1. Report No. FHWA/TX-06/0-1707-9	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle LONG-TERM RESEARCH ON BITUMINOUS COARSE AGGREGATE: USE OF MICRO-DEVAL TEST FOR PROJECT LEVEL AGGREGATE QUALITY CONTROL		5. Report Date August 2006 Published: March 2007
		6. Performing Organization Code
7. Author(s) Priyantha W. Jayawickrama, Shabbir Hossain, and Appa Rao Hoare		8. Performing Organization Report No. Report 0-1707-9
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. Project No. 0-1707
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office P. O. Box 5080 Austin, Texas 78763-5080		13. Type of Report and Period Covered Technical Report: February 2003 – August 2006
		14. Sponsoring Agency Code

15. Supplementary Notes

Research performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.

Project Title: Long-Term Research on Bituminous Coarse Aggregate

url:http://tti.tamu.edu/documents/0-1707-9.pdf

16. Abstract

This research evaluated the feasibility of implementing the Micro-Deval (MD) test in the Texas Department of Transportation's (TxDOT) Aggregate Quality Monitoring Program (AQMP) for bituminous coarse aggregate. In particular, the research investigated the possibility of using this test as a project level quality control tool. The study included review and analysis of TxDOT's Materials and test lab's AQMP data as well as independent laboratory testing. The findings showed that the Micro-Deval and magnesium sulfate soundness (MSS) tests are not adequately well correlated to allow the MD test to be used as a surrogate test for the MSS test. Alternative variations of the MD test did not yield significant improvement in the strength of the MD-MSS correlation. Based on these findings, it is recommended that an additional specification be introduced based on the MD test and this specification limit used for the purpose of project level quality control. The excellent repeatability of the MD test allows a smaller tolerance to be used in stockpile testing. Because of this the short testing time, the MD test will be an effective project level quality control test.

17. Key Words Durability, Bituminous Aggregate, Micro-Deval, Sulfate Soundness, Quality Control		18. Distribution Statement No restrictions. This document is available to the public through NTIS: National Technical Information Service Springfield, Virginia 22161 http://www.ntis.gov	
19. Security Classif.(of this report) Unclassified	20. Security Classif.(of this page) Unclassified	21. No. of Pages 90	22. Price

Form DOT F 1700.7 (8-72)

LONG TERM RESEARCH ON BITUMINOUS COARSE AGGREGATE: USE OF MICRO-DEVAL TEST FOR PROJECT LEVEL AGGREGATE QUALITY CONTROL

by

Priyantha W. Jayawickrama, Ph.D.
Associate Professor of Civil Engineering,
Texas Tech University

Shabbir Hossain, Ph.D., P.E.
Senior Research Associate
Texas Tech University

and

Appa Rao Hoare
Graduate Research Assistant
Texas Tech University

Report 0-1707-9
Project Number 0-1707

Performed in cooperation with the
Texas Department of Transportation
and the
Federal Highway Administration

August 2006
Published: March 2007

Center for Multidisciplinary Research in Transportation
Department of Civil and Environmental Engineering
Texas Tech University
Box 41023
Lubbock, TX 79409-1023

AUTHOR'S DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Texas Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

PATENT DISCLAIMER

There was no invention or discovery conceived or first actually reduced to practice in the course of or under this contract, including any art, method, process, machine, manufacture, design or composition of matter, or any new useful improvement thereof, or any variety of plant which is or may be patentable under the patent laws of the United States of America or any foreign country.

ENGINEERING DISCLAIMER

Not intended for construction, bidding, or permit purposes.

TRADE NAMES AND MANUFACTURERS' NAMES

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

ACKNOWLEDGMENTS

The authors wish to thank Ms. Caroline Herrera of the Materials and Test Division of TxDOT for her guidance and support during this project. We also thank TxDOT and FHWA for their cooperative sponsorship of this project.

TABLE OF CONTENTS

Page

TABLE OF CONTENTS (CONT'D)

Page

LIST OF FIGURES

LIST OF FIGURES (CONT'D)

Page

LIST OF TABLES

CHAPTER 1.
INTRODUCTION

GENERAL

The properties of mineral aggregates used in the bituminous mix have significant influence on the performance of the pavement. Therefore, in the production of bituminous mixes, it is important to carefully control the quality of aggregates used. Generally, this is accomplished by testing candidate aggregate materials in the laboratory and screening out those aggregates that fail to meet certain laboratory test criteria. The commonly used laboratory test parameters include: size and gradation, particle shape, aggregate cleanliness, toughness or abrasion resistance, durability and soundness, surface texture/frictional characteristics, absorption, and affinity for asphalt. These test parameters are considered to be indicators of the material's actual, in-service performance. Nevertheless, strong correlations between laboratory test parameters and the field performance of the final product do not necessarily exist. This is particularly true for aggregate "toughness and abrasion resistance" and "durability and soundness."

The primary focus of the research work described in this report is durability and soundness characteristics of bituminous aggregates. In Texas, where a large percentage of the available aggregate supply is derived from sedimentary rocks, it is especially important to closely monitor durability and soundness properties of construction aggregates. Aggregate soundness and durability issues become even more important with new mixture designs that seek to provide pavements that are structurally superior to traditional asphalt concrete pavement. Coarse open graded mixes such as coarse matrix high binder, stone matrix asphalt, and Superpave designs have fewer fines and higher asphalt contents. Due to the greater rock on rock contact that is found in these mixes, they demand even higher quality in aggregates. Therefore, it is important to use an appropriate aggregate durability test specification that correlates well with pavement in-service performance.

A laboratory test method that is used for the purpose of aggregate quality control must meet several requirements. The ability to accurately predict field behavior is only one of these requirements. Other requirements include: ease of testing, ability to produce consistent (repeatable and reproducible) results, and testing time. Construction aggregates are natural materials, and as a result, there is inherent variability in the material that is recovered from the same source. Therefore, it is vital that the material sampling and testing protocol is capable of capturing this variability. This imposes several other requirements on the lab test method used in the quality control process. First of all, the test must provide quick results so that it can be performed on a more frequent basis when necessary. This is critical for those sources that show high variability and for those that have very high rates of production. Similarly, a test method with quick turnaround time will allow the pavement engineer to test a material stockpile at the job site whenever there is uncertainty about the quality of the product delivered. A second but equally important issue is the variability in the test method itself. In other words any variability observed in the test parameter should reflect the variability in the product and not be due to variability in testing.

Historically, the Texas Department of Transportation (TxDOT) has relied on the magnesium sulfate soundness (MSS) test for aggregate quality control. Although good correlation between the percent loss in the MSS test and field performance has not been established, it is widely acknowledged that the aggregate quality control requirements based on the MSS test have led to improved pavement performance. However, there are a number of drawbacks in the use of the MSS test procedure for aggregate durability characterization. First, the MSS test typically takes 7-10 days to complete. This long turnaround time makes the MSS test a poor candidate to be used as a production quality control tool or for stockpile testing at the job site. Another is its high degree of variability, both within a single lab and between multiple labs. These factors have led the department to begin looking for alternative test procedures that can replicate the performance of aggregates in a more accurate and expedient manner.

In 1999, TxDOT initiated Project 0-1771 to evaluate the Micro-Deval (MD) test as a possible alternative to the MSS test in the durability characterization of bituminous aggregates. The Micro-Deval abrasion test tests coarse aggregates to determine their abrasion loss in the presence of water and a steel charge. It seeks to measure aggregates' toughness/abrasion resistance and durability/soundness when subjected to weathering forces. The Project 0-1771, which was conducted by Texas Tech University, focused on following specific aspects:

- comparison of single lab variability for the two test methods,

- comparison of multiple lab variability for the two test methods, and
- possible correlation between MSS and MD test results.

The project concluded that the variability associated with the MD test is approximately one fourth of that associated with the MSS test. It also observed that there was a fair correlation between the MD and MSS test results with a coefficient of determination (R^2) of 0.78. The project did not recommend that the MD test should be considered as replacement for the MSS test. Instead, it recommended implementation of the MD test for the purposes of project level quality control. This report documents findings from further research that investigated the viability of using the MD test for the above purpose.

AGGREGATE RESOURCES IN TEXAS

Aggregates commonly found in Texas can be categorized into a number of different lithological groups. The type of aggregate that is most abundant within the state is limestone. The limestones vary in quality depending upon the location from which they quarried. A common physical feature of limestones that has important implications for aggregate durability is its intrinsic porosity. Many limestones, particularly those of biogenic origin, have a medium to high degree of porosity. Porosities of 10-30 percent are not uncommon in limestones. A porous limestone can suffer rapid degradation due to freeze-thaw cycling. Another key characteristic of limestones is their relative softness when compared with other types of rocks. The softness is mainly a function of the mineral composition. Calcite, which is the predominant mineral found in limestone, has a hardness of 3 on the Mohs scale of hardness, whereas other limestone minerals, dolomite and aragonite, are a bit harder (3.5 to 4). Because of this softness, it can be easily degraded. At the same time, some sources provide limestones that have very good strength and durability characteristics.

Sandstones are also found in Texas but are less abundant. Only a few aggregate sources listed in TxDOT's Aggregate Quality Monitoring Program (AQMP) belong to this category. Sandstones vary from thinly laminated micaceous types to very thickly bedded varieties. They may be cross-bedded and are invariably jointed. With the exception of shaly sandstone, sandstone is not subject to rapid surface weathering. The dry density and porosity of sandstone are influenced by the amount of cement and/or matrix material occupying the pores. Usually the density of sandstone tends to increase with increasing depth below the surface. The compressive strength and deformability of sandstone is influenced by its porosity, the amount and type of cement and/or matrix material, grain contact, and composition. Siliceous cement is stronger than calcareous cement sandstones. Pore water plays a significant role in the compressive strength and deformation characteristics of sandstone. It can reduce the unconfined compressive strength by 30 to 60 percent.

In addition to the two types of aggregate materials described above (i.e., limestones and sandstones), TxDOT's AQMP also includes a significant number of sources that are identified as "gravel sources." Lithologically, gravel sources may consist of siliceous materials, carbonates, sandstones, igneous rocks, or a mixture of these. Their properties depend on the constituent components. Gravel deposits can show a high degree of variability. In addition, Texas aggregate resources also include a limited supply of igneous and metamorphic rocks. As a general rule, these materials tend to be strong and durable. There is less variability in the quality of these materials. Therefore, there is little concern with regard to the quality control of these materials.

TXDOT AGGREGATE QUALITY MONITORING PROGRAM

TxDOT's AQMP serves as the primary mechanism for accepting aggregate products that have shown continuing quality and uniformity. The AQMP lets the districts use aggregates from rated sources qualified through AQMP without project specific testing by Construction/Materials and Pavement divisions. The districts only require subjecting the aggregates to job control and self-regulating assurance tests for final acceptance.

The department implemented the AQMP in 1977 for polish value ratings. It was extended in 1994 to incorporate the Los Angeles abrasion and soundness tests. The objective of the program was to perk up the efficiency of TxDOT operations and to trim down the risk to both the department and the producers.

The AQMP has been planned to provide continuous quality assurance of aggregate products. The program includes:

- quality monitoring of aggregate products accounting for normal production at a single source,
- statistical assessment of recent aggregate quality test histories,
- expediency in aggregate quality acceptance, and

- maximized resource utilization by reducing aggregate reception on a test-prior-to-use basis.

Aggregate suppliers are included in the AQMP based on test history of aggregate products used on TxDOT projects. The following sections deal with specific details related to source approval based on AQMP testing.

AQMP Approval Requirements

It is mandatory for individual aggregate sources to meet the following criteria in order to be acknowledged on the AQMP:

- The source must possess a test record of at least five TxDOT project samples of the same type and grade within the past two years. This may include informational test histories established from TxDOT project and/or AQMP samples but apart from informational samples.
- The five most up to date project sample test results suit all the standard specification quality requirements for an aggregate product.
- The statistical ratings of the five-sample test history meet all the relevant project specification quality criteria for an aggregate product.
- The sampling dates of the above five project samples are spaced out over at least one month.
- The CST/M&P section possesses the authority to accept an aggregate product on the AQMP based on four agreeable TxDOT project sample test results.

Source Removal and Reinstatement

In the event that any of the statistical ratings of an aggregate product on the AQMP fail to meet the specification prerequisite, the CST/M&P section takes the subsequent measures:

- The CST/M&P will assess the producer's latest quality control test history, if the data are recent in CST/M&P's pit file, and determine if the condition warrants a check sample.
- If the condition does not merit a check sample or the check sample test result failed to generate a statistical value that satisfies the specification requirement, CST/M&P will notify the aggregate supplier and TxDOT client districts of the unacceptable statistical value. Within 15 calendar days of implementing the quality test(s), CST/M&P will send a

written notice to the aggregate supplier and TxDOT user districts to eliminate the aggregate product from the AQMP effective 60 days from the test completion date. It shall be the district's obligation to notify the concerned contractors of any status change of AQMP sources.

- Once a source is taken out of the program, AQMP sampling concerning the source are then discontinued. Once it is removed from the AQMP, the aggregate product can then be supplied only to TxDOT projects and requisitions on a test-prior-to-use basis. Reinstatement to an active status on the AQMP will require re-establishing an acceptable project sample test history and qualifying to the AQMP acceptance criteria.

AQMP Maintenance

The AQMP is maintained by statistical analyses of AQMP quality test results. Once an aggregate source or product on the AQMP is accepted, an AQMP sample is called for and tested. The test result of the first AQMP sample and the four most recent project samples is analyzed statistically to assign the first AQMP rating for the product. Test results from succeeding AQMP samples, either scheduled or unscheduled, are used to substitute the original project sample test results. When asked, CST/M&P provides the producer with his or her most current AQMP sample test results. An aggregate product remains on the AQMP on condition that its statistical rating of the five latest projects in addition to AQMP sample test results remain within the standard specification limits for the entire aggregate quality test. An aggregate product is kept on a temporary watch status for recurrent sampling and testing once its rated source statistical value (excluding residual single point value) is inside 10 percent of TxDOT's standard specification limits. Retention of an aggregate on the AQMP is reliant on the effectiveness of the producer's quality control endeavor as observed by the consistent quality and uniformity of the products.

Provided that the aggregate is sampled and tested for the AQMP, CST/M&P is able to issue reference test reports to meet districts' requirements. The existing AQMP statistical rating on the quality of the product can be obtained from the reference test reports.

In order to be used as an aggregate in bituminous mixes, the AQMP approval and maintenance uses the statistical assessment of the required test history by means of the following equation:

$$R = \overline{X} + P\left(\frac{MS}{N}\right)^{0.5} \tag{1.1}$$

where,

R = statistical rated source value, rounded to the nearest whole number,

$\overline{X}$ = mathematical average of the five most recent tests;

P = 3.747, for L.A. abrasion and soundness (this is the percentile value presenting the maximum or minimum of 99 percent of the test result outcome);

MS = variance of the five most recent test results; and.

N = 5, which is the number of tests used in the statistical calculation.

OBJECTIVE AND SCOPE OF RESEARCH

The findings from TxDOT Project 0-1771:" Comparative Analysis of Micro-Deval and Magnesium Sulfate Soundness Tests" demonstrated that the two test methods complement each other very well in terms of their strengths and weakness. As mentioned in Section 1.1 above, the MD test has much better repeatability and reproducibility than the MSS test. It also produces test results in a much shorter time when compared with the MSS test. However, it lacks the sensitivity that is found in the MSS test. In other words, the MSS test results change dramatically when the absorptivity of the material changes. Therefore, it can be expected that MSS tests will detect changes in material quality more readily. Based on these findings, Project 0-1771 researchers concluded that the MD test will be most effective when it is used in combination with the MSS test rather than when it is used as a substitute. The objective of this research was to evaluate different mechanisms for the implementation of the Micro-Deval test to achieve improved and more efficient quality control of bituminous coarse aggregates.

RESEARCH APPROACH

The research approach used in this project is based on the premise that the MSS test will continue to serve in the AQMP as the primary benchmark for durability/soundness evaluation of bituminous coarse aggregates. However, because of the long 7-10 day turnaround time, MSS is not a practical tool for project level quality control of aggregates. The MD test would be a much better candidate for this purpose. Accordingly, aggregate material delivered at a job site can be tested using the MD test to determine whether its quality is consistent with its AQMP rating. The MD test can also be used effectively to monitor the quality of an aggregate product during production. However, since the aggregate material's performance in the MSS test will eventually determine its acceptance or rejection, it is imperative that good correlation between Micro-Deval test and the five cycle magnesium sulfate soundness test exists. Accordingly, this research will place its primary emphasis on the improvement of the correlation between the two test methods. The research will investigate the possibility of using variations in the current MD test procedure to find out whether these variations will result in improved correlation.

It has generally been observed that the Micro-Deval losses for aggregates with higher absorption are significantly lower than the magnesium sulfate soundness losses for the same materials. Therefore, the researchers will experiment with variations of the Micro-Deval test that will yield higher percentage losses for absorptive material. These variations will include methods of more aggressive soaking of the material such as vacuum saturation, boiling of aggregates, increased soaking time, etc.

CHAPTER 2
REVIEW OF BACKGROUND LITERATURE

MICRO-DEVAL TEST PROCEDURE

The Micro-Deval test had its inception in France during the 1960s. Its predecessor, the Deval test, was developed in the early 1900s to evaluate the quality of railroad ballast materials. The Deval test provides a measure of abrasion resistance and durability of mineral aggregates through the actions of abrasion between aggregate particles and between aggregate particles and steel balls in the presence of water. The original Deval test requires 50 kilograms (approximately 110 pounds) of aggregate materials for a single test.

The Micro-Deval test is a modified version of the original Deval test. During its early days of development, the French sought a procedure that would apply frictional wear and degradation, without fragmentation of the aggregate. They found that the degradation was more pronounced in the presence of water than when dry. The degree to which this varies is dependent on the amount of softer minerals present, such as clays, micas, calcite, and dolomite. The Micro-Deval test uses a much smaller sample of 1500 grams (3.3 lbs) of aggregate retained b a 4.75 mm (No. 4) sieve and an abrasive charge of 5000 g of 9.5 mm diameter steel balls. This test is conducted by first soaking the aggregate material for 24 hours and then placing it in a stainless steel mill jar with 2.5 liters of water and a steel charge. The jar and its contents are then revolved at 100 revolutions per minute for two hours. At the end of this two-hour period the sample is removed from the jar, washed, and oven dried, and its loss is calculated as the amount of material passing the 1.18mm (No. 16) sieve.

In the 1980s the Ontario Ministry of Transportation (OMT) made some slight alteration to the French Micro-Deval test and took it up as their standard specification. The OMT has done a number of studies involving Micro-Deval and found it to be one of the best measures of the physical qualities of aggregates.

Previous Research Studies on Micro-Deval Test

Ontario Ministry of Transportation Study

The OMT began a comprehensive evaluation of their aggregate test procedures in the late 1980s and early 90's *(1, 2, 3)*. Increasing demand for aggregate along with the declining supply resulted in elevated prices for quality sources. Therefore, the OMT started looking at the probable inclusion of marginal or lower quality aggregates in highway construction. The areas they considered were asphaltic concrete pavements, Portland cement concrete, and granular bases. An aggregate in Ontario would be considered marginal based on the mineralogy and intended use. For bituminous surface courses, the greatest loss that any type of aggregate is allowed is 15% (Table 2.1). Most state departments of transportation (DOTs) in the United States had adopted the American Association of State Highway and Transportation Officials standard of 18 percent.

Table 2.1. Micro-Deval Specifications for Coarse Aggregates in Ontario (*3*).

