwater Creek near Lowell.
Ad-161c	Sediments and sedimentary rocks (Pleistocene and Pliocene)	Older gravel, sand, and silt deposited in fans, streams, and lakes. Includes older terrace gravels and Tuana Gravel northwest of Twin Falls.
Ore-16c	Alluvial deposits (Quaternary)	Deposits in valleys consisting of gravel, sand, and silt. Includes younger terrace deposits. May contain some glacial deposits and colluvium in uplands.
Vy-62c	Columbia River Basalt Group (Miocene)	Large-volume lava flows of tholeiitic basalt, basaltic andesite, and subordinate andesite in western Idaho; consists of Imnaha Basalt (17.5-16.5 Ma), Grande Ronde Basalt (16.5-15.6 Ma), Wanapum Basalt (15.6-14.5 Ma), and Saddle Mountains Basalt (14.5-6 Ma). Includes porphyritic basalt and basaltic andesite in western Owyhee County.
Cs-193s	Basalt (Pleistocene and Pliocene)	Flows and cinder cones of olivine tholeiite basalt in and near Snake River Plain. Largely Pleistocene (<2.6 Ma) but includes flows as old as 3 Ma. Covered with 1-3 m (3-10 ft) of loess.
Cs-185s	Alluvial-fan deposits (Quaternary)	Gravel and subordinate sand and silt deposited at mouths of canyons; largest fans are in Basin and Range Province in east-central and southeastern Idaho.
Tf-25s	Alluvial deposits (Quaternary)	Deposits in valleys consisting of gravel, sand, and silt. Includes younger terrace deposits. May contain some glacial deposits and colluvium in uplands.
Bl-70s	Alluvial deposits (Quaternary)	Deposits in valleys consisting of gravel, sand, and silt. Includes younger terrace deposits. May contain some glacial deposits and colluvium in uplands.
Cr-14s	Sedimentary rocks (Permian and Pennsylvanian)	Marine phosphorite, shale, and chert of Phosphoria Formation, fine-grained sandstone and mudrock of Wells, Quadrant, Amsden, and Shedhorn formations, and fine-grained sandstone, carbonaceous mudstone, and limestone of the Snaky Canyon Formation and Sun Valley and Oquirrh groups. Located in south-central and eastern Idaho.
Bn-128s	Alluvial deposits (Quaternary)	Deposits in valleys consisting of gravel, sand, and silt. Includes younger terrace deposits. May contain some glacial deposits and colluvium in uplands.
Fr-76s	Alluvial deposits (Quaternary)	Deposits in valleys consisting of gravel, sand, and silt. Includes younger terrace deposits. May contain some glacial deposits and colluvium in uplands.
Ma-54s	Alluvial deposits (Quaternary)	Deposits in valleys consisting of gravel, sand, and silt. Includes younger terrace deposits. May contain some glacial deposits and colluvium in uplands.

Appendix J. XRD Clay Identification Flow Chart



Appendix K. The Modified Idaho Degradation Test (MIDT)

Idaho Standard Method of Test for

Idaho Degradation

IDAHO Designation: IT-15-XX

1. SCOPE

1.1. This test method is intended as a quantitative measure of the resistance of a graded aggregate to the production of fines by abrasion in the presence of water. The test provides a means by which it is possible to evaluate how the aggregate may perform in the road.

1.2. *This standard does not purport to address all the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use*.

2. REFERENCE DOCUMENTS

2.1 *AASHTO Standards*

- M 92, Wire Cloth Sieves for Testing Purposes
- M 231, Weighing Devices Used in the Testing of Materials
- R 76, Reducing Field Samples of Aggregates to Testing Size.
- R 90, Sampling Aggregate Products
- T 11, Materials Finer than 75 µm (No. 200) Sieve in Mineral by Washing
- T 27, Sieve Analysis of Fine and Coarse Aggregates
- T 176, Plastic Fines in Graded Aggregates and Soils by Use of the Sand Equivalent Test.

2.2 *ASTM Standards*

- E11, Woven Wire Test Sieve Cloth and Test Sieves

3. APPARATUS

3.1. *Container* Shall be meeting the following*:*

- Plastic: Polypropylene or Polyethylene
- Size: 1 gallon
- Height: 10 ± ¼ in.
- Diameter: 6 ± ¼ in.
- Opening Diameter: 4 ± ¼ in.
- Lid: 4 3/8 ± 1/8 in. (Plastic with Plastic foam or rubber liner 3/64 ± 1/64 in.