Application	Maximum loss (%)
Granular sub-base	30
Granular base	25
Open graded base course	17
Bituminous wearing courses	
Premium[1]	5-15[3]
Secondary[2]	17
Bituminous base course	21
Structural concrete	17
Concrete Pavement	13

Notes:

[1] AADT>2500 lane

[2] AADT<2500 lane

[3] Varies with rock type, 5% for igneous and metamorphic gravel; 10% for trap rock, diabase (dolerite), and andesite; and 15% for dolomitic sandstone, granitic metaarkose, and gneiss.

These specifications were adopted in the period from 1992 to 1997.

Quality control tests for aggregates are designed to simulate physical processes and conditions the aggregates would experience in the field and to measure their response. Ontario's requirements for coarse aggregate used for road construction included the following quality control tests:

- Los Angeles impact and abrasion test American Society for Testing and Materials (ASTM C131);
- magnesium sulfate soundness (MSS) test (ASTM C88);
- 24-hour water absorption test (ASTM C127), and
- petrographic evaluation to obtain a petrographic number (MTO LS-609) (*4*)

The acceptance of aggregates was dependent on materials meeting all of the minimum requirements as stated in the specifications. These tests were useful in differentiating between an excellent aggregate and a poor one. However, they are not as useful in differentiating the subtle variations found in borderline or marginal materials. Particularly, the researchers found that the Los Angeles abrasion test did not correlate well with field performance. The large steel balls create a severe impact on the test sample, which masked effects of inter-particle abrasion, which is the predominant process in pavement subject to traffic stress. Some of the softer rocks tend to absorb the impact energy of the steel balls, resulting in better test results that fall within the acceptable tolerance limits.

Thus OMT initiated a comprehensive research program to identify test methods that were superior indicators of aggregate quality. The criteria for selection required that each test correlate well with field performance and have outstanding reproducibility of results, both within the lab and between labs. In addition, these test methods should be precise and relatively quick to run at a minimal cost. A number of tests used throughout the world were looked into. The five most promising procedures were:

- unconfined freeze-thaw test for coarse aggregate;
- Micro-Deval abrasion test;
- aggregate impact value test;
- polished stone value test; and
- aggregate abrasion value test.

Evaluations of the conventional and alternative tests were conducted by using more than 100 aggregate sources from across Ontario. The aggregates selected represented a wide range of rock types and mineralogy. The OMT had used most of the sources in their projects so that their field performance could be evaluated as part of the study. Standard test procedures included in the study were the Los Angeles impact and abrasion, MSS, water absorption, and petrographic examination. A comparative analysis was done to determine which tests did the best job separating those aggregates that performed poorly versus those that did well. Aggregates used in bituminous pavements must have the physical strength to counteract thermal cycles, wetting and drying, and impact loads, as well as a resistance to abrasion and polishing action. An aggregate's ability to resist weathering cannot be measured by a single test. The best we can hope for is a suite of tests that closely approximates field conditions an aggregate is subjected to. Tests that are more accurate predictors of pavement performance are essential for the reliable selection of aggregates.

Roger and Senior's (*2*) research in the area of bituminous mixes has found that aggregates with soundness losses greater than 17 percent usually performed poorly. However there were some sources that had soundness losses less than 10 percent which were classified as fair or poor performers. This is due to the differences in mineralogy of aggregates. As shown in Table 2.1, categories were developed for different applications of aggregates used by the OMT based on maximum allowable Micro-Deval loss in order to delineate a more precise definition of acceptability. These values were set by the OMT, based on their experience with the aggregate and climatic conditions in Canada. Correlations were developed between the various tests included in the study. Combining soundness results with petrographic numbers showed a fairly good separation between aggregate performance ratings (good, fair, and poor). The unconfined freeze-thaw test was slightly better than the MSS test because it was more discriminating and precise.

Based on the findings of the research, the authors concluded that the Micro-Deval test and petrographic examinations were the top performance predictors for granular bases. For prtland concrete cement, the authors suggested the unconfined freeze-thaw test and the Micro-Deval test [5] in order to make a distinction between marginal and poor performing aggregates. The authors also concluded that the Micro-Deval, unconfined freeze-thaw, and polished stone value tests were required to categorize aggregates for hot-mix asphalt surface courses.

While a single test may not reliably separate good, fair or poor aggregate performance, using a combination of these tests, which are simple and in most cases rapid, gives the best approximation of how an aggregate will perform in a weathering and construction environment.

National Cooperative Highway Research Program Project 405 Conducted by National Center for Asphalt Technology

In the summer of 1998, the NCAT released the findings from a study, NCHRP Report 405, which evaluated existing aggregate tests and identified new tests which could best provide a more definitive relationship to performance of aggregates used in bituminous pavements (*6*, *7*). This research, which was divided into two phases, was initiated with following goals in mind.

- identify performance parameters that may be affected by aggregate properties,
- identify aggregate properties that influence these parameters:
- identify test procedures and evaluate whether they can be used to measure properties not currently being evaluated, and
- develop a research plan to validate new techniques through lab testing and develop protocols for the recommended tests.

Their approach to this research was to conduct an extensive literature review, select the appropriate aggregate properties to consider, identify the aggregate sources for testing, and evaluate existing and proposed testing methods. An extensive survey was conducted to determine the various types of aggregate specifications and tests used by transportation departments in the United States, Canada, Europe, Asia, and Australia.

Researchers found that the primary pavement performance parameters that were influenced most by aggregate properties were pavement deformation, raveling and pop-outs, and fatigue cracking. Table 2.2 summarizes the pavement parameters and the corresponding aggregate properties that they determined to have the greatest influence.

Table 2.2. Aggregate Failure Properties and Parameters.

HMA parameter	Aggregate properties that have major influence
Pavement deformation	(1) Coarse aggregate particle shape and surface texture (2) Fine aggregate particle shape and surface texture (3) Properties of minus 200 material (4) Plastic fines in the aggregate
Raveling, pop-outs, and potholing	(1) Toughness and abrasion resistance (2) Durability and soundness
Fatigue cracking	(1) Coarse aggregate particle shape and surface texture (2) Fine aggregate particle shape and surface texture (3) Properties of minus 200 material

In the selection of the aggregates for use in the study, NCAT wanted sources that exhibited a wide range of mineral compositions providing differing test results. In addition they needed material that was being used or had been used for bituminous mixes.

Two of the primary areas of study were the toughness and abrasion resistance of aggregates and their durability and soundness. Sixteen aggregates were selected for this portion of the research, they included: five crushed carbonate stones, four gravels, two granites, one traprock, one basalt, and one steel slag.

Five different tests were conducted on each of the sources to determine the toughness and abrasion resistance: L.A. abrasion test, aggregate impact value (British standard) test, aggregate crushing value (British standard) test, SuperPave gyratory compaction, and the Micro-Deval abrasion test.

For durability and soundness, seven test procedures were evaluated using the same group of aggregate sources:

- soundness of aggregate by use of sodium sulfate (AASHTO T 104),
- soundness of aggregate by use of magnesium sulfate (AASHTO T 104),
- soundness of aggregate by freezing and thawing (AASHTO T 103 A, B, and C),
- aggregate durability index (AASHTO T 210), and
- Canadian freeze-thaw test.

Since Micro-Deval is a combination of abrasion (steel balls) and weathering (water), NCAT developed a correlation matrix between the toughness and abrasion results and those from durability and soundness. They found that the Micro-Deval had a better correlation with the durability and soundness than with the toughness and abrasion resistance. Results showed a good correlation with the MSS test and a fair correlation with the sodium sulfate soundness and the durability index. Micro-Deval did not appear to have a good or fair correlation with any of the toughness and abrasion procedures.

Petrographic analyses were done on the 16 aggregate sources. Parameters identified were grain size, foliation, hardness, fractures, and porosity. Results from the analysis were not included in any correlation but were used as supplemental information.

Researchers polled the state DOTs that had been using the aggregates selected for this study and asked them to rate the pavement performance using these sources. The guidelines used were as follows:

- Good – Used for many years with no significant aggregate degradation problem during construction and no significant pop-outs, raveling, or potholes during service life.
- Fair – Used at least once where some degradation occurred during construction and some pop-outs, raveling, and potholes developed, but pavement life extended for over eight years.
- Poor – Used at least once where raveling, pop-outs or a combination thereof developed during the first two years, severely restricting pavement life.

Additional data were used to further define this pavement performance rating. Pavements that received a fair or poor rating were further evaluated for pavement distress modes, aggregate-related causes for distress, and other information that could help further define the performance of aggregates in asphalt concrete pavements.

A more qualitative evaluation of pavement performance was conducted by rating aggregates independently in terms of both toughness and abrasion, and durability and soundness. The results were compared with state specifications and rated on their expected overall performance. Based on these results, it was concluded that toughness and abrasion were found to be more indicative of degradation problems during production, which could affect the quality of the bituminous mix and therefore impact its long term performance.

In evaluating durability and soundness with respect to pavement performance, significant correlation was found in regards to degradation of pavements due to weathering. These effects can lead to loss of aggregate strength and stability, resulting in pop-outs, raveling, and cracking.

Both single and multiple regression analyses were used in the development of correlations between pavement performance and aggregate toughness and abrasion, pavement performance and durability and soundness, and overall pavement performance with all four parameters. Regression analysis using single variables provided the best correlation coefficients.

As many as 13 independent variables were evaluated using single variable coefficients. These included Micro-Deval, AASHTO freeze-thaw, Canadian freeze-thaw, MSS specific gravity, absorption, L.A. abrasion, dust ratio from L.A. abrasion, methylene blue index on the dust from the L.A. abrasion, aggregate durability index, Superpave gyratory compactor on bare rock, and the aggregate impact value. Qualitative examination of the various values and pavement performance ratings found that Micro-Deval and MSS were the two best indicators of potential pavement performance. Micro-Deval had the highest, and MSS had the second highest R^2- values.

They concluded that the Micro-Deval and the MSS were the best tests in relating bituminous mix performance in terms of pop-outs, raveling, and potholing.

TxDOT Research Project 0-1771 Conducted by TechMRT

Asphalt concrete pavement is the primary pavement type used by the Texas Department of Transportation. Due to the increase in heavy truck traffic and the increase in loads they are allowed to carry, the department has begun using newer designs such as coarse matrix high binder, stone matrix asphalt, and Superpave to build pavements that are structurally superior to conventional asphalt concrete pavements. When these mixes are used in pavement construction, the quality of aggregates becomes even more important because of the greater level of rock on rock contact that exists in these open graded mixes. Thus, in the late 1990s TxDOT began reevaluation of its quality control procedures for bituminous coarse aggregates. A part of this reevaluation process was a research project that specifically focused on the Micro-Deval test *(8)*.

The Project 0-1771 database consisted of results obtained from a comprehensive laboratory test program that included a total of 52 bituminous aggregate sources. These aggregate sources were chosen in order to have a wide representation of mineralogical type, quality, and level of use by the department. Consideration was also given to aggregates that represented a wide geographical distribution. The majority of these sources were chosen from TxDOT's AQMP. The database consisted of test results from following test methods:

- five-cycle MSS test,
- Micro-Deval test,
- lithological evaluation,
- petrographical evaluation, and
- aggregate absorption test.

The primary objectives of the Project 0-1771 included the determination of repeatability and reproducibility of both Micro-Deval and MSS test methods. Therefore, in the above research, both of these test procedures were conducted in triplicate for all 52 aggregate sources. The analysis presented below uses the average of the three test measurements made in each test method for each source. The use of average Micro-Deval and MSS loss in the analyses minimizes potential error arising from test measurement variability. This attribute in the Project 0-1771 database is particularly valuable because MSS test results generally tend to show significant variability. One of the limitations in the Project 0-1771 database, however, is that each source that was included in this test program had been sampled only one time. Therefore, the data obtained cannot be used to quantify the variability that occurs in the material that is produced from the same source but at different times.

MSS and Micro-Deval tests have both been developed for the purpose of evaluating the durability of construction aggregate. Therefore, logically one would expect a positive correlation between the results obtained from these two test methods. As mentioned previously in this chapter, the strength of the correlation between Micro-Deval and MSS tests is of significant interest to TxDOT. A strong correlation between the two tests will make implementation of the Micro-Deval test in the AQMP much easier. If a strong correlation between Micro-Deval and MSS can be established, then this correlation can be used to determine the Micro-Deval specification limits that correspond to existing MSS specification limits. Accordingly, as a first step, the Project 0-1771 database was used to examine the strength of the correlation that exists between Micro-Deval and MSS test methods.

Appropriate regression analyses were performed to determine the correlation between the two test results. Since the existing TxDOT knowledge base of aggregate durability is strongly related to MSS values, the MSS value was used as the dependent variable. The only two parameters that were used as independent variables in this correlation study were Micro-Deval test results as the primary variable and absorption values as the secondary variable. In a correlation analysis, the coefficient of determination (R^2) provides an estimate of the degree of correlation that exists between the two variables. The higher the R^2 value, the better the correlation between the two tests, with 1.0 being a perfect correlation.

As a preliminary step in the development of a useful correlation between MSS and Micro-Deval values, curve fitting techniques were used to obtain the best relationship between the two test variables. Scatter plots of percent MSS loss versus percent Micro-Deval loss clearly show that the relationship between these two parameters is non-linear. This result occurs because as the aggregate quality deteriorates, the percent MSS loss increases at a faster rate than percent Micro-Deval loss does. Accordingly, a second order power curve was fitted between MSS and Micro-Deval. This type of curve is steeper at the higher end (high Micro-Deval, high MSS) than at the lower end and, therefore, is capable of representing the observed trend better than a linear model. The resulting second order predictive model for MSS has an $R^2 = 0.78$, while R^2 for the linear model was 0.66 (see Figure 2.1).

The primary motivation for examining the strength of Micro-Deval-magnesium sulfate soundness test correlation is to determine whether Micro-Deval test results could be used as a predictor of the aggregate's performance in the MSS test. Of particular interest is the predictive capability for the marginal aggregates. In this regard, the correlation presented above has a major limitation. First of all, there are very few data points representing marginal (i.e., high Micro-Deval-high MSS) aggregates. The department's maximum allowable soundness loss for aggregate used in bituminous pavements is 30 percent. There are only two sources of aggregate with MSS values above this specification limit. This is because the majority of the aggregate sources used in this research were sources that belonged to TxDOT's AQMP. Due to very limited data in the high Micro-Deval high MSS range, the reliability of prediction for marginal aggregate is not likely to be good. Therefore, for further analysis, only those sources with less than 30 percent MSS values were included. When the MSS value is restricted to a maximum of 30%, the relationship between Micro-Deval and MSS is best represented with a linear model. This model is identified as Model I here.

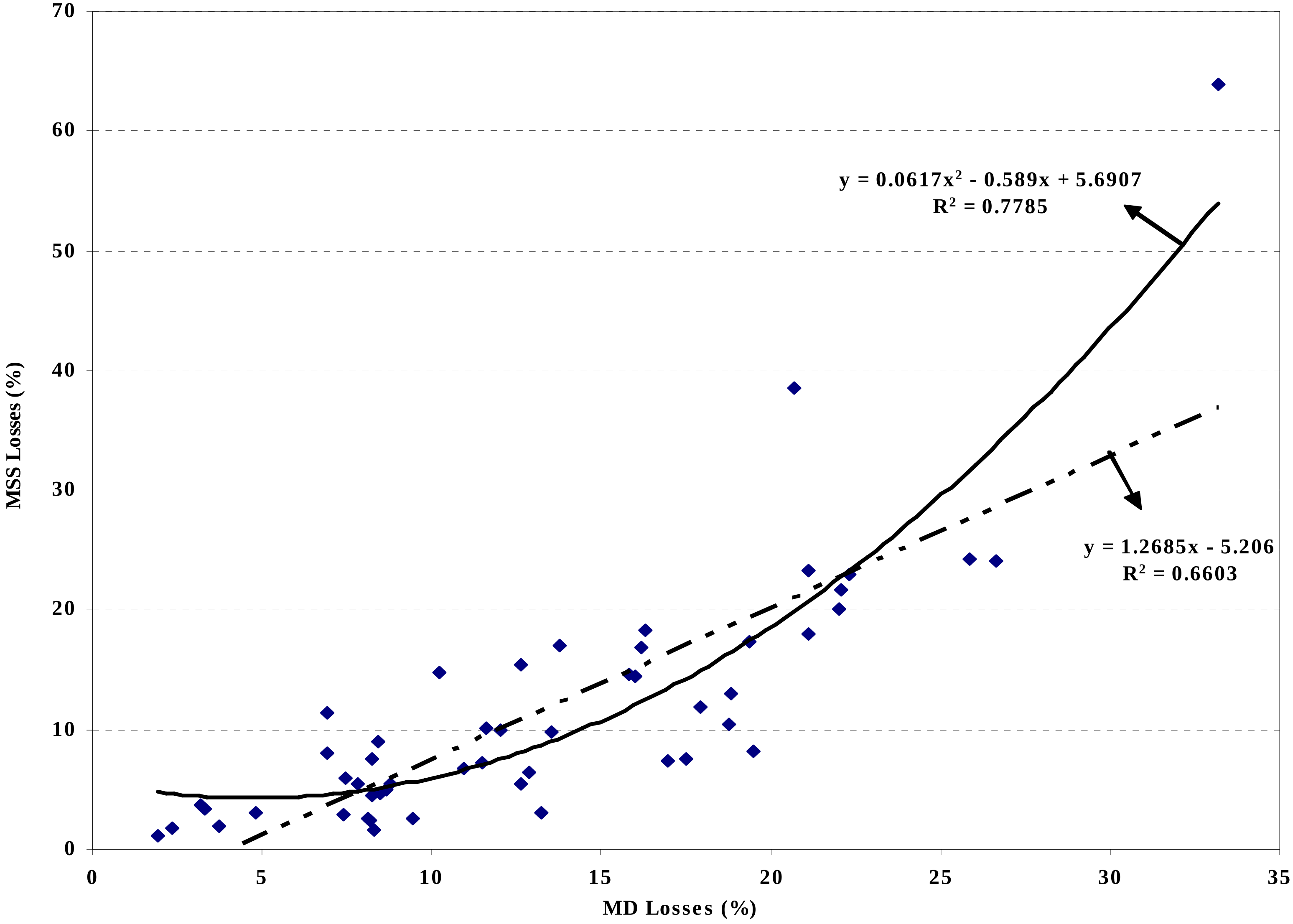


Figure 2.1. Plot of Linear and Second Order Predictive Model between MD and MSS.

Regression Model I:

$$MSS\ (\%) = -1.7134 + 0.9098 * MD\ (\%) \quad (2.1)$$

Model I is shown in Figure 2.2. It has an R^2 value of 0.70. To examine the prediction reliability of this model, 95 percent and 99 percent confidence bands have been drawn. If one considers an aggregate source with a percent Micro-Deval loss of 25, then the equation yields a value of 21.6 for the corresponding percent MSS loss. Obviously, this prediction is not exact because the actual MSS loss can be below or above the predicted value. The degree of certainty associated with this prediction can be evaluated based on the confidence bands. For example. at a confidence level of 95 percent the actual MSS value can vary between 14.0 and 28.0, which is a significantly large range. Accordingly, the strength of the Micro-Deval and MSS correlation in the present model is not adequate for implementation purposes.