3.2. *Idaho Degradation Testing Apparatus.* The apparatus is equipped with an electric motor

that shall maintain a substantially uniform speed of 31±2 rotation per minute (rpm). It shall be equipped with spring tension or other suitable apparatus to securely hold the container(s) in section 3.1 in place and can be inserted and removed without binding. The container(s) shall be positioned so that the rotating axis passes at the center of the container(s) and the container(s) shall rotate in an end-over-end motion. The apparatus should also have a counter device to record the number of rotations.

3.3. *Sieves:* A set of U.S. Standard sieves of ¾ in. through No. 200 shall meet ASTM E 11 specifications.

3.4. *Sieve Shaker* - Shaker that meets the requirements of AASHTO T 27/T 11

3.5. *Sand Equivalent apparatus:* As described in AASHTO T 176.

3.6. *Pans*: Suitable rust-proof drying pans

3.7. *Drying Oven:* Sufficient size, capable of maintaining a uniform temperature of 230 ± 9°F.

3.8. *Balance or scale* —Capacity sufficient for the masses shown in Table 1, accurate to 0.1 percent of the sample mass or readable to 0.1 g, and meeting the requirements of AASHTO M 231

3.9. *Utensils*: Spoons, spatulas, brushes, etc.

3.10. *Aggregate Containers*: Bins, pans, or buckets, etc.

3.11. *Digital Timer:* Readable in minutes and seconds

4. SAMPLING

4.1. Obtain samples of aggregate to be tested in accordance with R 90.

5. INITIAL SAMPLE PREPARATRION

5.1. If testing pit run and quarry materials: For materials with original portions that can be fractioned into the gradation in 6.1.1 as intended for use, use the original sample without crushing. Dry the material at 230 ± 9°F to allow for clean separation from the fine material. Separate the material over the 3/4 in sieve and discard that coarser than the 3/4 in and proceed to step 5.4. For materials with original portions that cannot be fractioned into the gradation in 6.1.1 as intended for use, dry at 230 ± 9°F to allow for clean separation from the fine material. Crush the entire material to be tested to pass the 3/4 in. sieve and proceed to Step 5.4.

5.2. If testing crushed and stockpiled material (produced product): Dry at 230 ± 9°F to allow for clean separation from the fine material.

5.3. If the sample contains an appreciable amount of clay, turn the aggregate frequently during the drying process. Break up any hard clods using spoons or spatulas to obtain even drying throughout and prevent the formation of hard clay lumps.

5.4. Separate the dried samples by sieving into ¾ in., ½ in., 3/8 in., No. 4, No. 8, No.16, No.30, No. 50, No. 100, No. 200, and Pan. Keep the #200 minus material in a labeled aggregate container. Wash the #200 plus aggregates with water thoroughly following AASHTO T27/T11 and oven-dry these materials at 230 ± 9°F to constant weight (Note 1). Carefully empty the material retained on each sieve into aggregate containers and label them according to size.

Note 1— The test sample is dried at a temperature of 230 ± 9°F to a condition such that it would not lose more than 0.1 percent moisture after an additional 2 h of drying at 230 ± 9°F. Such a condition of dryness can be verified by determining the mass of the sample before and after successive 2-h drying periods.

6. PREPARATION OF TEST SAMPLE

6.1. Sample makeup (Oven-dry at 230 ± 9°F) to constant weight.

6.1.1. The sample for testing shall have the following gradation:

16.6% passing the ¾ in. and retained on the ½ in.	183 ± 1 g
6.6% passing the ½ in. and retained on the 3/8 in.	183 ± 1 g
16.7% passing the 3/8 in. and retained on the No. 4	184 ± 1 g
10.0 % passing the No. 4 and retained on the No. 8	110 ± 0.5 g
10.0 % passing the No. 8 and retained on the No. 16	110 ± 0.5 g
6.8 % passing the No. 16 and retained on the No. 30	75 ± 0.3 g
6.8 % passing the No. 30 and retained on the No. 50	75 ± 0.3 g
5.9 % passing the No. 50 and retained on the No. 100	65 ± 0.2 g
5.5 % passing the No. 100 and retained on the No. 200	60 ± 0.1 g
5.0% passing the No. 200 and retained in the Pan	55 ± 0.1 g
	Total 1100 ± 5 g

6.2. Makeup three 1100 ± 5 g Idaho Degradation Test Samples following the makeup listed in 6.1.1.

6.3. Omitting the portions of No.4 and larger, prepare a 550 ± 2 g companion sample according to makeup in section 6.1.1 for the sand equivalent tests.