The regression analysis performed above included test results from all 52 sources of aggregate combined together regardless of their lithological classification. It has been suggested in previous research that the strength of the Micro-Deval versus MSS correlation could be improved if the aggregates are categorized according to their lithological group. Therefore, as

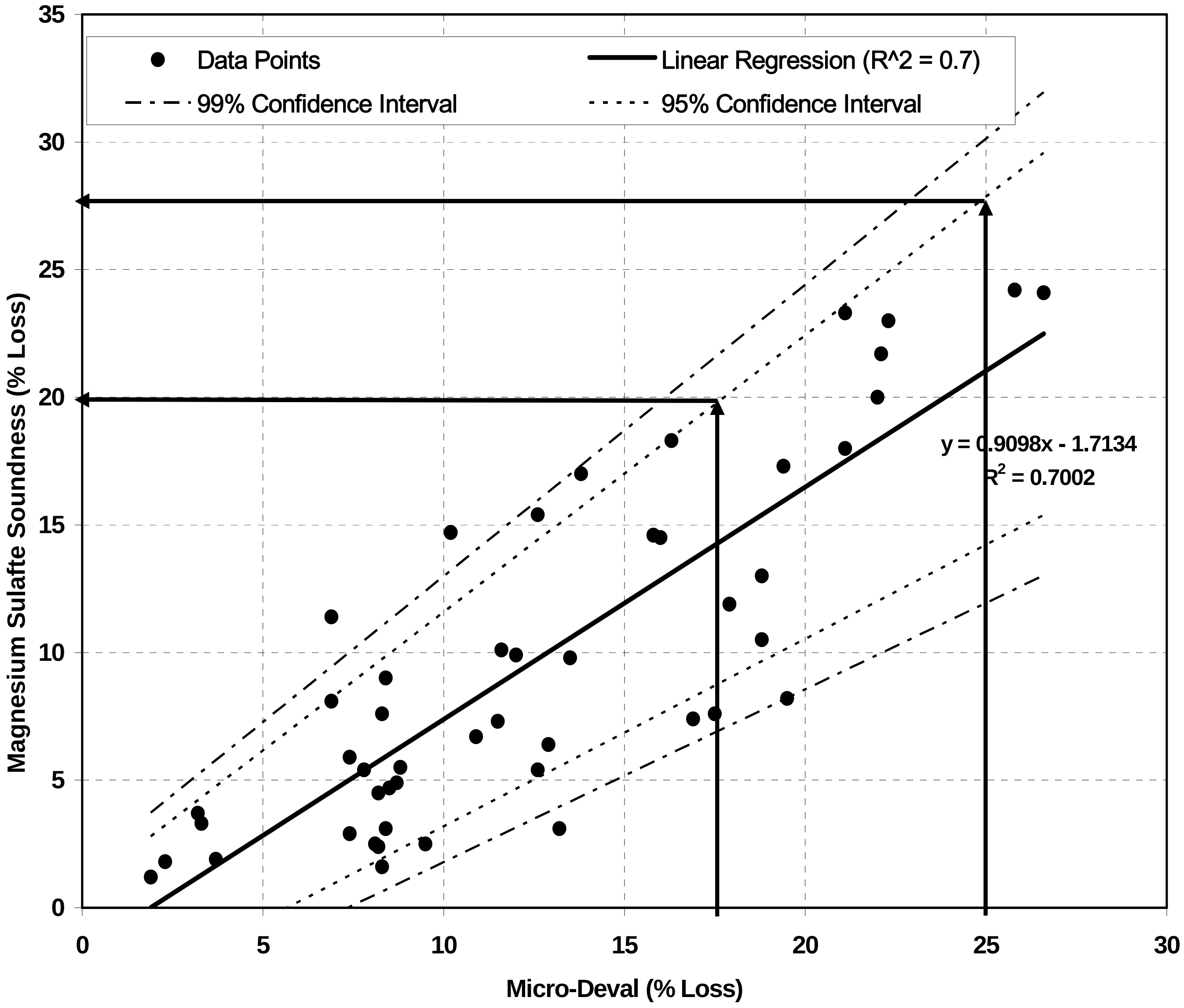


Figure 2.2. Relationship between Magnesium Sulfate Soundness and Micro-Deval Results for Aggregate with Magnesium Sulfate Soundness < 30 Percent.

the next step in this research, such analysis was undertaken. However, no improvement in the correlation between the Micro-Deval and MSS was observed.

A number of different parameters that could be used as a third variable to further improve the correlation coefficient were also examined. These included parameters such as porosity, grain to matrix ratio, form, sphericity, calcite-dolomite ratio, hardness and size, etc.

Project 0-1771 data did not show that any of these properties would improve the correlation if used as a second variable. The only variable that helped improve such correlation was aggregate absorption. Therefore, a multiple regression model with absorption as the second independent variable was developed.

Project 0-1771 data showed that aggregate absorption, as determined by ASTM C127, has a significant effect on MSS and Micro-Deval results. This is evident in Figure 2.3. Therefore, it is logical to conclude that the prediction of MSS value will depend on both Micro-Deval and absorption. However, Micro-Deval and absorption are correlated with each other and therefore an interaction between them will most likely influence the prediction of MSS. A multiple regression model to predict MSS was attempted using Micro-Deval, absorption (ABS), and their interaction terms as independent variables. The model $R^2 = 0.84$ is a significant improvement over the previous linear model. But only the interaction term came out to be significant at the 5 percent level while all other coefficients and intercepts were not significant at the 5 percent level. Therefore, only the interaction term was retained in the model with $R^2 = 0.837$ Therefore, the final selected model, named Model II, is as follows and is presented in Figure 2.4.

<u>Regression Model II</u>:

$$\text{MSS (\%)} = 3.359 + 0.410 * \text{MD (\%)} * \text{ABS (\%)} \tag{2.2}$$

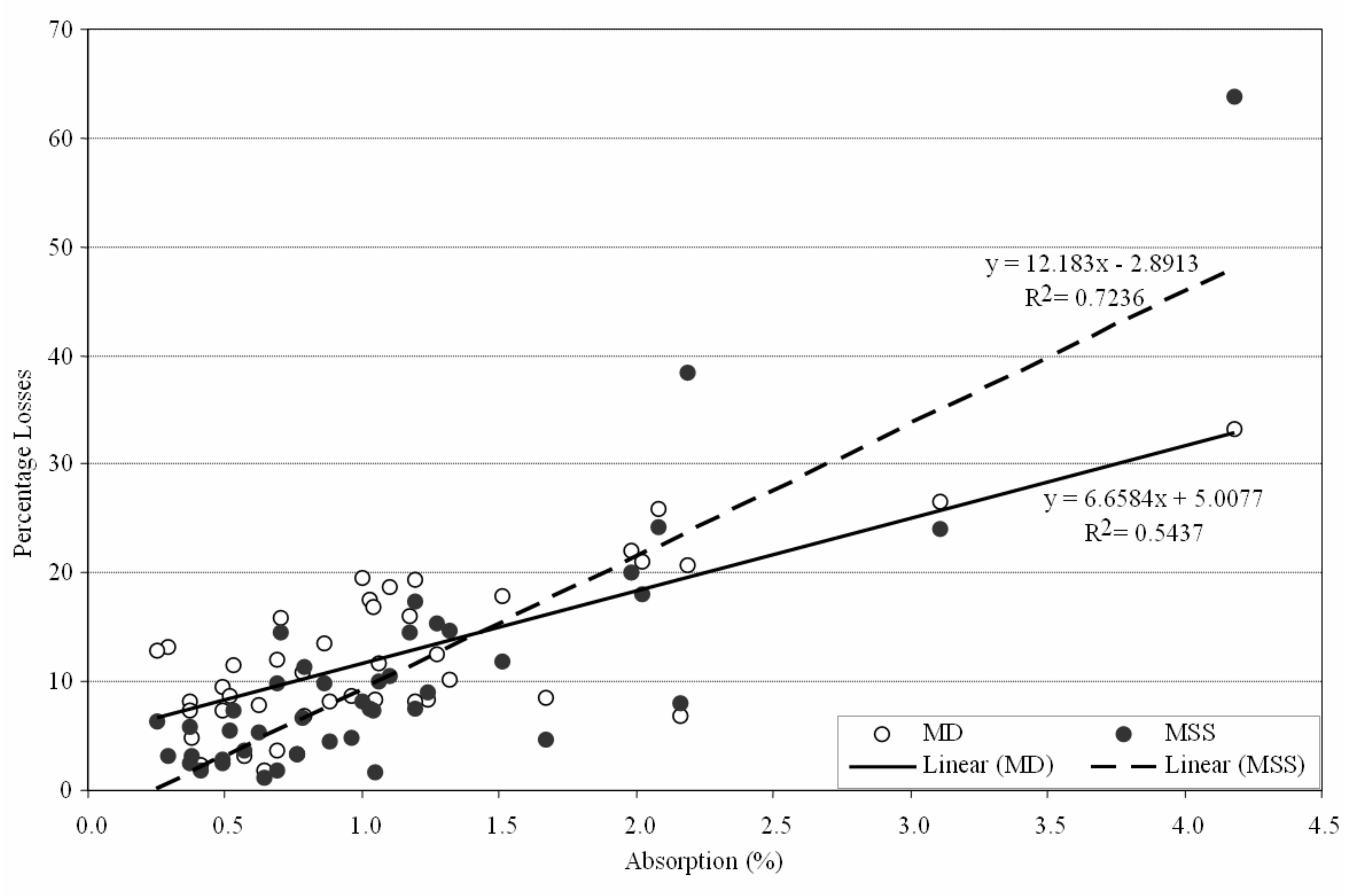


Figure 2.3. Influence of Regular Absorption on Micro-Deval and Magnesium Sulfate Soundness Tests.

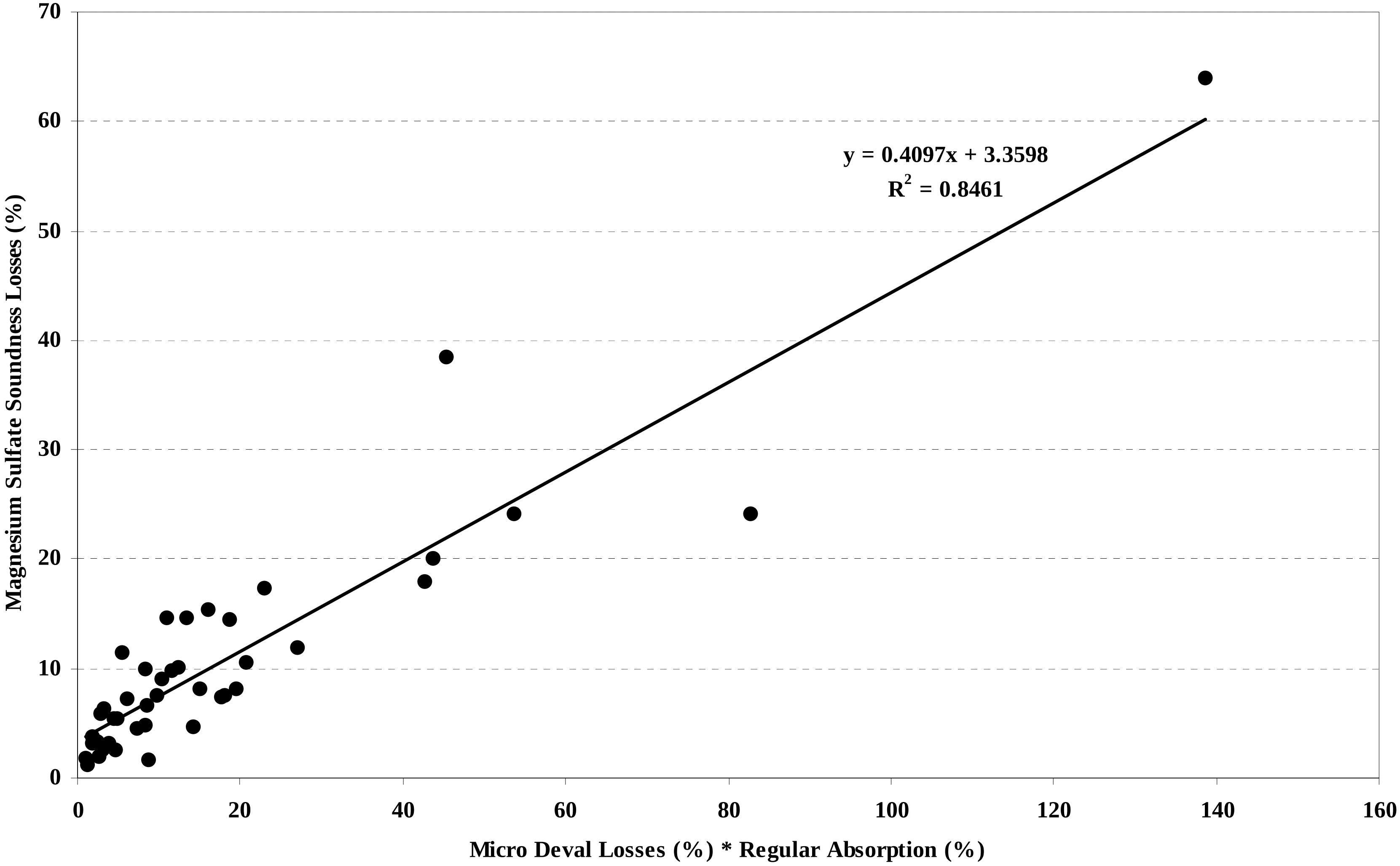


Figure 2.4. Predictive Model for Magnesium Sulfate Loss Based on Micro-Deval and Regular Absorption Value.

CHAPTER 3
ANALYSIS OF TXDOT AQMP DATA

OVERVIEW

As stated previously, the primary focus in this research project was the implementation of the Micro-Deval test in TxDOT's bituminous aggregate quality control program. Of special interest was the evaluation of this test procedure to determine its suitability as a project level aggregate quality control test. As a first step in this evaluation process, a preliminary review was conducted on existing data on the performance of various bituminous aggregate sources in the MD-test. The database used for this purpose was compiled by the TxDOT Materials and Tests Division as a part of its aggregate quality monitoring program.

DESCRIPTION OF TXDOT AQMP DATABASE

As explained in Chapter I, bituminous aggregate sources that are included in the TxDOT Aggregate Quality Monitoring Program are sampled and tested on a regular basis by the TxDOT Materials and Tests Laboratories. The tests conducted as a part of the above AQMP include: standard polished value, residual polished value (solid tire), residual polished value (cross-hatched tire), MSS, Micro-Deval, L.A. abrasion, and acid insoluble residue. The database that was developed based on AQMP test data included a total of 169 aggregate sources representing a large number of aggregate producers and source locations. The vast majority of these sources are located within the state although the database included several sources from neighboring states as well. The version of the database that was used in the present analysis was obtained by Texas Tech researchers in May of 2001. It mostly contained data collected in 1998, 1999, and 2000. It must be noted that the list of aggregate sources found in the above database is not the same as the current AQMP list of sources. Some of these sources found in the original list are no longer in production. Others have dropped out of the list because of failure to meet required specifications.

The special value in the TxDOT AQMP database lies in the fact that it contains quality monitoring data that span a fairly long time period. In particular, it has data from tests conducted on material obtained from each source but at different times. Such data allow the time variability of the material to be quantified. Review of the data shows that some of the aggregate sources have been sampled and tested more frequently than others. As a result they have more data points. This may have been because these particular sources have been in more frequent use or because material had exhibited a greater degree of variability when compared with others.

There are two issues of special interest in the evaluation of the suitability of the Micro-Deval Test as an aggregate quality monitoring tool. The first is the strength of the correlation between the new Micro-Deval Test and the currently used MSS Test. This is important because the MSS test will continue to serve as the primary benchmark for aggregate durability assessment. Therefore, it is important to know whether the MD Test can be used as an indicator when the material delivered at the job site has an MSS loss that is significantly different from its rated source value. The second issue involves the sensitivity of the MD Test when compared with that of MSS-test. Accordingly, the analyses described in this chapter are specifically focused on these two issues.

CORRELATION BETWEEN MICRO-DEVAL AND MAGNESIUM SULFATE SOUNDNESS

To examine the correlation between Micro-Deval and MSS using the TxDOT AQMP database, it was decided that each source should be represented by a single pair of Micro-Deval and MSS values. Accordingly, the multiple test measurements that were available for each source were summed up and divided by the number of test measurements to obtain a mean Micro-Deval and mean MSS value for each source. MD and MSS data compiled in this manner are shown in Table 3.1. These values were then used to prepare the scatter plots shown in Figure 3.1. It was observed that the relationship between the MSS and Micro-Deval tests results is non-linear. This trend is consistent with that observed in Project 0-1771. In order to capture the non-linear data trend, a second order curve was fitted between MSS and MD test data. This predictive model is represented by Equation 3.1. The coefficient of determination for this regression model is $R^2 = 0.69$.

$$\text{MSS (\%)} = 0.0202*(\text{MD})^2 + 0.3879*\text{ MD (\%)}+1.2113 \qquad (3.1)$$

$$R^2 = 0.69$$

Table 3.1. Micro-Deval and Magnesium Sulfate Soundness Results from TxDOT Database.

Serial no.	Source	Pit 8/20/1999	Material type	Prod. Code	Micro-Deval	Mg soundness
1	Bay	Sweet 16	Gravel	2206706	3.6	4.4
2	Byod Sand & Gravel	Fulton	Gravel	Z170006	7.5	2.5
3	Capital	Del Rio	Gravel	2223301	7.6	4.0
4	Capital	Montgomery	Gravel	1501519	8.0	1.6
5	Capital	Hoban	Gravel	619502	6.0	6.8
6	E.D. Baker	Johnson	Gravel	411807	8.0	7.2
7	Fordyce	Murphy	Gravel	1323505	2.4	1.0
8	Fordyce	Showers	Gravel	2110904	2.8	3.0
9	Hanson	Arena	Gravel	1304509	2.2	1.2
10	Hanson	Cobb #4	Gravel	1805703	12.7	11.7
11	Hanson	Delight	Gravel	50116	3.2	2.8
12	Hanson	Eagle Mills	Gravel	50119	3.5	4.0
13	Hanson	Little River	Gravel	50114	3.5	4.2
14	Hanson	Prescott Az	Gravel	Z190007	2.5	3.3
15	Hanson	Stewart	Gravel	916101	10.0	12.8
16	Hanson	Tascosa	Gravel	418004	11.0	10.0
17	Janes	Goode-Anderson	Gravel	801701	4.0	6.0
18	Janes	Noodle	Gravel	812803	12.7	5.3
19	Janes	Woods	Gravel	505402	15.8	20.2
20	J.L. Milligan	Boys Ranch	Gravel	Z040023	9.7	8.1
21	Jobe	McNary	Gravel	Z240016	9.4	2.7
22	Jordan	Rothwell	Gravel	Z250009	6.5	6.2
23	Leyendecker	Tasitas	Gravel	2224014	3.8	4.3
24	Lipham	Bundy	Gravel	2517308	7.0	4.6
25	Price	Phillips	Gravel	222401	3.7	5.2
26	Price	Wynn	Gravel	Z220010	5.0	5.0
27	Sanco	Blackburn	Gravel	704110	6.0	2.7
28	Southwest	Knippa	Gravel	1523209	8.8	1.6
29	Texas S&G	Mansfield	Gravel	418001	9.8	7.8
30	Texcon Mat.l Ltd.	Pettibone	Gravel	Z170008	9.0	4.0
31	Thrasher	Thrasher	Gravel	2517302	8.2	6.6
32	Trinity	Luckett	Gravel	916104	7.2	7.4
33	Trintiy	E. Fork #53	Gravel	1805710	15.0	8.4
34	Upper Valley	D. Garcia	Gravel	2110905	5.8	9.0
35	Valley Caliche	Beck	Gravel	2110901	5.4	6.0
36	Weirich Brothers	Bobby Davis	Gravel	713408	11.8	4.0
37	Wright	Realitos	Gravel	2206701	1.8	1.6
38	Granite Mt	Sweet Home	Igneous	50106	3.5	1.6
39	Hanson	Davis	Igneous	50439	6.5	3.3
40	Hanson	Pedernal	Igneous	50309	13.3	3.

Table 3.1. Micro-Deval and Magnesium Sulfate Soundness Results from TxDOT Database. (Cont'd)

Serial no.	Source	Pit 8/20/1999	Material type	Prod. Code	Micro-Deval	Mg soundness
41	Jobe	McKelligon (Grnt)	Igneous	2407206	10.7	10.5
42	Jobe	Vado	Igneous	50310	9.6	3.2
43	Martin Marietta	Jones Mill	Igneous	Z190008	7.3	5.5
44	Martin Marietta	Mill Creek Gr.	Igneous	50433	6.4	1.4
45	Martin Marietta	Mill Creek Trap	Igneous	50438	7.0	2.6
46	Martin Marietta	Porcupine Mtn. Ca.	Igneous	Z200004	2.8	2.0
47	Martin Marietta	Snyder	Igneous	50435	5.0	3.2
48	Vulcan	Knippa	Igneous	1523206	8.8	4.6
49	Alamo	Weir	Limestone	1424603	24.0	20.3
50	Amarillo	4DG	Limestone	507805	19.6	12.4
51	Border Pacfic	Matrimar	Limestone	40103	11.3	3.2
52	Burkett	Leach	Limestone	Z030006	14.4	6.0
53	Burkett	Perry #2	Limestone	325204	16.6	10.6
54	Capitol	Wood	Limestone	1424604	22.6	17.6
55	Centex	Ruby	Limestone	1410607	23.0	22.0
56	Colorado	Hunter	Limestone	1404605	21.5	20.8
57	CSA	Turner	Limestone	Z070008	23.5	18.8
58	Del Mar	Del Mar	Limestone	Z090031	17.0	17.0
59	Dolese	Ardmore	Limestone	50412	10.6	8.8
60	Dolese	Coleman	Limestone	50414	8.0	7.5
61	Dolese	Cooperton	Limestone	50415	10.2	4.2
62	Dolese	Richard Spur	Limestone	50405	12.3	6.2
63	Hanson	Bridgeport	Limestone	224902	20.8	19.2
64	Hanson	Nbfls	Limestone	1504603	15.0	9.0
65	Hanson	Perch Hill	Limestone	224901	12.4	4.2
66	J.L. Milligan	Aztec Canyon	Limestone	418814	11.4	15.6
67	Jobe	McKelligon (Dolo)	Limestone	2407201	11.0	7.2
68	Jobe	South Quarry	Limestone	2407213	14.3	15.0
69	Killeen	Gibbs	Limestone	Z140007	18.5	10.0
70	Lattimore	Coleman	Limestone	50430	9.0	7.0
71	Luhr	Tower Rock	Limestone	50601	20.2	21.4
72	Martin Marietta	Beckman	Limestone	501503	23.3	18.6
73	Martin Marietta	Chambers	Limestone	224921	23.0	24.6
74	Martin Marietta	SH 211	Limestone	1516310	19.0	8.0
75	Martin Marietta	Three Rivers	Limestone	50501	20.0	12.0
76	Medina C.S.	Medina	Limestone	Z150016	16.0	11.0
77	Meridian	Troy	Limestone	50434	10.0	9.0
78	Odell Geer	Youngsport	Limestone	Z090018	17.2	18.6

Table 3.1. Micro-Deval and Magnesium Sulfate Soundness Results from TxDOT Database. (Cont'd).

Serial no.	Source	Pit 8/20/1999	Material type	Prod. code	Micro-Deval	Mg soundness
79	Price	Clement	Limestone	708802	23.3	25.6
80	Price	Jordan	Limestone	Z080004	24.0	23.0
81	Shallow Ford	Warner	Limestone	1402706	10.0	3.0
82	Stringtown	Stringtown	Limestone	50407	9.0	6.0
83	Sunbelt	New Braunfels	Limestone	1504602	19.5	10.6
84	Texas Crush Stone	Feld	Limestone	1424602	24.5	21.6
85	TXI	Bridgeport	Limestone	224904	19.0	17.6
86	US Stone	Bridgeport	Limestone	Z020015	12.0	5.8
87	Vulcan	Black	Limestone	822107	20.7	26.2
88	Vulcan	Brownwood	Limestone	2302501	13.0	7.5
89	Vulcan	Eastland	Limestone	2306805	13.0	4.3
90	Vulcan	FM 1604	Limestone	1501506	19.5	18.2
91	Vulcan	Geronimo Cr.	Limestone	Z1500018	18.0	6.0
92	Vulcan	Hailey	Limestone	820901	19.5	31.4
93	Vulcan	Helotes	Limestone	1501514	25.6	18.2
94	Vulcan	Higgins	Limestone	803005	21.6	22.8
95	Vulcan	Huebner	Limestone	1501507	17.5	7.5
96	Vulcan	Kelly	Limestone	218409	14.0	7.2
97	Vulcan	Sactun	Limestone	40102	13.5	8.8
98	Vulcan	Smyth	Limestone	1523205	21.6	19.8
99	Vulcan	Tehuacana	Limestone	914708	18.0	7.0
100	Vulcan	Yates	Limestone	Z230008	24.0	32.4
101	Word	Dow Chem	Limestone	1402702	7.8	2.4
102	Word Dean	Martin	Limestone	Z150005	25.3	21.2
103	Young	SkyHi (Maddox)	Limestone	914709	27.0	20.4
104	Delta	Brownlee	Sandstone	1402704	12.0	10.0
105	Dolese	Cyril	Sandstone	50411	21.0	19.3
106	Meridian	Apple, OK	Sandstone	50437	8.0	10.0
107	Rock Products	Sawyer	Sandstone	Z010009	7.0	10.0
108	TXI	Streetman	Synthetic	1817502	14.0	1.0
109	Allied Aggregates	Brock	Unknown	Z020019	14.7	7.0
110	Border Pacific	Montgomery	Unknown	40104	6.5	2.0
111	Brazos Valley	Cameron	Unknown	Z170003	8.4	3.0
112	Capital	Fm 1604 #2	Unknown	1501515	10.3	1.3
113	Construction	Las Colitas	Unknown	Z210020	9.0	8.0
114	CSA	Allison	Unknown	Z070012	19.0	9.0

Table 3.1. Micro-Deval and Magnesium Sulfate Soundness Results from TxDOT Database. (Cont'd)

Serial no.	Source	Pit 8/20/1999	Material type	Prod. code	Micro-Deval	Mg soundness
115	Dal-Tile	Willis	Unknown	Z120021	4.0	1.0
116	Gilbert	Jim Hill	Unknown	Z040022	10.0	9.0
117	Gilvin-Terrell	Babe Jones	Unknown	Z250011	6.0	3.0
118	Gilvin-Terrell	Campbell	Unknown	Z250015	4.0	4.0
119	Gilvin-Terrell	Chestnut	Unknown	z040026	7.0	7.0
120	Granite Consruction	Chapote	Unknown	Z220033	3.0	4.0
121	Granite Mt.	Granite Mt	Unknown	Z140010	8.0	8.0
122	Granite Mt.	Little Rrock	Unknown	Z120023	4.0	3.0
123	H&B	Ramos	Unknown	Z090009	17.0	21.0
124	Holmes	South Canyon	Unknown	Z040019	29.0	8.5
125	J.L. Milligan	Hedley	Unknown	Z250013	8.0	8.0
126	J.L. Milligan	Roach	Unknown	Z04001	9.5	8.0
127	Jones	Blocker	Unknown	80009	20.3	34.0
128	Jones	Flint	Unknown	Z080010	15.0	28.5
129	Jones	Goldwire	Unknown	Z060016	27.0	29.0
130	Jones	Hurt	Unknown	Z060017	29	22.3
131	Jones	No Tree	Unknown	Z060008	21.0	22.3
132	La Grange	Holman	Unknown	Z130007	3.0	7.3
133	Lindsey Contractors	Double E	Unknown	Z090029	10.0	7.0
134	Luhr	Grays Point	Unknown	Z200006	7.4	1.0
135	Matermia	Cerro Picacho	Unknown	Z210021	10.0	4.0
136	McCardle	O'Leary	Unknown	Z240014	19.5	19.2
137	Meridian	Palestine	Unknown	1708201	13.6	8.4
138	Meridian	Steen Dome	Unknown	Z100003	18.0	13.0
139	Midstate	Malvern	Unknown	Z190004	7.0	5.0
140	P&S Stone	T. .D Williams	Unknown	Z030001	16.0	24.0
141	Pioneer	Clinton	Unknown	1402701	9.8	5.2
142	Pioneer	Davis	Unknown	224905	14.6	6.8
143	Pioneer	Spring Creek	Unknown	411801	10.0	8.0
144	Price	Cowsert	Unknown	Z070004	35.0	35.0
145	Price	Gary Boyd	Unknown	Z220038	2.2	1.0
146	Price	Hargrove	Unknown	Z220034	20.0	22.0
147	Price	Hargus	Unknown	Z060008	30.0	51.0
148	Price	Parker	Unknown	Z07001	19.8	18.6
149	Price	Pinto Valley	Unknown	2224016	4.0	6.0
150	Price	Friend	Unknown	Z070013	34.0	37.0

Table 3.1. Micro-Deval and Magnesium Sulfate Soundness Results from TxDOT Database. (Cont'd).

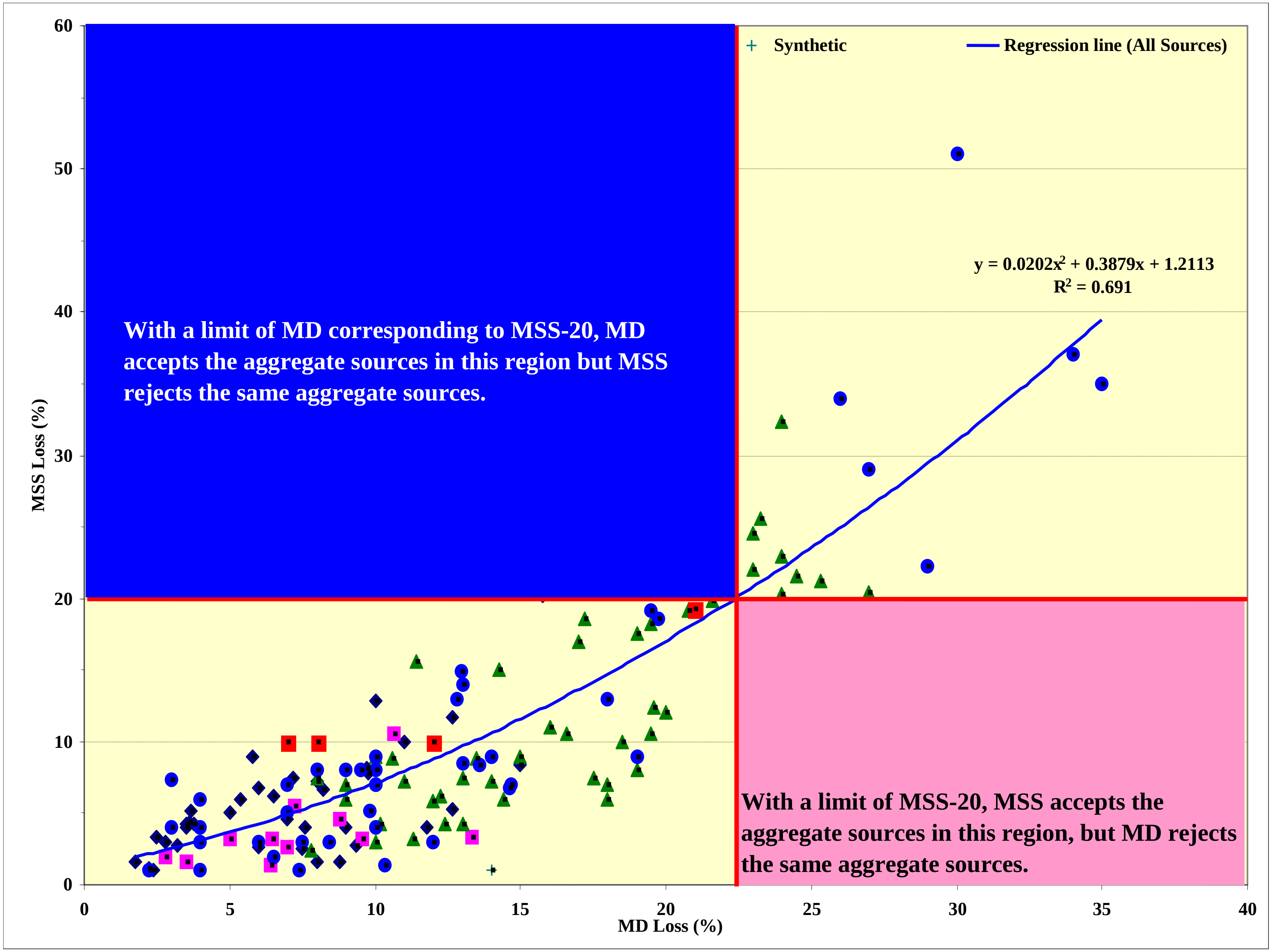
Serial no.	Source	Pit 8/20/1999	Material type	Prod. code	Micro-Deval	Mg soundness
151	Smyth Mines	Blades Quarry	Unknown	Z150020	26.0	34.0
152	South Tx Aggregates	Rio Medina	Unknown	Z150015	12.0	3.0
153	Southway Const.	Clayton, NM	Unknown	Z040021	7.5	3.0
154	Texas S&G	Kritser-Fain	Unknown	418812	13.0	14.9
155	Vega	Tom Green	Unknown	418001	12.8	13.0
156	Volcanic Stone	Cinder Mtn.	Unknown	Z040025	13.0	14.0
157	Weirich Bros.	Boerner	Unknown	1408702	13.0	8.5
158	Word	Seco Creek	Unknown	Z150014	14.0	9.0
159	Young	FM 1860	Unknown	916113	10.0	7.0

The symbols denote different lithologic categories of aggregate, limestone, sandstone, gravel, igneous, and synthetic materials. The trend line representing this model is shown on the scatter plot. This trend line is then used to determine the Micro-Deval specification limits corresponding to MSS specification limits of 20, 25, and 30. These Micro-Deval Specification limits are shown in Table 3.2.

Table 3.2. New Micro-Deval Specification Limits.

Magnesium sulfate soundness = 20.0%	Micro-Deval = 22.5%
Magnesium sulfate soundness = 25.0%	Micro-Deval = 26.0%
Magnesium sulfate soundness = 30.0%	Micro-Deval = 29.0%

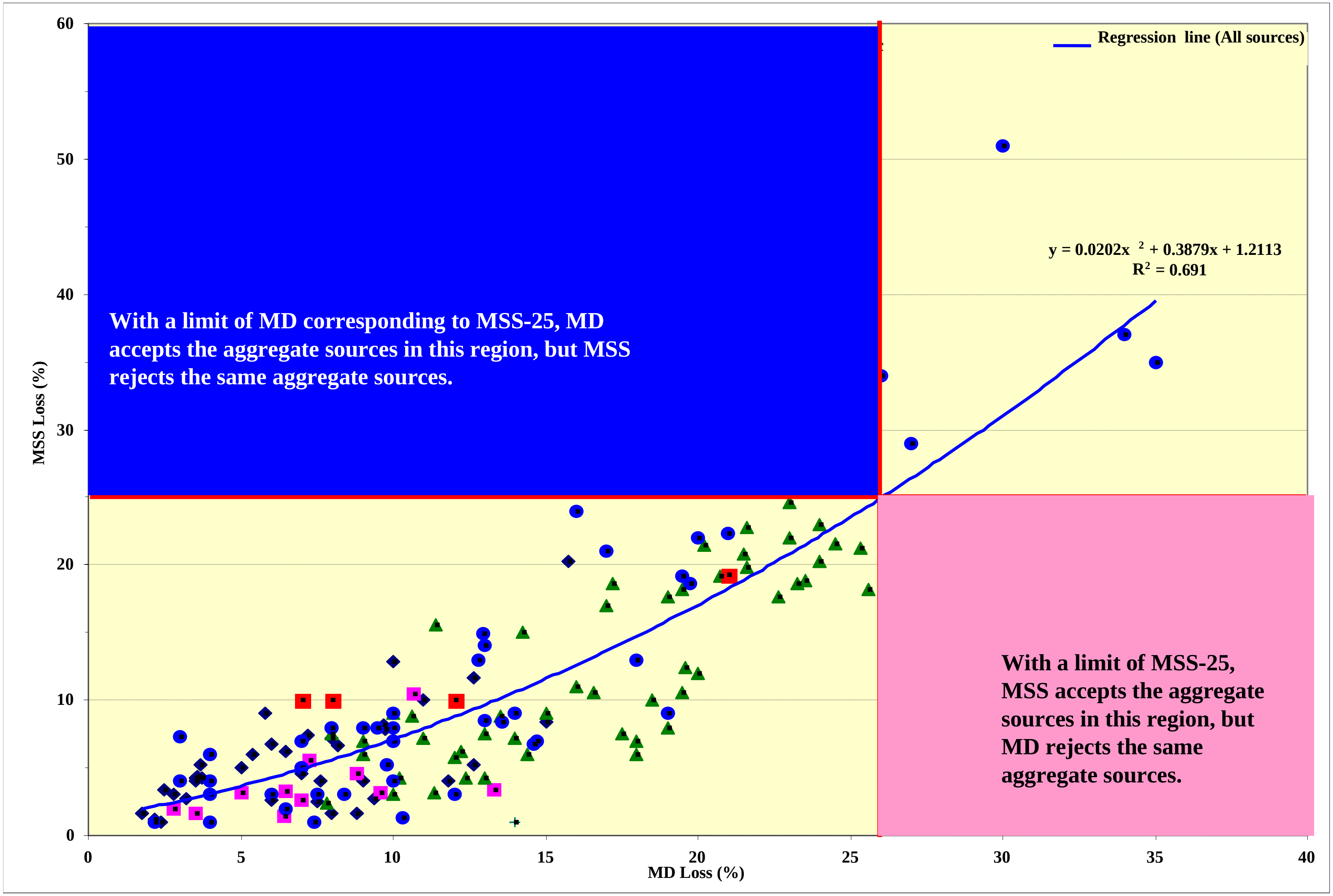
Because of the scatter that exists in the MSS versus Micro-Deval data plot, aggregate sources that meet a given MSS specification limit will not be identical to those that meet the equivalent Micro-Deval specification limit. For example, when the MSS limit is set to 20, there are five aggregate sources that meet this requirement but would fail to meet the equivalent Micro-Deval specification limit of 22.5. Similarly, there are 12 other aggregate sources that meet the Micro-Deval test requirement but will be rejected based on the MSS test requirement. This apparent contradiction is a significant barrier against the implementation of the Micro-Deval test as a substitute for MSS.



With a limit of MD corresponding to MSS-20, MD accepts the aggregate sources in this region but MSS rejects the same aggregate sources.

With a limit of MSS-20, MSS accepts the aggregate sources in this region, but MD rejects the same aggregate sources.

Figure 3.1. Micro-Deval Specification Limits Corresponding to Magnesium Sulfate Soundness Specification Limit of 20 Percent.