7. PROCEDURE

7.1. Conduct sand equivalent test on the companion sample prepared in section 6.3 following Alternative Method No.2 (Pre-Wet) in AASHTO T 176. The result is the sand equivalent before the test (SE_B). The result of SE_B is the average of two test results (Note 2).

Note 2— Sand Equivalent should be recorded to the nearest 1%. If the difference between the two test results is more than 4%, a third sample needs to be prepared and tested.

7.2. Place the prepared Idaho Degradation test sample from section 6.2 into a Container. Add 350 ± 5 g of water to cover the aggregate to a depth of approximately 1/2 in (12.5 mm). Place and tighten the cap onto the container after adding the water.

7.3. Allow the Container to stand in an upright position undisturbed for 16 to 20 hrs.

7.4. Fit the Container into the Idaho Degradation Machine and make certain that the spring tension or other apparatus is securely holding it and that the rotating axis passes through the center (±1/8 in.) of the Container.

7.5. Start the Idaho Degradation Machine and allow the Container to make 1,850 ± 5 revolutions at 31 ± 2 rpm. The tumbling action of the aggregate as the container rotates end over end produces the degradation.

7.6. Select one of the three Idaho Degradation Samples in section 7.2 for SE Tests.

7.6.1. At the end of the test period, empty the container's contents over a No. 4 sieve placed over a pan to catch all the minus No. 4 material and water.

7.6.2. Wash out the Container using as little water as possible. Wash the plus No. 4 material until all the fines sticking to the aggregate are washed into a large and shallow pan with all the minus No. 4 portion of the sample. Then, shake to refusal over the No.4 sieve. If any material passes the No. 4 sieve, it is to be added to the minus No. 4 portion. Discard the plus No. 4 material after the shake.

7.6.3. Place the pan with the minus No. 4 portion in the oven at 230 ± 9°F and dry to constant weight. Leave the pan in a slanted position until the free water that drains to the lower side becomes clear, and then decant this clear water without losing any fine aggregates to speed drying.

7.6.4. After allowing the oven-dried material to cool, run the sand equivalent according to AASHTO T 176 following Alternative Method No.2 (Pre-Wet) in AASHTO T176. The result is the sand equivalent after the test (SEA), which is the average of two test results.

7.7. For the remaining two of the three Idaho Degradation Samples in section 7.2, test each sample separately as follows:

7.7.1. At the end of each sample's test period, empty the container's contents over a No. 200 sieve and wash the aggregate according to AASHTO T 11.

7.7.2. Oven-dry the aggregates retained on No. 200 sieve at 230 ± 9°F to constant mass and sieve as described in AASHTO T 11 (Note 3). Compute the total gradation based on the initial oven dry weight in section 6.2. This becomes the gradation after the degradation test. The passing No. 200 (75 µm) percentage is recorded as $P200_A$.

Note 3— Weights should be recorded to the nearest 0.1 gram. The passing No. 200 percentage should be recorded to the nearest 0.1%. If the difference between the two test results of $P200_A$ is more than 1.0%, a third sample needs to be prepared and tested.

8. REPORT

8.1. The gradations, $P200_A$, and sand equivalent results before (SE_B) and after (SE_A) the Idaho Degradation Test are reported on Form ITD-802.

8.2. The amount of degradation is indicated by the difference in the passing No. 200 sieves (D_{P200}) to the nearest 0.1% using the following formula:

$$D_{P200} = P200_A - 5.0$$

The result of $P200_A$ is the average of two test results in section 7.7.

Appendix L. Petrographic Analysis

1. By-0068c (Micaceous, Quartz-Rich Granitoid)

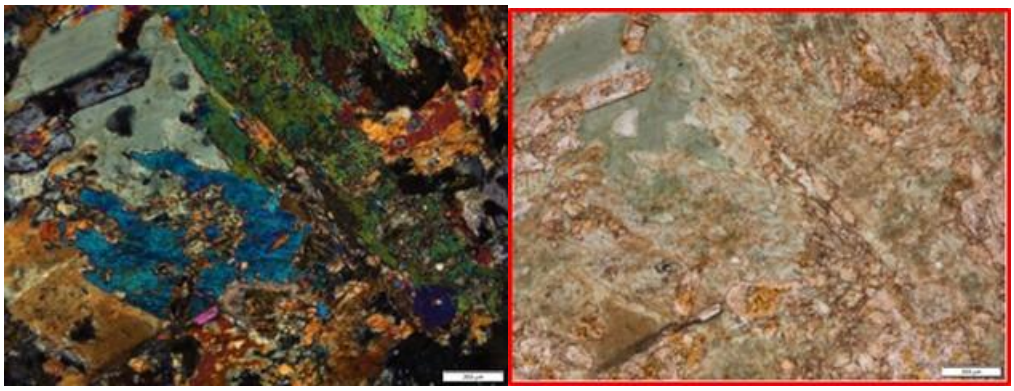


Image A: 20X, 2.0 mm XPL

Image B: 45X, 200 microns PPL

2. Br-0134c (Greywacke)

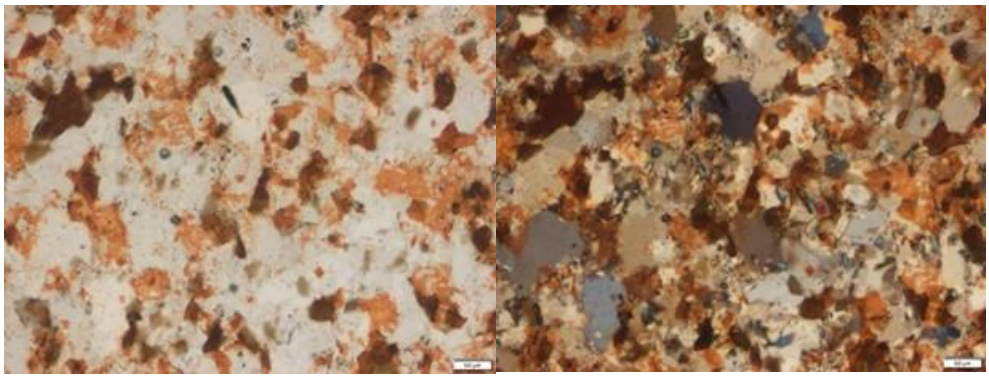


Image A: 120X, 50 microns PPL

Image B: 20X, 2.0 mm XPL

3. Kt-0214c (Micaceous, Quartz-Rich Granitoid)

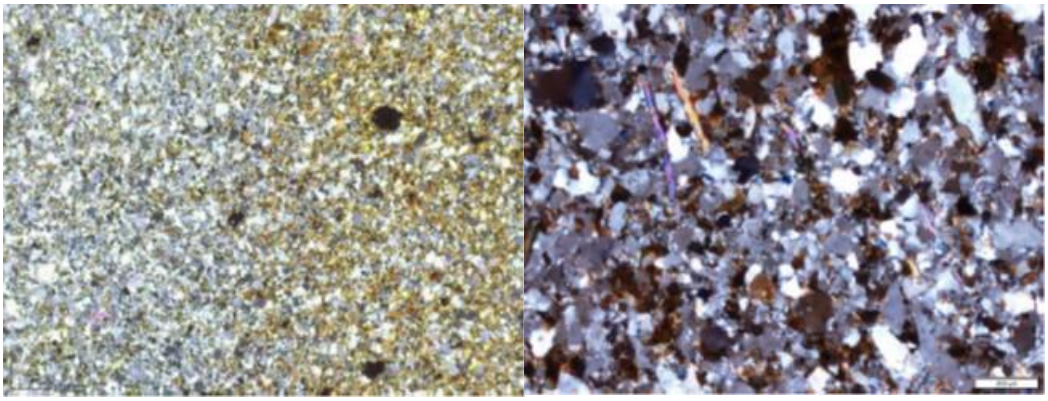


Image A: 60X, 500 microns XPL