$y = 0.0202x^2 + 0.3879x + 1.2113$

$R^2 = 0.691$

With a limit of MD corresponding to MSS-25, MD accepts the aggregate sources in this region, but MSS rejects the same aggregate sources.

With a limit of MSS-25, MSS accepts the aggregate sources in this region, but MD rejects the same aggregate sources.

Figure 3.2. Micro-Deval Specification Limits Corresponding to Magnesium Sulfate Soundness Specification Limit of 25 Percent.

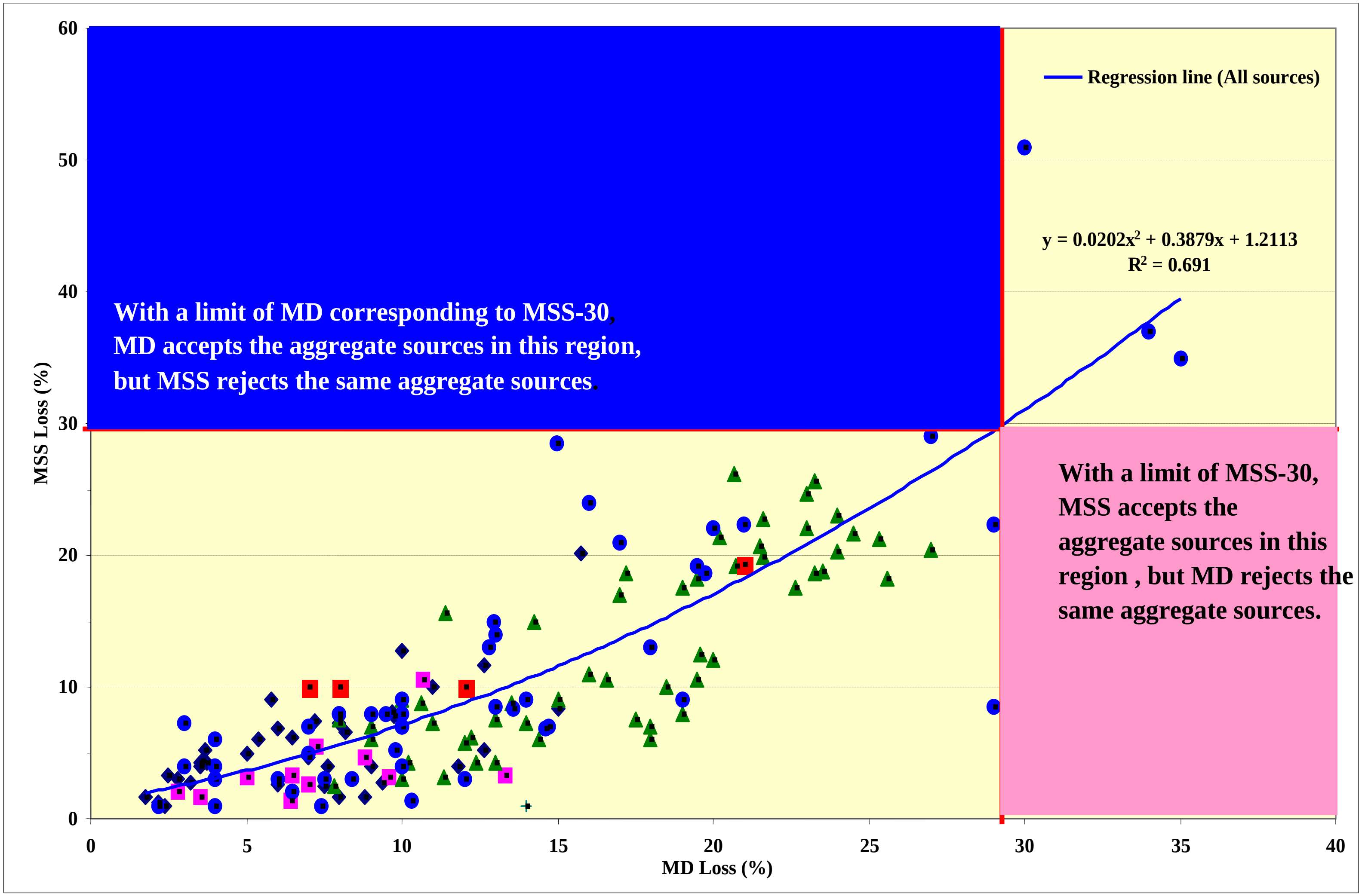


Figure 3.3. Micro-Deval Specification Limits Corresponding to Magnesium Sulfate Soundness Specification Limit of 30 Percent.

The aggregate sources that qualify under MSS specification but fail under the equivalent Micro-Deval specification are shown in Table 3.3.

Table 3.3. Aggregate Sources That Fail MD = 22.5 but Pass MSS = 20.

Serial No.	Source	Pit	Material Type
1	Vulcan	Helotes	Limestone
2	Martin Marietta	Beckman	Limestone
3	Capitol	Wood	Limestone
4	Holmes	South Canyon	Unknown

The aggregate sources that qualify under the new Micro-Deval specification but fail under the MSS specification areare shown in Table 3.4.

Table 3.4. Aggregate Sources That Pass MD = 22.5 but Fail MSS = 20.

Serial No.	Source	Pit	Material Type
1	Vulcan	Higgins	Limestone
2	Colorado	Hunter	Limestone
3	Luhr	Tower Rock	Limestone
4	Vulcan	Black	Limestone
5	Vulcan	Hailey	Limestone
6	Janes	Woods	Gravel
7	Jones	Blocker	Unknown
8	Jones	Flint	Unknown
9	P&S Stone	T. D. Williams	Unknown
10	H&B	Ramos	Unknown
11	Price	Hargrove	Unknown
12	Jones	No Tree	Unknown

Similarly, when the MSS limit was set to 25, it was observed that three aggregate sources fall within Quadrant 4. These aggregates qualify under the MSS test requirement but are rejected based on the Micro-Deval test specification. Similarly, with the same limits there are six aggregate sources that are within Quadrant 2. These sources are accepted based on the Micro-Deval test but are rejected based on MSS. Quadrant 4 aggregate sources corresponding to an MSS specification limit of 25 are shown in Table 3.5.

Table 3.5. Aggregate Sources That Fail MD = 26 but Pass MSS = 25.

Serial no.	Source	Pit	Material type
1	Young	SkyHi (Maddox)	Limestone
2	Holmes	South Canyon	Unknown
3	Jones	Hurt	Unknown

Quadrant 2 aggregate sources are shown in Table 3.6.

Table 3.6. Aggregate Sources That Pass MD = 26 but Fail MSS = 25.

Serial No.	Source	Pit	Material Type
1	Price	Clement	Limestone
2	Vulcan	Black	Limestone
3	Vulcan	Yates	Limestone
4	Vulcan	Hailey	Limestone
5	Jones	Blocker	Unknown
6	Jones	Flint	Unknown

Finally, if the MSS limit was set to 30, then there were no aggregate sources that fell within Quadrant 4. In other words, all aggregates that are accepted by MSS are also accepted by the Micro-Deval test. However, with the same limits, there are four aggregate sources that fall within Quadrant 2 where they are accepted by Micro-Deval but rejected by MSS test. These four Quadrant 2 aggregate sources are shown in Table 3.7.

Table 3.7. Aggregate Sources That Pass MD = 29 but Fail MSS = 30.

Serial no.	Source	Pit	Material type
1	Vulcan	Yates	Limestone
2	Vulcan	Hailey	Limestone
3	Smyth Mines	Blades Quarry	Unknown
4	Jones	Blocker	Unknown

TIME VARIABILITY OF SOURCES

Almost all of the aggregates used by TxDOT come from natural sources. Typically a given natural aggregate source is spread over a large area. Consequently, the quality of aggregate will vary as the quarrying operation moves from one area to another within the same pit. Therefore, the quality of the material supplied from a given source will vary with time. Thus it is important that the quality control tests performed on these aggregates are capable of detecting changes in the quality of the aggregate. In order to determine the capability and effectiveness of these tests for detecting changes in material quality, data from 159 sources out of 169 sources were analyzed to check the time variability. A total of 159 sources were chosen because only these sources had results from both Micro-Deval and MSS tests.

Analysis of these data shows that both Micro-Deval and MSS tests follow the same general trend in predicting the material change. However, this consistent pattern is not seen consistently in all aggregate sources and at all times. In fact, deviations from this general trend were found to be not too uncommon. Figures 3.4 and 3.5 are the graphical representations of the trends described above.

From Figures 3.4 and 3.5, it can also be noticed that the MSS test shows much larger fluctuations than the MD test. This observation raises one important question. Is the large fluctuation in MSS test data indicative of its superior sensitivity, or is it a result of the poor repeatability of the test? To address this issue, a more detailed analysis was performed on the data obtained from the TxDOT database. This analysis is described in Section 3.5 below.

COMPARATIVE REVIEW OF THE SENSITIVITY MD AND MSS TEST METHODS

The variability in test data shown in Figures 3.4 and 3.5 represents the cumulative effect of variability of material as well as variability inherent in the test procedure. Therefore, the standard deviations and coefficients of variation calculated for these data will represent the overall or composite variability. To determine the sensitivity of the test procedure, one must separate the two types of variability. This can be accomplished by using the “precision statements” that are available for each of the test procedures in question.

Texas Tech University developed such precision statements for Micro-Deval and MSS tests in Project 0 –1771. These precision statements were developed by performing replicate tests on multiple samples of the same material. Accordingly, they represent variability inherent in the test procedure. Table 3.8 summarizes the precision statements for both Micro-Deval and MSS tests. Based on these results, the single lab coefficient of variation for the Micro-Deval test is 3.4 percent compared to 13.0 percent for the MSS test. The multi-lab coefficients of variation for the Micro-Deval and MSS tests are 7.1 and 27.7, respectively.

The test data available in the TxDOT AQMP database were obtained from tests that were performed in the same laboratory at frequent intervals. Therefore, the precision statement corresponding to “within laboratory” conditions will best represent the test variability found in these tests. The product of coefficient of variation (within laboratory precision) and the mean value of the test results should estimate the standard deviation due to variability of the tests and not the variability resulting from change in material. Therefore the ratio between the composite standard deviation and the standard deviation for the lab test procedure can be used as a measure of the sensitivity of the test to any material change.

Therefore, the ratios between the standard deviations (composite variability/lab test variability) were then calculated for both Micro-Deval and MSS tests, and graphs were plotted to check the sensitivity of both of the tests to change in material. Out of the results obtained through both tests for 30 out of 37 gravel sources, it can be seen that the Micro-Deval test has better capability in predicting any material change within a particular source. A similar set of procedures conducted on igneous rocks showed that in 8 out of 11 sources the Micro-Deval test was superior in predicting any change in the material. A similar trend was found for limestone, where in 39 out of 55 sources, the Micro-Deval test was a better indicator of any change in material. A mean value for the ratio of standard deviations for both the Micro-Deval and MSS tests was also calculated for each type of material, e.g. gravels, igneous, limestone and sandstone. The mean values for the Micro-Deval test were more than those for the MSS test for all categories of aggregates, which indicated that the Micro-Deval test was superior in predicting any change in the material.

Figure 3.6 shows the comparison between the sensitivity of the MD Test versus that of the MSS Test for different lithological aggregate groups based on analysis conducted using the Project 0-1771 precision statement. Figure 3.7 shows similar comparison obtained when only tests conducted by TxDOT/Materials labs in Austin are considered in the determination of test procedure precision.

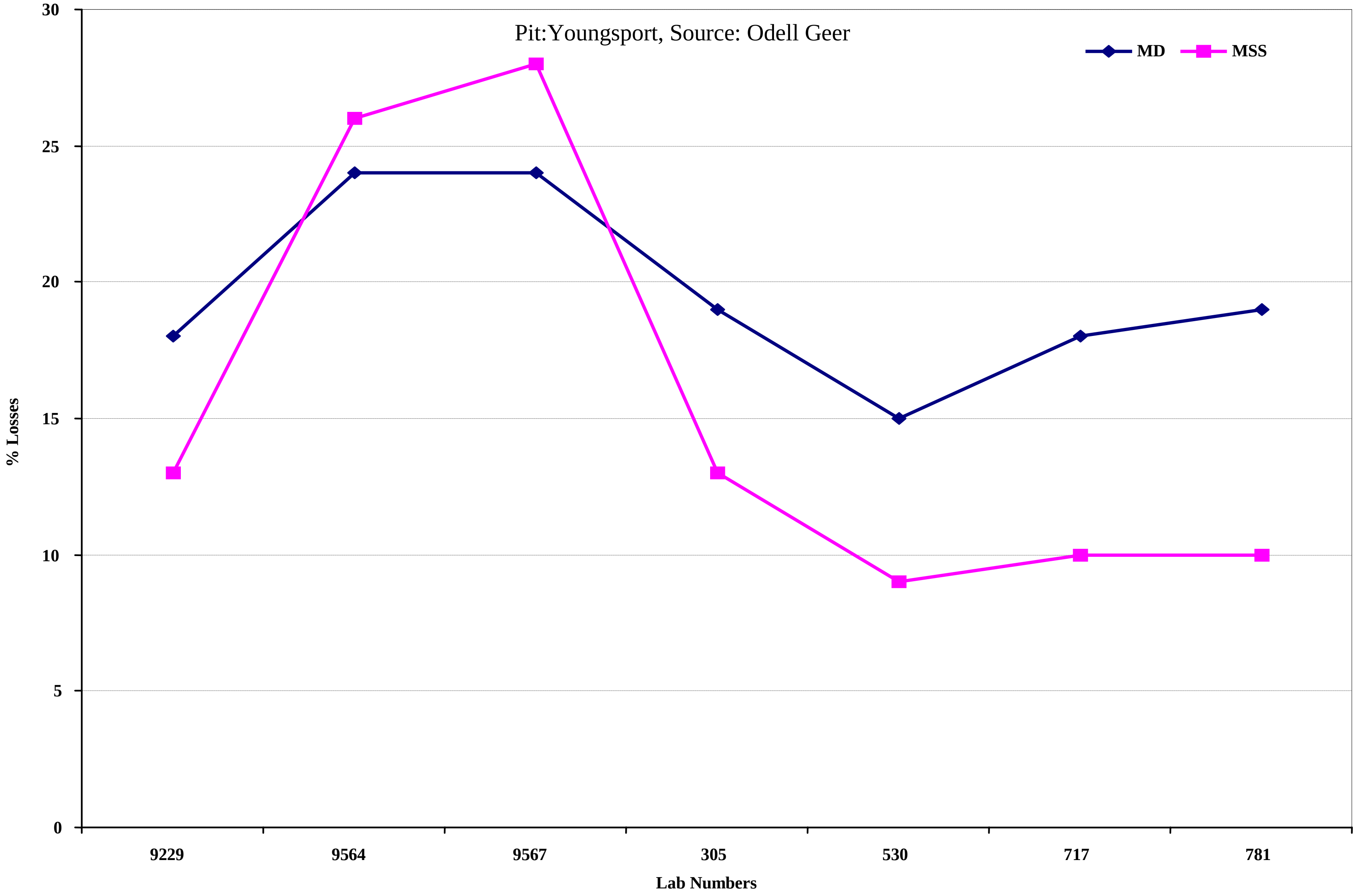


Figure 3.4. Time Variability of Aggregate Received from Youngsport/Odell Geer Source.

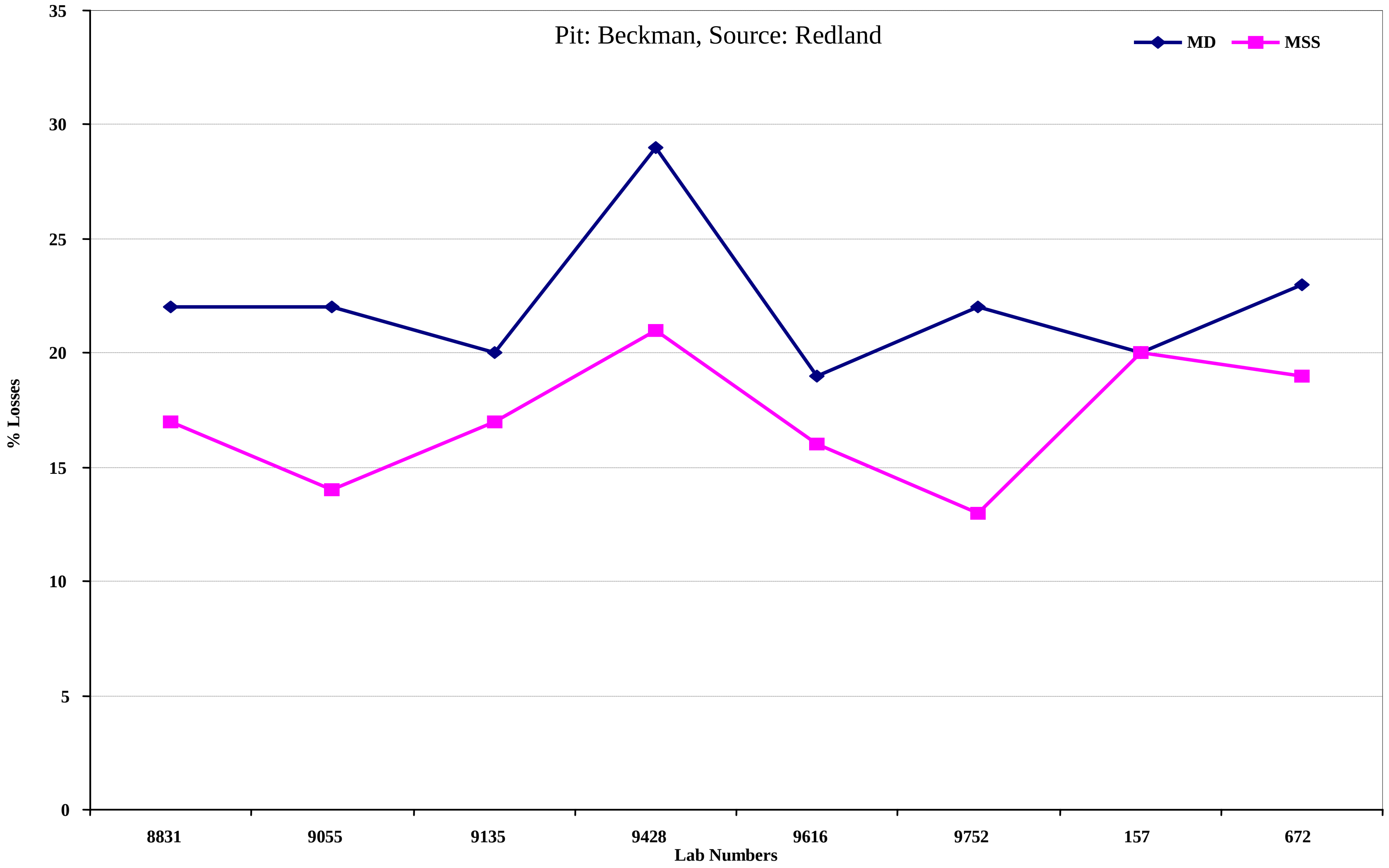


Figure 3.5. Time Variability of Aggregate Received from Beckman/Redland Source.

Table 3.8. Precision Statement for Micro-Deval and Soundness Test.