Image B: 45X, 200 microns XPL

4. Cs-267c (Calcareous Basalt)

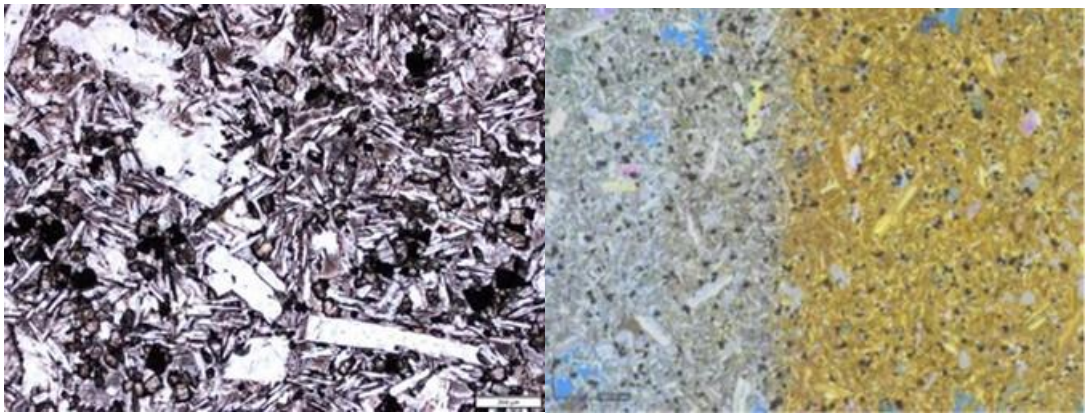


Image A: 45X, 200 microns PPL

Image B: 60X, 500 microns XPL

5. Cs-276c (Marble)

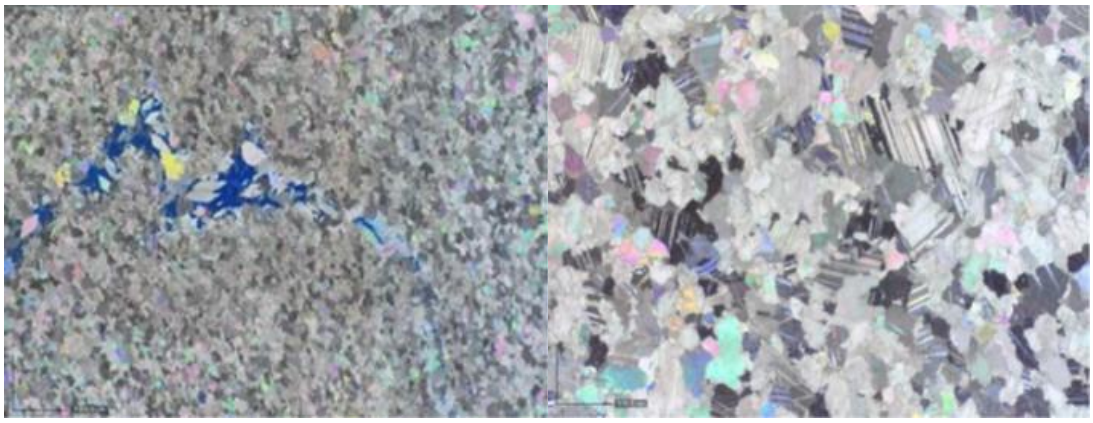


Image A: 45X, 200 microns PPL

Image B: 60X, 500 microns XPL

6. Ad-161c (Micaceous Syenogranite)

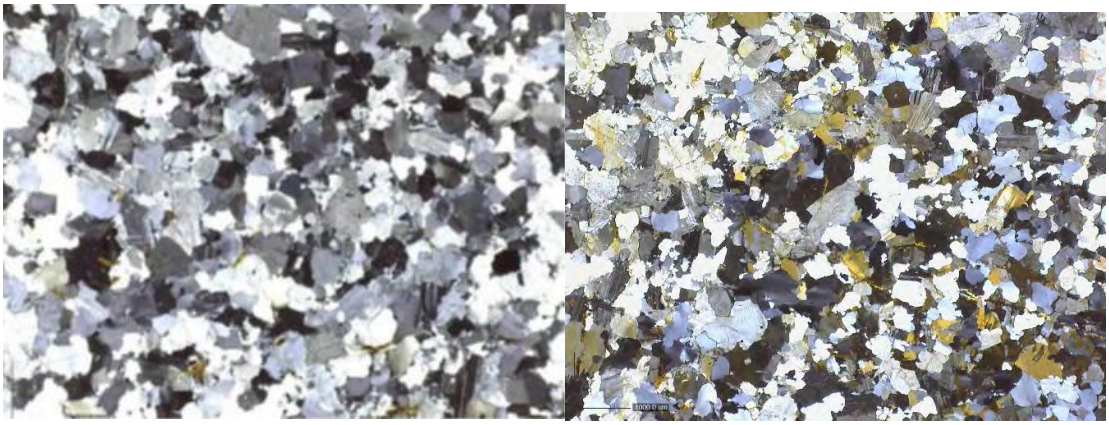


Image A: 40X, 1000 microns PPL

Image B: 40X, 1000 microns XPL

7. Ore-16c (Quartz Syenite)

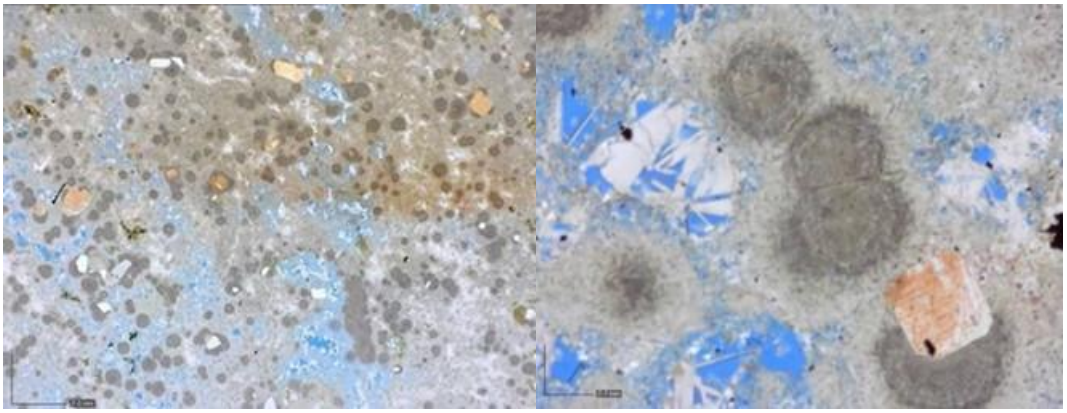


Image A: 20X, 2000 microns XPL

Image B: 45X, 200 microns PPL

8. Vy-62c (Basalt)

Image A: 180X, 200 microns XPL

Image B: 45X, 200 microns XPL

9. Cs-185s (Quartz-Rich Granitoid)

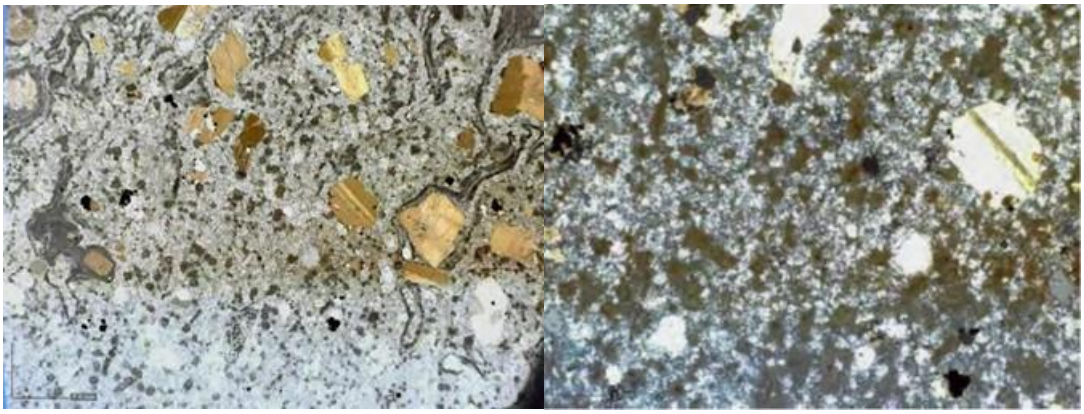


Image A: 20X, 2000 microns XPL

Image B: 40X, 1000 microns XPL

10. Cs-193s (Basalt)

Image A: 50X, 1000 microns PPL

Image B: 120X, 300 microns XPL