Micro-Deval test

Precision Index	Standard deviation^A	Acceptable Range of two results^A
Within lab (single operator)	0.35	0.99
Multi-laboratory	0.92	2.60
In terms of percent of mean		
Precision Index	Coefficient of Variation (%)^B	Acceptable range of two results^B
Within lab (single operator)	3.4	9.6
Multi-laboratory	7.1	20.1

Magnesium Sulfate Soundness

Precision index	Standard deviation^A	Acceptable range of two results^A
Within lab (single operator)	1.55	4.39
Multi-laboratory	3.35	9.48
In terms of percent of mean		
Precision index	Coefficient of variation (%)^B	Acceptable range fo two results^B
Within lab (single operator)	13.0	36.8
Multi-laboratory	27.7	78.4

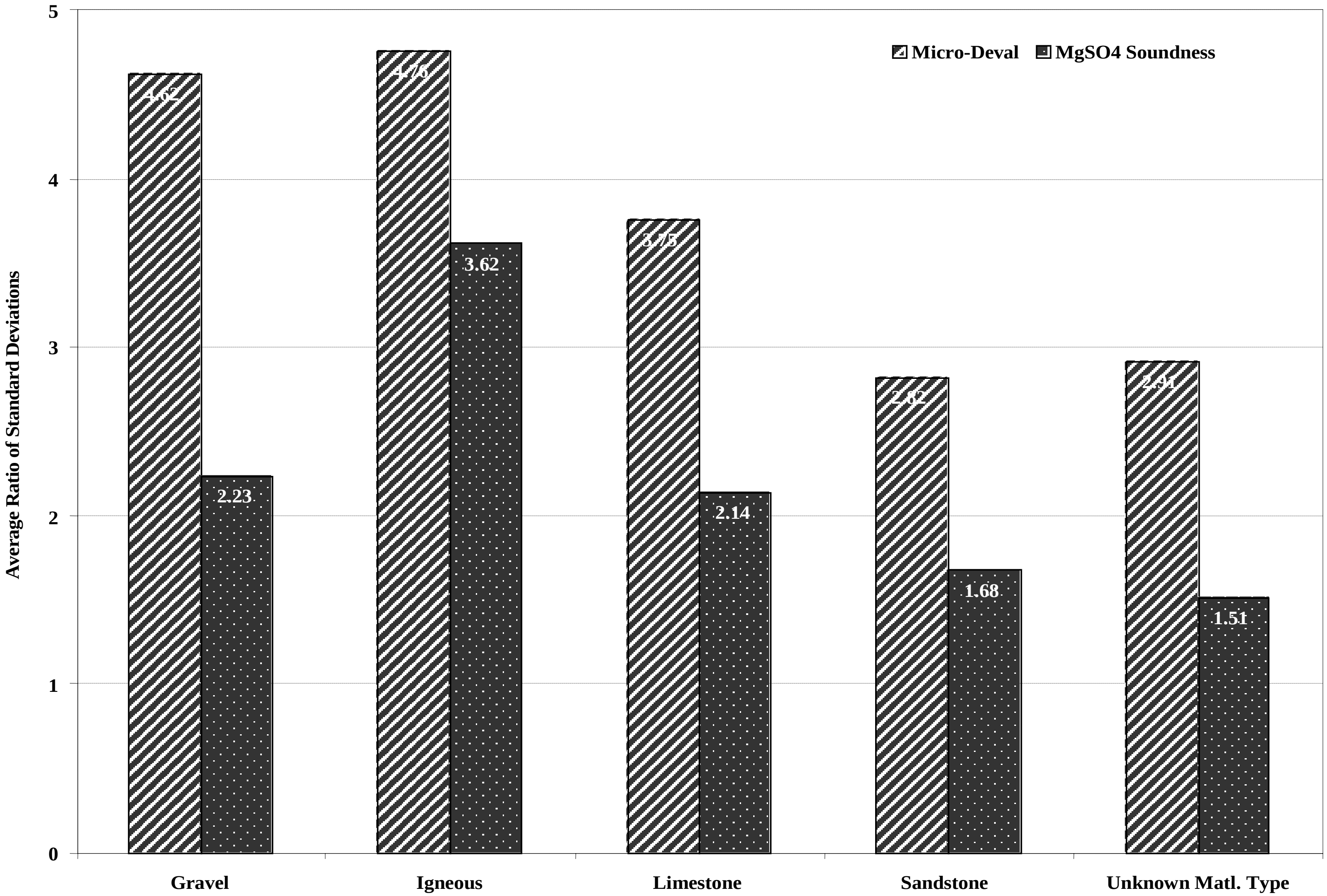


Figure 3.6. Sensitivity of Micro-Deval and Magnesium Sulfate Soundness Test to Material Change (Using Texas Tech University's Single Lab Precision Statement).

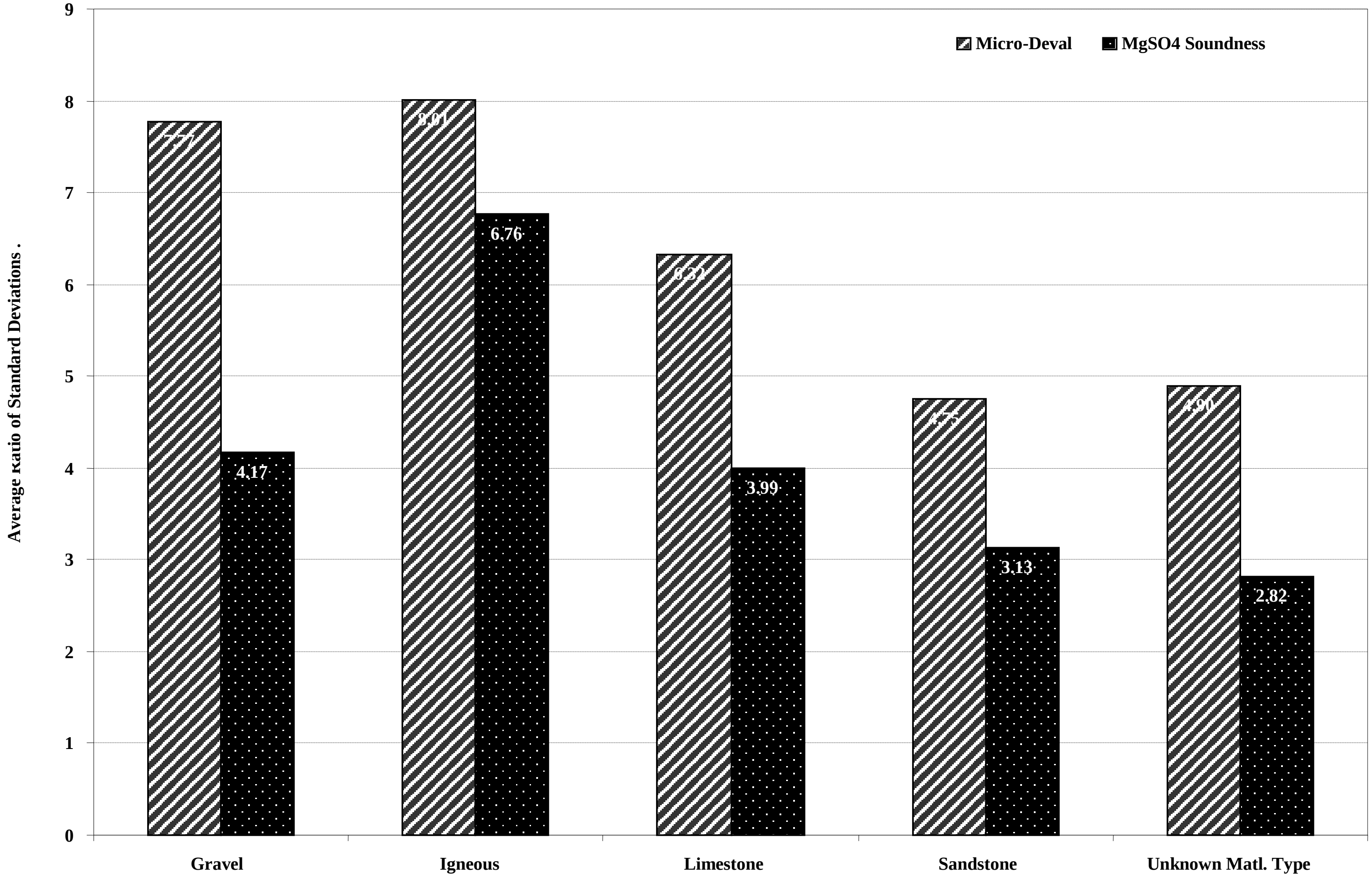


Figure 3.7. Sensitivity of Micro-Deval and Magnesium Sulfate Soundness Test to Material Change (Using Materials and Tests Lab's Single Lab Precision Statement).

CHAPTER 4
LABORATORY TEST PROGRAM

OVERVIEW

The percent losses measured by Micro-Deval and magnesium sulfate soundness tests increase with increasing aggregates absorption. Between these two tests, the MSS test shows greater sensitivity to aggregate absorption than the MD test. Review of data presented in the previous chapter demonstrates that the Micro-Deval test yielded larger percentage losses for aggregates with low absorptivity while the MSS test yielded larger percentage losses for aggregates with high absorptivity. In other words, the Micro-Deval test was less harsh on aggregates with higher absorption when compared with the MSS test. This data trend appeared to be one of the major reasons for poor correlation between MSS and MD tests.

As stated earlier, this research plan was developed on the premise that the MSS test will remain in TxDOT's aggregate AQMP program as the primary benchmark for aggregate durability assessment. The MD test will be implemented as a supplementary test and, in particular, as a project level aggregate quality control test. Therefore, the MD test's ability to mimic the MSS test (or in other words, the strength of the correlation between the MD and MSS tests) is an important consideration. Accordingly, an attempt was made to come up with a different variation of the Micro-Deval test that could be used to enhance the Micro-Deval test's sensitivity to absorption and consequently improve the strength of its correlation with the MSS test.

The laboratory test program included two key components: MD and MSS tests based on standard procedures and secondly MD tests based on several different trial procedures. All of the new procedures were designed with the intent of improving correlation between the MD and MSS tests. They included: (a) MD test conducted using the same aggregate gradation as the MSS test, (b) use of increased soaking time in the MD test, and (c) use of aggregate boiling to achieve increased absorption.

MD AND MSS TESTS BASED ON STANDARD PROCEDURES

Preparation of Samples for the Tests

Four bags of aggregates weighing around 50 pounds each were opened at a time and mixed thoroughly to ensure uniformity. The aggregates were subsequently split using a mechanical splitter. A 1000 gram sample was split into size fractions of 10 mm, 5 mm and 2 mm using standard sieves. The percentage weight of each size fraction was calculated. Samples were then washed in a mechanical aggregate washer to eliminate any fine dust and the unwanted foreign material. After that the aggregate was allowed to dry, it was sieved using the standard sieves into different size fractions, and the aggregates retained on each sieve was stored in 7 gallon buckets. Each bucket were labeled to store a specific size fraction for future use.

Five Cycle Magnesium Sulfate Soundness Test

The MSS tests were conducted in conformance with the Texas Department of Transportation's test procedure Tex-411-A. Each source was tested in triplicates for laboratory precision testing. Most of the aggregates shipped to Texas Tech University were type D materials. The gradation size fractions and weights used with this material are shown in Table 4.1.

Table 4.1. Magnesium Sulfate Soundness Test, Normalized Gradation.

Size range	Weight used	Percentage used
No. 8 to No. 4	100 ± 5 grams	7.14%
No. 4 to 1/4 in.	120 ± 5 grams	8.57%
1/4 in. to 3/8 in.	180 ± 5 grams	12.85%
3/8 in. to 1/2 in.	1000 ± 10 grams	71.42%
Total	1400 grams	100%

Micro-Deval Test

This test procedure was conducted according to the Ontario Ministry of Transportation specification with only some minor changes in standard sieve sizes. Based upon the materials sampled, nominal gradation sizes were assigned. All the samples tested were 16 mm or 12.5 mm nominal size. Once the actual testing started, we were able to run three Micro-Deval tests a day.

Figure 4.1 shows the three-tier Micro-Deval apparatus and its accessories. In the study conducted by NCAT at Auburn, it was reported that after some usage, slippage between the steel jars and the rotating rubber rollers in the equipment began to take place. Slippage of the jars causes a variation in the number of specified rotations. If slippage had taken place, roughening of the surface of the rubber rollers would correct the problem. No problem in the form of slippage was experienced at Texas Tech University while conducting the tests. However, the number of revolutions per minute in the apparatus decreased due to lack of lubrication. This was overcome subsequently through the use of lubrication and servicing of the ball bearings and the chain.

A control sample aggregate was tested every 10th test as part of the Micro-Deval test. The Ontario Ministry of Transportation utilizes pre-Cambrian limestone from the Brechin quarry in Canada as its control sample. Among the aggregates used and available in Texas, the aggregate source that closely resembled the Brechin quarry from a mineralogical aspect was the aggregate from Vulcan Brownwood. This quarry had a history of consistent production, which made this an excellent source for our control sample.

Table 4.2 provides MD and MSS test data obtained from this lab test series.

Figure 4.1. Three-Tier Micro-Deval Apparatus and Accessories.

Table 4.2. Data from Standard MD and MSS Tests.

No	Material type	Pit	MD loss (%)	MSS loss (%)
1	Sandstone	Brownlee	12.6	15.4
2	Sandstone	Cyril, OK	19.4	17.3
6	Metamorphic	Pedernal, NM	13.2	3.1
3	Igneous	Sweet Home, AK	3.7	1.9
4	Igneous	Mill Creek, OK	8.5	4.7
5	Igneous	Vado	9.5	2.5
7	Igneous	Davis, OK	8.2	4.5
8	Igneous	Knppa	7.8	5.4
9	Igneous	McKelligon Granite, NM	10.2	14.7
51	Igneous/Gravel	Hoban	6.9	8.1
10	Limestone	Brechin, CA	16.2	16.8
11	Limestone	Clinton	7.4	2.9
12	Limestone	Coleman, OK	15.8	14.6
13	Limestone	Perch Hill	12.6	5.4
14	Limestone	Richard Spur, OK	12.9	6.4
15	Limestone	Brownwood	12.0	9.9
16	Limestone	McKelligon Dolomite	13.5	9.8
17	Limestone	Tehucana (Bullard)	19.5	8.2
18	Limestone	Cooperton, OK	8.1	2.5
19	Limestone	Dow Chem	4.8	3.1
20	Limestone	Stringtown, OK	8.7	4.9
21	Limestone	SH 211	18.8	10.5
22	Limestone	Hubner Rd.	17.5	7.6
23	Limestone	4DGs	18.8	13.0
24	Limestone	New Braunfels	16.9	7.4
25	Limestone	Bridgeport	16.0	14.5
26	Limestone	Kelly	11.5	7.3
27	Limestone	Helotes	26.6	24.1
28	Limestone	Smyth	22.1	21.7
29	Limestone	Coleman, OK	10.9	6.7
30	Limestone	Maddox	22.0	20.0

Table 4.2. Data from Standard MD and MSS Tests (Cont'd).

No	Material type	Pit	MD loss (%)	MSS loss (%)
31	Limestone	Ardmore, OK	8.8	5.5
32	Limestone	Chambers	25.8	24.2
33	Limestone	Jordan	21.1	23.3
34	Limestone	Clements	22.3	23.0
35	Limestone	Hunter	17.9	11.9
36	Limestone	Tower Rock, MO	21.1	18.0
37	Limestone	Hensley	13.8	17.0
38	Limestone	No trees	16.3	18.3
39	Limestone	Black	20.7	38.5
40	Limestone	Nunnley	33.2	63.9
41	Gravel	Realotis	1.9	1.2
42	Gravel	Loop 1604 East #2	8.2	2.4
43	Gravel	Eagle Mills, AK	3.2	3.7
44	Gravel	Knippa	8.3	1.6
45	Gravel	Delight, AK	3.3	3.3
46	Gravel	Showers	2.3	1.8
47	Gravel	Johnson	7.4	5.9
48	Gravel	Beck	6.9	11.4
49	Gravel	Luckett	8.4	9.0
50	Gravel	Mansfield	11.6	10.1
52	Gravel	Creslenn	8.3	7.6

Effects of Increased Soaking Temperature on Aggregate Absorptivity

The percent absorption of an aggregate increases significantly when it is subjected to boiling. Boiling forces the air present in the voids out and replaces it with water. Accordingly, all aggregate samples were soaked in water under boiling temperatures for 2-hours and aggregate absorption determined. The test results were then compared with results from standard absorption tests. Table 4.3 summarizes the above data. When boiling temperatures were used, aggregate absorption values increased in nearly all of the aggregates. The average increase in percent absorption was 0.47. On a percentage basis, largest percent increase was obtained for aggregates with low absorption. Table 4.4 summarizes the effect of using boiling temperatures on the absorption of different aggregate categories.

In order to determine whether increased absorption values obtained from boiling would yield better correlation, regression analyses similar to those conducted in Project 0-1771 were repeated.

Figure 4.2 shows the relationships between MD and MD test data with percent boiling absorption. The corresponding regression models are as follows:

$$\text{MD } (\%) = 3.425 + 5.685 * \text{BOIL ABS } (\%) \tag{4.1}$$

$R^2 = 0.547$

$$\text{MSS } (\%) = 4.952 + 9.872 * \text{BOIL ABS } (\%) \tag{4.2}$$

$R^2 = 0.655$

Accordingly, both tests show positive correlation with boiling absorption values. The large slope in the MSS plot is consistent with its greater sensitivity to absorption. Also, the MSS test is slightly better correlated with absorption than the MD test.

Table 4.3. Absorption Test Results (Standard and after Boiling).

No.	Producer	Pit	% absorp. Std.	% absorp. boiling	% change
1	Delta Materials Corporation	Brownlee	1.27	1.75	37.8
2	Dolese Brothers Co.	Cyril, OK	1.19	2.31	94.1
3	Granite Mountain	Sweet Home, AK	0.69	0.45	-34.8
4	Meridian Aggregate (Granite)	Mill Creek , OK	1.67	1.09	-34.7
5	Jobe Concrete Products, Inc.	Vado	0.49	2.57	424.5
6	Western Rock Products	Pedernal, NM	0.29	1.50	417.2
7	Western Rock Products	Davis, OK.	0.88	1.41	60.2
8	Vulcan Materials Co,	Knippa	0.62	0.84	35.5
9	Jobe Concrete Products, Inc.	McKelligon Dolomite	1.32	1.79	35.6
11	Pioneer Aggregates	Clinton	0.49	0.76	55.1
12	Latimore	Coleman, OK	0.70	1.16	65.7
14	Dolese Brothers Co.	Richards Spur, OK	0.25	0.50	100.0
15	Vulcan Materials Co,	Brownwood	0.69	0.83	20.3
16	Jobe Concrete Products, Inc.	McKelligon Dolomite	0.86	0.74	-14.0
17	Vulcan Materials	Tehuacana (Bullard)	1.00	1.57	57.0
18	Dolese Brothers Co.	Cooperton, OK	0.37	0.60	62.2
19	Dean Word Co.	Dow Chem	0.38	0.83	118.4
20	Amis Materials	Stringtown, OK	0.96	1.49	55.2
21	Redland Stone	SH 211	1.10	1.80	63.6
22	Vulcan Materials	Huebner Rd.	1.03	1.58	53.4
24	Sunbelt Materials	New Braunfels	1.04	1.84	76.9
25	Texas Industries, Inc.	Bridgeport	1.17	1.99	70.1
26	Vulcan Materials	Kelly	0.53	0.94	77.4
27	Vulcan Materials	Helotes	3.11	3.48	11.9
29	Dolese Brothers Co.	Coleman, OK	0.78	1.15	47.4
30	Young Contractors	Maddox	1.98	2.50	26.3
31	Dolese Bros.	Ardmore, OK	0.52	0.87	67.3
32	Marock, Inc.	Chambers	2.08	2.51	20.7
35	Colorado Materials	Hunter	1.51	2.17	43.7
36	Luhr	Tower Rock, MO	2.02	2.14	5.9
39	Vulcan Materials	Black	2.19	2.88	31.5

Table 4.3. Absorption Test Results (Standard and after Boiling) (Cont'd)

No.	Producer	Pit	% absorp. Std.	% absorp. boiling	% change
40	J. R. Thompson, Inc.,	Nunnley	4.18	5.16	23.4
41	Wright Brothers	Realitos	0.64	1.14	78.1
43	Gifford-Hill & Company, Inc.	Eagle Mills, AK	0.57	1.59	178.9
44	Southwest Aggregates	Knippa	1.05	1.21	15.2
45	Gifford-Hill & Company, Inc.	Delight, AK	0.76	1.22	60.5
46	Fordyce Co.	Showers	0.41	0.60	46.3
47	E.D. Baker	Johnson	0.37	0.58	56.8
48	Valley Caliche Products, Inc.	Beck	0.79	0.79	0.0
49	Trinity Materials Inc.	Luckette	1.24	1.40	12.9
50	Texas Sand & Gravel	Mansfield	1.06	1.44	35.8
51	Trans-Pecos Materials	Hoban	2.16	2.90	34.3
52	Trinity Materials	Creslenn	1.19	1.66	39.5

Table 4.4 Percent Increase in Aggregate Absorption due to Boiling.