11. Tf-25s (Dolosmite)

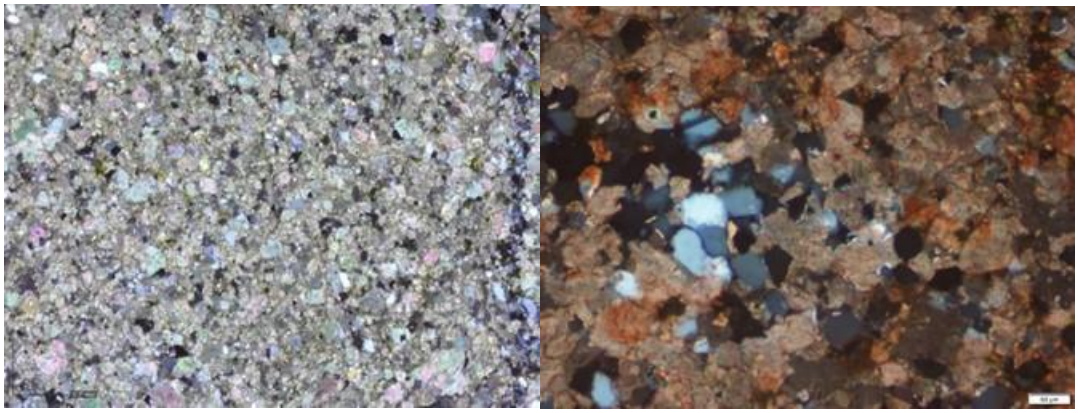


Image A: 200X, 200 microns XPL

Image B: 45X, 200 microns PPL

12. Bl-70s (Very Calcareous, Silty Sandstone)

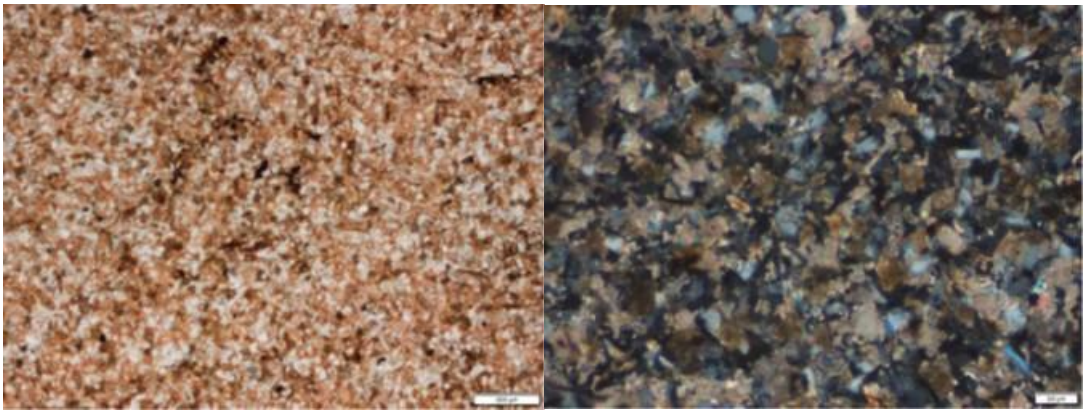


Image A: 45X, 200 microns PPL

Image B: 120X, 200 microns XPL

13. Cr-14s (Very Fossiliferous Limestone)

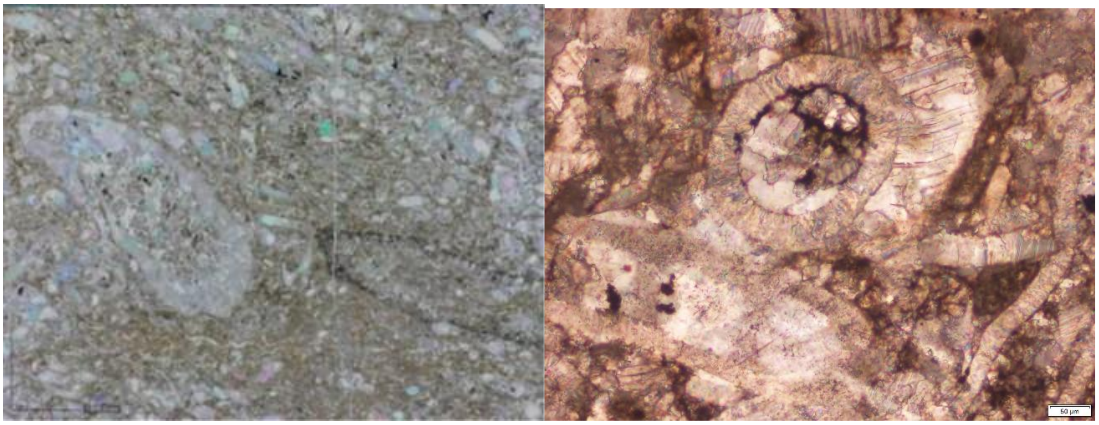


Image A: 50X, 0.1 mm XPL

Image B: 120X, 200 microns XPL