Range of aggregate absorption	Percent increase due to boiling
ABS < 0.5%	160
0.5% < ABS < 1.0%	50
1.0% < ABS < 2.0%	41
2.0% < ABS < 3.0%	23
ABS > 3.0%	18

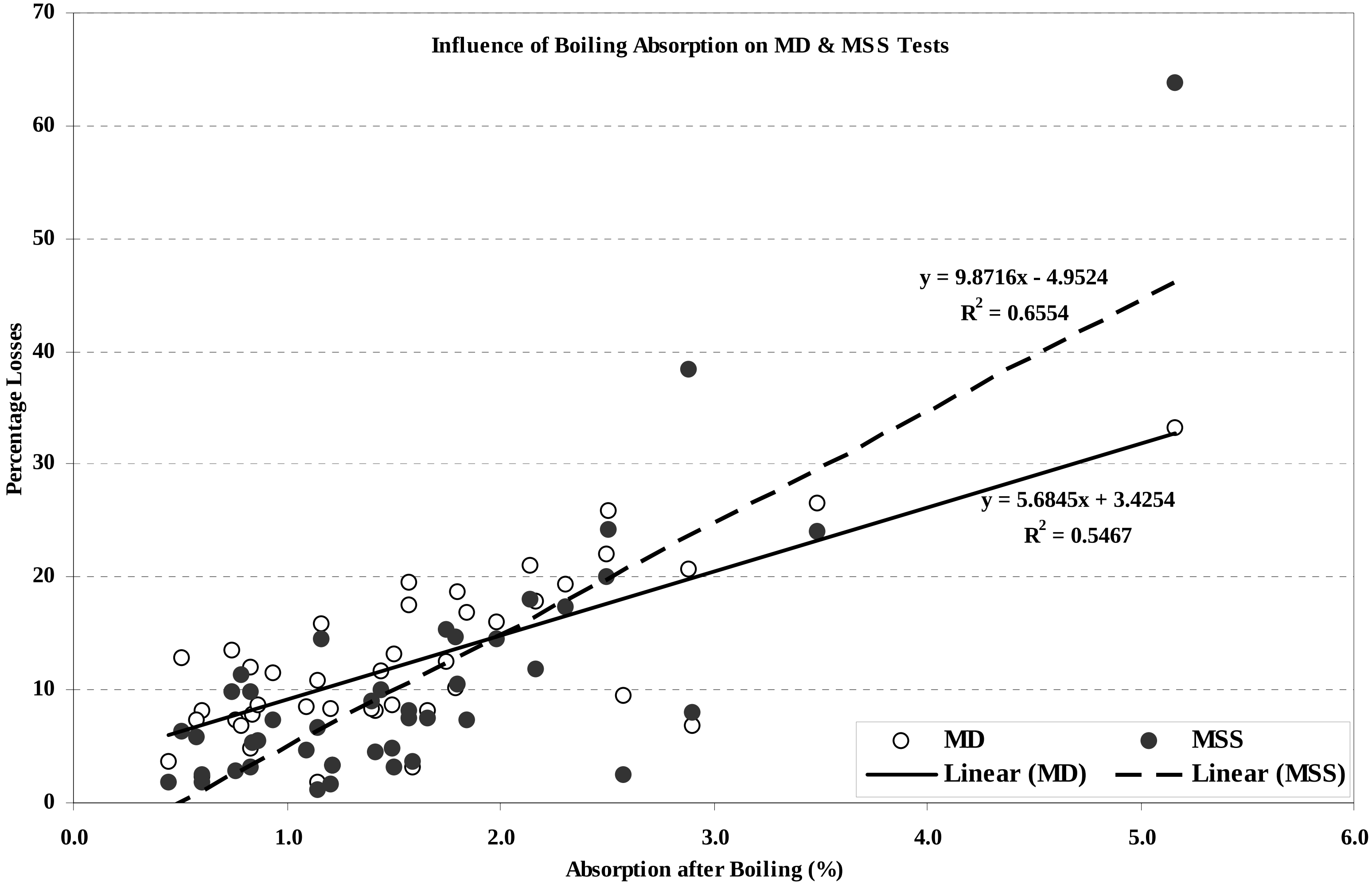


Figure 4.2. Influence of Boiling Absorption on Micro-Deval and Magnesium Sulfate Soundness Tests.

In the next step, regression analysis was repeated by incorporating the boiling absorption in the equation. This analysis yielded the following regression model:

$$\text{MSS (\%)} = 2.389 + 0.339 * \text{MD (\%)} * \text{BOIL ABS (\%)} \qquad (4.3)$$

The R^2 value obtained for this regression was equal to 0.8463. When compared with the previous regression analysis with standard absorption which yielded an R^2 value of 0.83, little improvement can be seen. Table 4.5 provides summary details with respect to the above regression model. Figure 4.3 shows the actual MSS value versus MSS value predicted by the model.

MD TESTS BASED ON ALTERNATIVE PROCEDURES

This section deals with variations of the MD test procedure that were attempted as a part of this project with the objective of improving the strength of the correlation between this test and the MSS test.

The selection of aggregate sources for this phase of the lab test program began in March of 2002. Based on the analysis of data obtained in the first phase as well as analysis of TxDOT AQMP data, it was apparent that there are several aggregate sources in the AGMP that show high Micro-Deval losses while showing a very low MSS loss. Similarly some of the aggregate sources show high MSS loss while showing low Micro-Deval loss. In this phase of laboratory study, the primary focus is placed on those aggregate sources to find out whether the large disparity in the performance of these sources in the two tests could be reconciled. All of these sources were chosen from the quality monitoring program. The districts where the sources were located were contacted. All the aggregates for a source were sampled from a single stockpile at a single point of time by the Texas Tech University research team. The samples listed in Table 4.6 were then shipped to Texas Tech University for further testing.

Table 4.5. Results of Regression Analysis with Boiling Absorption.

Absorption after boiling

Independent Variable = MSS Loss (%)
Dependent Variable = MD Loss (%) * Absorption after Boiling

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.9200
R Square	0.8463
Adjusted R Square	0.8426
Standard Error	4.4328
Observations	43

ANOVA

	Df	*SS*	*MS*	*F*	*Significance F*
Regression	1	4436.2669	4436.2669	225.7692	2.84188E-18
Residual	41	805.6321	19.6496		
Total	42	5241.8991			

	Coefficients	*Standard error*	*t Stat*	*P value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	2.3895	0.8690	2.7496	0.0088	0.6344	4.1445	0.6344	4.1445
X Variable 1	0.3397	0.0226	15.0256	0.0000	0.2940	0.3854	0.2940	0.3854

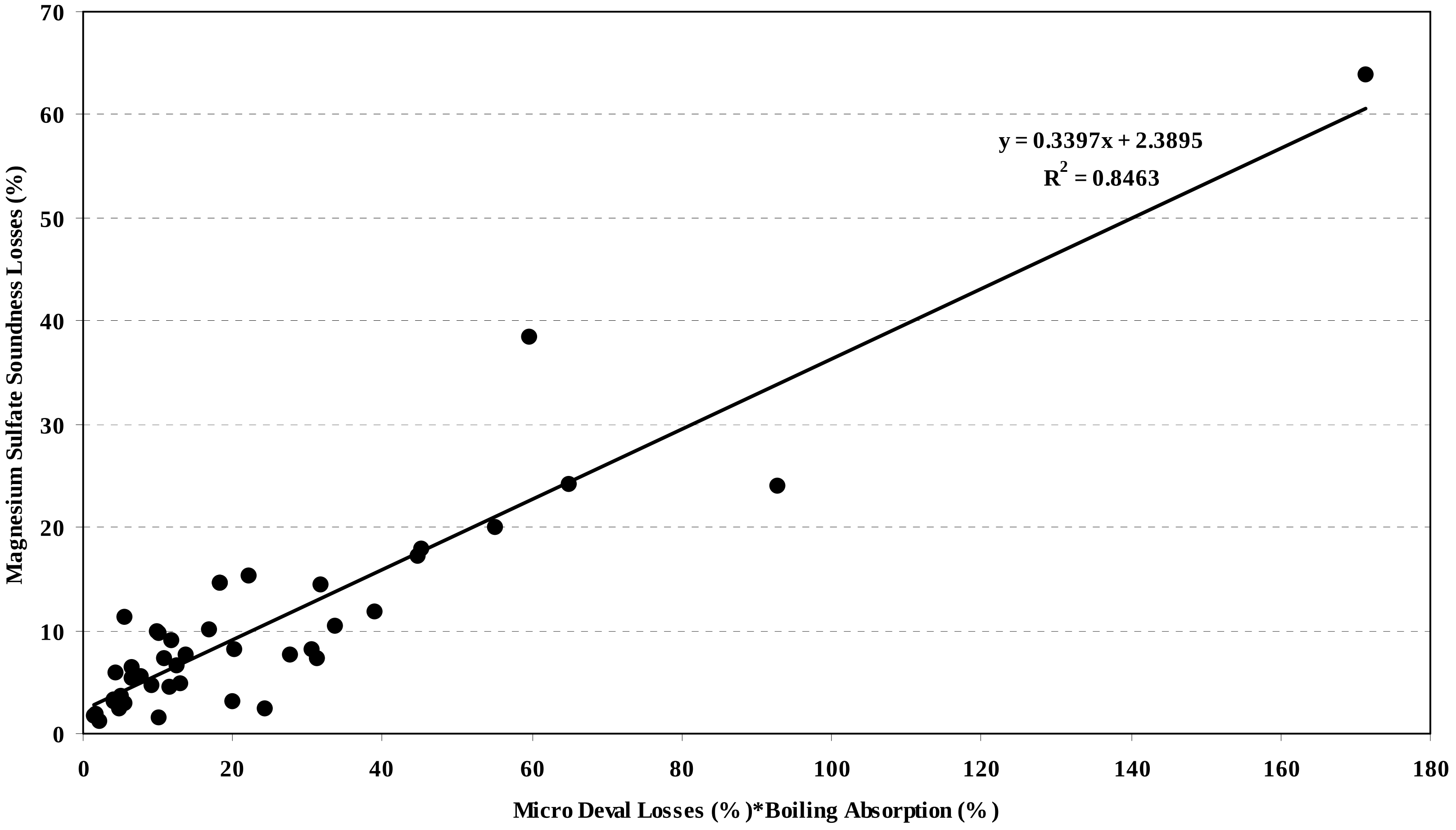


Figure 4.3. Predictive Model for MSS Loss Based on MD and Boiling Absorption Values.

Table 4.6. List of Aggregates Chosen for Second Phase of Laboratory Testing

No.	District	Material	Producer	Pit
1	Wichita Falls	Limestone	J.R Thompson, Inc.	Nunnley
2	Abilene	Limestone	Vulcan Materials	Black
3	El Paso	Igneous	Jobe Concrete Products, Inc	Vado
4	Pharr	Gravel	Valley Caliche Products, IncC	Beck
5	San Antonio	Limestone	Vulcan Materials	C.R. Geronimo
6	San Antonio	Limestone	Vulcan Materials	Helotes
7	San Antonio	Limestone	Sunbelt Materials	New Braunfels
8	Waco	Limestone	Vulcan Materials	Tehuacana
9	Laredo	Gravel	Wright Brothers	Realitos
10	Atlanta	Gravel	Gifford-Hill & Co, Inc	Delight, AK
11	El Paso	Igneous	Jobe Concrete Products, Inc.	McKelligon Granite, NM
12	Atlanta	Igneous	Granite Mountain	Sweet Home, AK

Increasing the Soaking Time of Aggregates to 24 Hours

In accordance with AASHTO provisional standard procedure, an aggregate sample with standard gradation would be initially soaked in water for one to two hours to saturate voids in the aggregate. Then the sample is placed in a jar mill with 2 liters of water and an abrasive charge consisting of 5000 grams of 9.5 mm diameter steel balls. In the modified testing procedure of Micro-Deval, the soaking time of aggregates prior to testing was extended to 24 hours, in order to achieve complete saturation. Eight aggregate sources were tested following the above procedure. The test results are listed in Table 4.7

A scatter graph was plotted with Micro-Deval losses on the X-axis and MSS losses on the Y-axis, and two second order polynomial regression lines were drawn, one with regular Micro-Deval test values and one with 24 hour soaking Micro-Deval test values. The regression line for regular Micro-Deval had an R^2 value of 0.83 however, when plotted after soaking the aggregates for 24 hours, the value of the Micro-Deval test increased the R^2 value to 0.84. The plot is shown as Figure 4.4.

Boiling of the Aggregates prior to Testing

As shown in Section 4.2.4, the absorption capacity of aggregate increases upon boiling to a significant amount. In this procedure the aggregates are boiled for about two hours in water and allowed to cool down to the room temperature. On boiling, the air voids in the aggregates are driven out and the voids get filled with water, thus saturating the aggregate void structure.

Applying the above procedure in the modified Micro-Deval test, one hour soaking of aggregates prior to testing was replaced by boiling the aggregates for two hours. After boiling, the aggregates remained soaked and were brought down to room temperature and the Micro-Deval tests were performed. Eight aggregate sources were tested. The percentage losses of aggregate were then recorded. The test results are listed in Table 4.8.

A scatter graph was plotted with Micro-Deval loss values and MSS loss values. Second order polynomial regression lines were plotted, one with regular Micro-Deval test values and one with Micro-Deval (boiling) test values. The regression line for regular Micro-Deval had an R^2 value of 0.83 however, when plotted after soaking the aggregates for 24 hours, the value of the Micro-Deval test increased the R^2 value to 0.84. The plot is shown as Figure 4.5

Micro-Deval Test Performed with MSS Gradation

The gradation of aggregates used in the standard MD and MSS test procedures are different from each other. Since the mineralogical makeup of aggregate particles vary with gradation, it can be expected that the use of different gradations may impact the strength of correlation between the two test procedures. Therefore, as a part of this study selected aggregates were tested using a modified MD test procedure that utilized the same gradation as the MSS test.

Table 4.7. Micro-Deval Test Results with Aggregates Soaked for 24 Hours Prior to Testing.

Serial number	District	Material type	Producer	Pit	24hr Soaking MD loss (%)	Regular MD loss (%)	MSS loss (%)
1	Waco	Limestone	Vulcan Materials	Tehucan	20.13	19.79	7.67
2	San Antonio	Limestone	Sunbelt Materials	New Braunfels	14.69	14.46	6.65
3	San Antonio	Limestone	Vulcan Materials	Helotes	15.03	14.97	5.39
4	San Antonio	Limestone	Vulcan Materials	C. R.Geronimo	19.56	19.28	9.53
5	Wichita Falls	Limestone	J. R Thompson, Inc.	Nunnley	36.48	33.17	63.90
6	Abilene	Limestone	Vulcan Materials	Black	21.86	20.70	38.50
7	El Paso	Igneous	Jobe Concrete	Vado	10.23	9.47	2.50
8	Pharr	Gravel	Valley Caliche Products	Beck	9.50	6.93	11.40

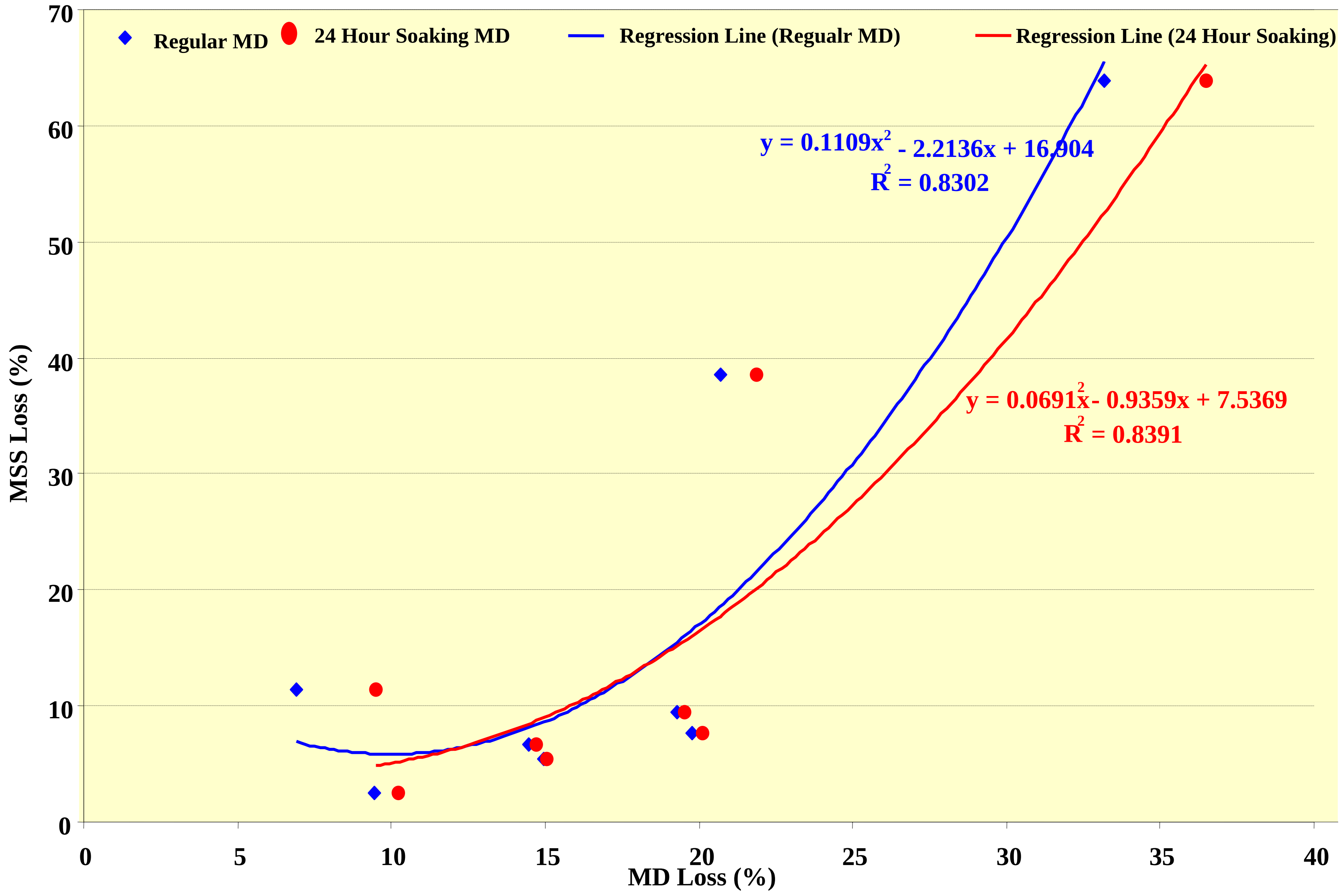


Figure 4.4. Comparative Analyses of Standard Micro-Deval and 24 Hour Soaking Micro-Deval Test.