14. Bn-128s (Calcite cemented sandstone)

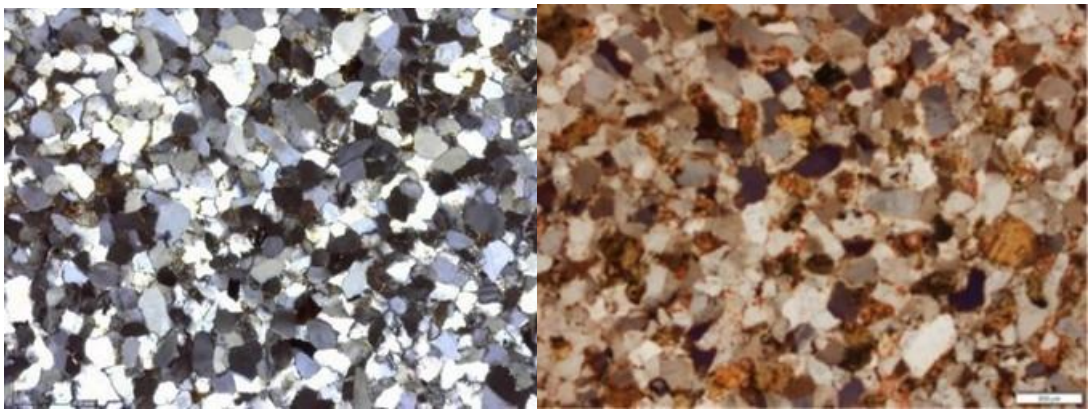


Image A: 200X, 0.2 mm XPL

Image B: 45X, 200 microns XPL

15. Fr-76s (Porous, Quartz-Rich Sandstone)

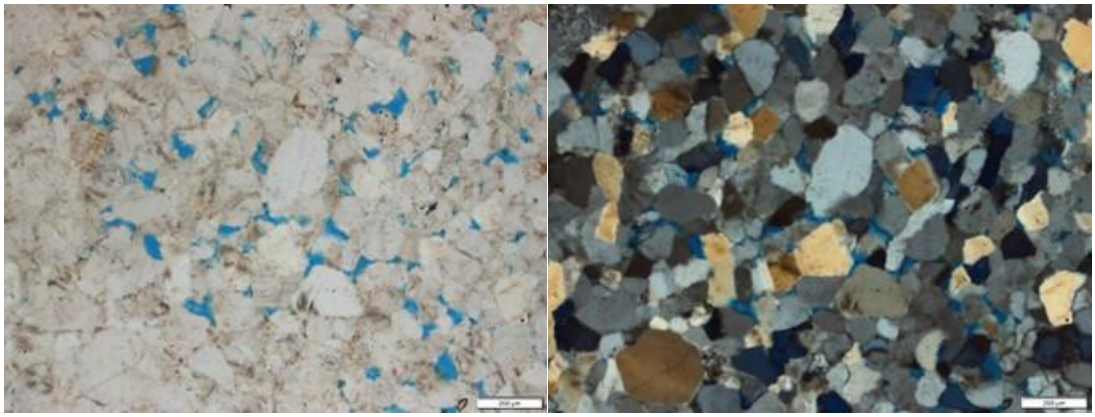


Image A: 120X, 50 microns PPL

Image B: 120X, 50 microns XPL

16. Ma-54s (Fine-grained, calcite cemented sandstone)

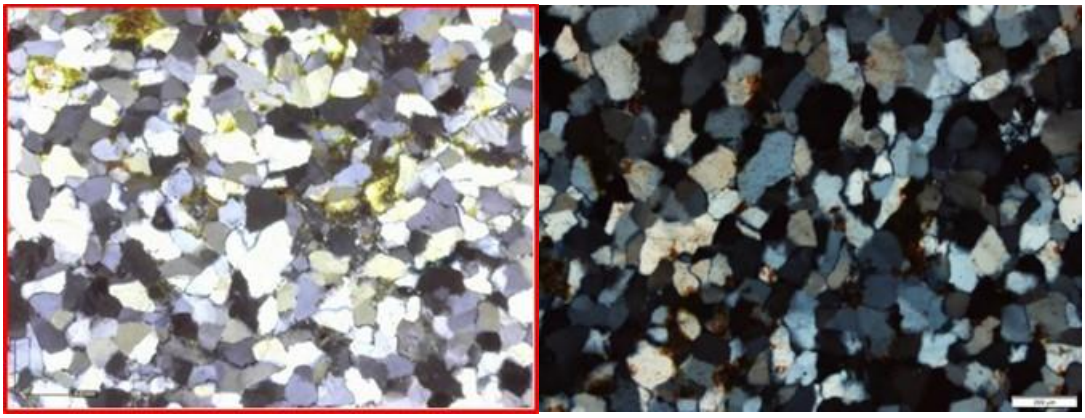


Image A: 20X, 2.0 mm PPL

Image B: 20X, 2.0 mm XPL