Table 4.8. Micro-Deval Test Results after Boiling the Aggregates for Two Hours.

Serial number	District	Material type	Producer	Pit	Boiling MD loss (%)	Regular MD loss (%)	MSS loss (%)
1	Waco	Limestone	Vulcan Materials	Tehucana	20.22	19.79	7.67
2	San Antonio	Limestone	Sunbelt Materials	New Braunfels	15.06	14.46	6.65
3	San Antonio	Limestone	Vulcan Materials	Helotes	15.07	14.97	5.39
4	San Antonio	Limestone	Vulcan Materials	C.R. Geronimo	19.78	19.28	9.53
5	Wichita Falls	Limestone	J. R. Thompson, Inc.	Nunnlley	37.09	33.20	63.90
6	Abilene	Limestone	Vulcan Materials	Black	22.19	20.70	38.50
7	El Paso	Igneous	Jobe Concrete	Vado	11.10	9.47	2.50
8	Pharr	Gravel	Valley Caliche Products	Beck	9.80	6.93	11.40

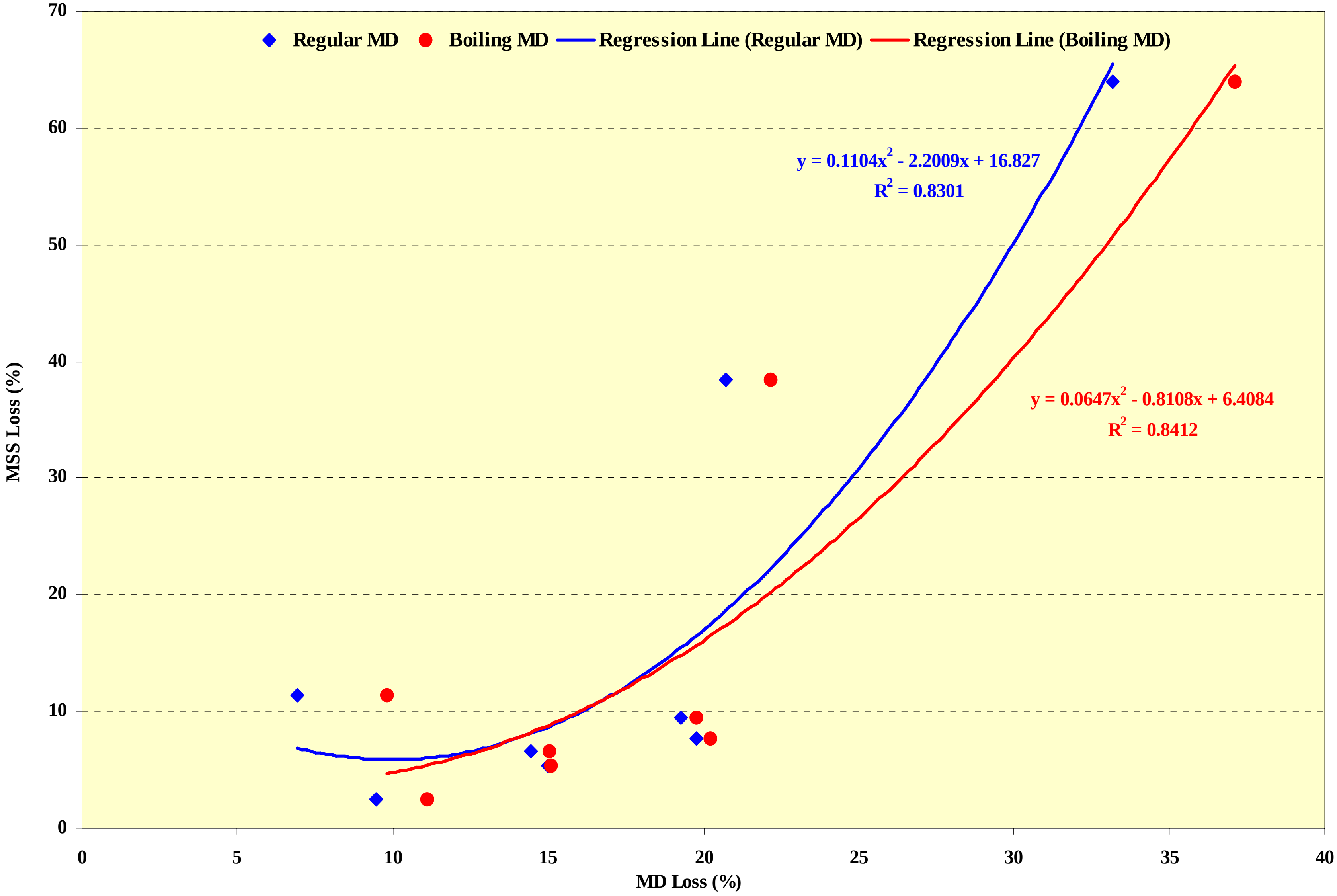


Figure 4.5. Comparative Analyses of Standard Micro-Deval and Boiling Micro-Deval Test.

In the standard Micro-Deval test, the gradation of aggregates used for the test depends on the maximum nominal size of the aggregates. The MSS uses a fixed gradation of aggregates while testing aggregates for hot mix asphalt concrete, and it does not depend on the maximum nominal size of the aggregates used. In the modified Micro-Deval test performed by Texas Tech University, the original gradation of the standard Micro-Deval test was replaced with the gradation of the MSS test. In the Micro-Deval test a total of 1500 grams of aggregates are used as listed in Table 4.9, while in the MSS test a total of 1400 grams of aggregates are used as listed in Table 4.1.

Table 4.9. Gradation Used for Micro-Deval Test.

Size range	Weight used	Percentage used
No. 8 to No. 4	107 ± 5 grams	7.14%
No. 4 to 1/4 in.	129 ± 5 grams	8.57%
1/4 in. to 3/8 in.	193 ± 5 grams	12.85%
3/8 in. to 1/2 in.	1071 ± 10 grams	71.42%
Total	1500 grams	100 %

In the modified Micro-Deval tests, the total quantities of aggregates used were not changed. However, the size fraction of aggregates was kept in the same ratio as in the MSS test. Using the above size fraction, 12 Micro-Deval tests were performed. The percentage losses of aggregate were then recorded. The test results are shown in Table 4.10.

Following this, a scatter graph was developed with Micro-Deval loss values and MSS loss values in the X and Y axes, respectively. Next, second order polynomial regression lines were plotted for both parameters one with regular Micro-Deval test values and one with Micro-Deval test values using MSS gradation. The regression line for regular Micro-Deval had an R^2 value of 0.44. The regression line plotted with the values of the Micro-Deval test performed after boiling the aggregates, shows the R^2 value increased to 0.55. The plot is shown as Figure 4.6.

Table 4.10. Micro-Deval Test Results Using Magnesium Sulfate Soundness Gradation.

Serial number	District	Material type	Producer	Pit	MSS gradation MD loss (%)	Regular MD loss (%)	MSS loss (%)
1	Waco	Limestone	Vulcan Materials	Tehucana	**20.39**	**19.79**	**7.67**
2	San Antonio	Limestone	Sunbelt Materials	New Braunfels	**16.03**	**14.46**	**6.65**
3	San Antonio	Limestone	Vulcan Materials	Helotes	**16.14**	**14.97**	**5.39**
4	San Antonio	Limestone	Vulcan Materials	C. R. Geronimo	**20.54**	**19.28**	**9.53**
5	Laredo	Gravel	Wright Brothers	Realitos	**1.92**	**1.90**	**1.20**
6	Atlanta	Gravel	Gifford-Hill	Delight AK	**3.27**	**3.30**	**3.30**
7	Abilene	Limestone	Vulcan materials	Black	**24.01**	**20.70**	**38.50**
8	El Paso	Igneous	Jobe Concrete	Vado	**9.35**	**9.47**	**2.50**
9	Pharr	Gravel	Valley Ccaliche	Beck	**6.93**	**6.93**	**11.40**
10	San Antonio	Limestone	Vulcan Mateirals	Helotes (Sample # 2)	**28.49**	**26.63**	**24.10**
11	El Paso	Igneous	Jobe Concrete	G.R. McKelligon, NM	**13.54**	**10.22**	**14.70**
12	Atlanta	Igneous	Granite Mountain	Sweet Home, AK	**3.93**	**3.70**	**1.90**

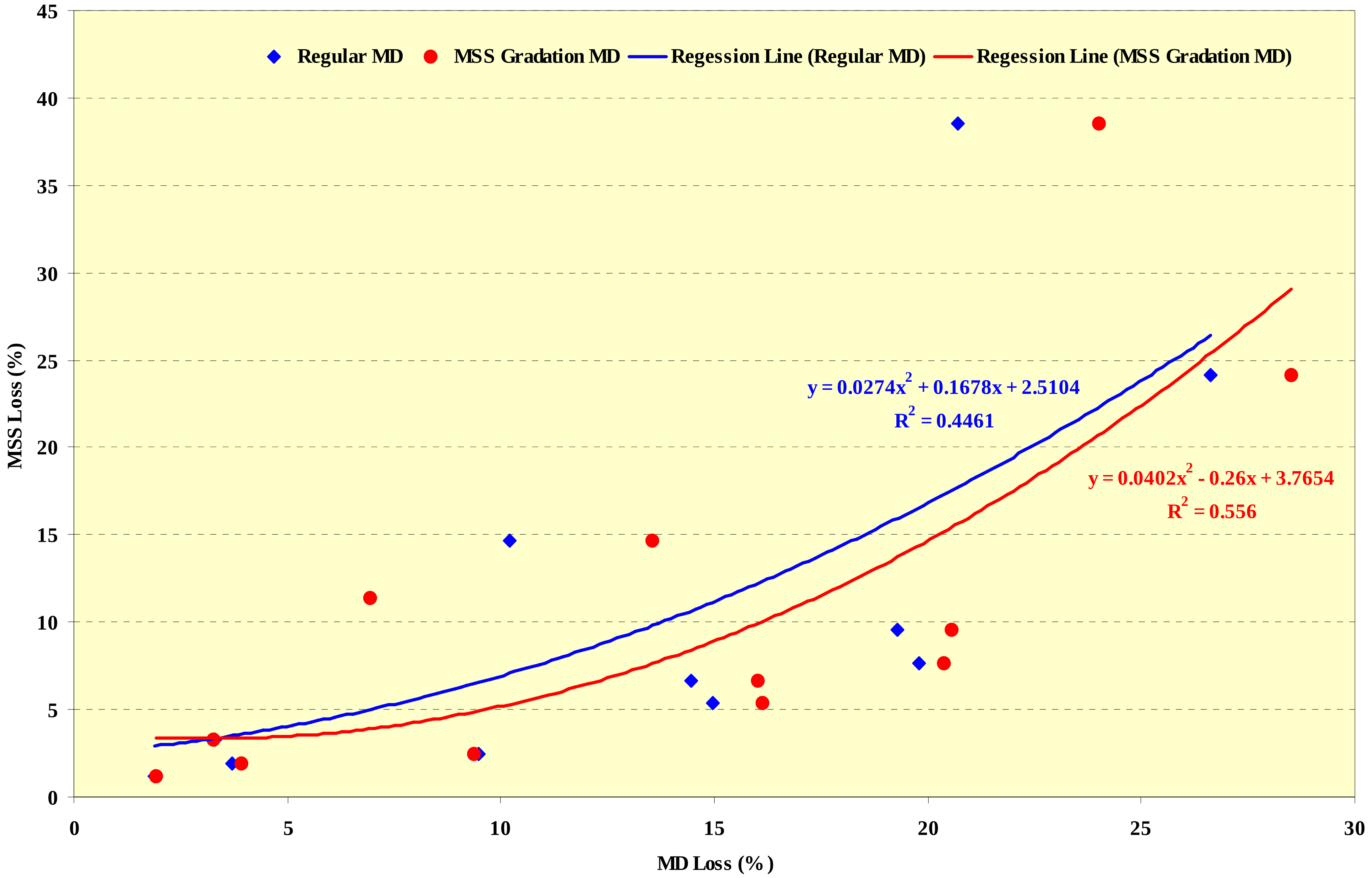


Figure 4.6. Comparative Analyses of Standard Micro-Deval and Micro-Deval Test Using Magnesium Sulfate Soundness Gradation.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

This research was initiated with the objective of evaluating the feasibility of implementing the Micro-Deval test in the Texas Department of Transportation's Aggregate Quality Monitoring Program for bituminous coarse aggregate. In particular, the research investigated the possibility of using this test as a project level quality control tool. In the development of the research plan, it was assumed that the MD test was more likely to be implemented in the AQMP program as a surrogate to the MSS test. In other words, the MSS test that had been an integral part of AQMP for a long time will remain as the primary benchmark for aggregate durability assessment, while the MD test will be used as an indicator test that detects material changes in an aggregate stockpile causing it to fail desired MSS specifications. In order to use the MD test in such a surrogate role, it is necessary that the MD test mimics the MSS test closely. In other words, there should be strong correlation between the two tests.

There were two primary phases in the research project. The first phase involved the review and analysis of existing data that have been compiled by the TxDOT Materials and Tests Labs as a part of the AQMP program. The database included data collected from 169 sources over more than a three year period. The analysis of TxDOT AQMP data examined the strength of the correlation between MD and MSS tests as well as the variability of MD and MSS test parameters over time. The ability of these two test methods to detect changes in material quality with time was quantified in terms of test procedure sensitivity. Regression analyses were also performed on the data obtained from TxDOT so that new Micro-Deval specification limits corresponding to the MSS specification limits can be established. Those aggregate sources that show contradictory behavior in the two test methods (pass one test but fail the other) were identified.

The second phase of the research involved a laboratory study. This laboratory test experimented with alternative variations of the MD test with the primary intent of developing a test procedure that will provide better correlation with the MSS test. These alternative variations included:

- using uniform aggregate gradation identical to that used in the MSS test,
- using increased soaking time (24 hours as opposed to 1 hour), and
- soaking aggregate in boiling temperatures.

It was expected that the modified procedures would be harsher on more absorptive aggregate, and therefore, the resulting correlation with MSS would be better. The following are the important conclusions from this study.

CONCLUSIONS

In many ways, the data obtained and analysis conducted in this research reaffirmed the findings from Project 0-1771 and other previous research studies. Both MD and MSS tests yield higher losses for softer, more absorptive aggregates. However, the correlation between the two test methods remains fair with R^2 values varying within the range 0.70 to 0.80. Different research studies that analyzed different data sets (Project 0-1771, TxDOT AQMP, Ontario Ministry of Transportation, and NCAT) all came up with similar conclusions with respect to the strength of MD-MSS correlation. In the present study, other variations of the MD test were examined with the objective of improving MD-MSS correlation, but these efforts did not lead to any significant improvement in the R^2 value. These alternative variations of the MD test included:

- using identical gradation as in the MSS test,
- increasing the aggregate soaking time to 24 hours, and
- using boiling temperatures during the aggregate soaking cycle.

Although slight improvements in the R^2 value were observed in each case, the data suggested that no dramatic improvement in the strength of the correlation can be expected. All of these observations support the viewpoint that the absence of a strong correlation between the two test methods is largely due to the two fundamentally different degradation mechanisms used in the two tests. The MD test uses the mechanical impact on aggregates that have been soaked in water and, therefore, is similar to the wet ball mill test used by TxDOT for base materials. MSS uses internal pressure from the growth of salt crystals inside aggregate pores to cause degradation. While many aggregates respond similarly in both MD and MSS tests, others perform differently in the two tests. The MSS prediction capability based on MD can be improved if aggregate absorption is incorporated into the predictive model. This model has an R^2 value of about 0.85.

Both MD and MSS test parameters increased with increasing aggregate absorptivity. Between the two test methods, however, the MSS test showed greater sensitivity to aggregate absorption. When MD and MSS test data for aggregate samples recovered from the same source but at different times were compared, it was evident that the variability in MSS test data was significantly higher. This variability represents the cumulative effect of material variability and the variability inherent in the test procedure itself. Therefore, the standard deviation calculated for the above variability was normalized by dividing it with the single lab standard deviation corresponding to the test procedure. This ratio of standard deviations was used as a measure of the "sensitivity" of the test procedure. In other words, the ratio provides an indication of the test method's ability to detect changes in the material when such changes occur. A comparison of "sensitivity" parameters calculated for both MD and MSS tests for all aggregate categories shows that the MD test is a more reliable indicator of changes in material quality than the MSS test.

RECOMMENDATIONS

It is recommended that the Department (TxDOT) continue to use the current test standard for Micro-Deval testing of bituminous coarse aggregates. This recommendation is based on the finding that alternative variations of the MD test procedure (i.e. increased soaking time, increased soaking temperature, use of identical gradation as in the MSS test) did not yield significant improvement of the MD-MSS correlation. At the same time, it must be pointed out that these test results strongly suggest that the differences in the MD and MSS test results are due to fundamental differences in the degradation mechanisms used in the two test methods. Since no revisions to the existing MD test standard are recommended, the development of a new product as the proposed new standard was not necessary. The existing standard test procedure for the Micro-Deval test is included as an appendix in this report for the sake of completeness.

The Department has now taken the first step towards implementing the Micro-Deval test for bituminous aggregate quality control by introducing the test procedure in the Standard Specifications for Construction (2004). In addition, the Department's Guide Schedule for Sampling and Testing (2005) also requires MD testing in addition to MSS testing. The test frequency for the MD test is higher than it is for the MSS test. However, the current Standard Standards still do not specify any Micro-Deval cutoff values for the acceptance and rejection of bituminous coarse aggregate. Instead, it requires the Micro-Deval test to be performed as an indicator test to alert the engineer of the need for further evaluation of the aggregate's durability. In other words, a stockpile with high MD-loss can only be rejected after a MSS-test had been performed and the poor durability of the aggregate sample had been verified through the MSS-test. Unfortunately, information gathered from TxDOT engineers throughout the state, indicate that the quality control process is rarely implemented because hot mix production generally occurs at such high rates that it is not feasible to suspend production until the aggregate durability has been verified through necessary MSS testing. Thus it appears that the current quality control procedure that utilizes MD-Test as an indicator test is not achieving its intended objective. Therefore, it is recommended that the department introduce Micro-Deval specification limits in addition to those based on Magnesium Soundness limits.

The selection of appropriate MD-loss cutoff values may be done at several different levels:

(a) For those aggregates that do not have sufficient MSS and MD time history, select MD cutoff values based on the general MSS-MD correlations shown in Figures 3.1 through 3.3. Accordingly, a MD cutoff value of 22% would correspond to MSS value of 20%, MD value of 26% to MSS value of 25% and MD value of 29% to MSS value of 30%. There is one drawback in this approach. It results from the lack of a tight correlation between MSS and MD test data. Because of this, there is a chance that an aggregate stockpile that fails the MD requirement may pass the MSS requirement. For example, if you review the MD and MSS data for the 159 aggregate sources listed in Table 3.1, there are 20 sources that fail MD-loss≤22.0% requirement. Out of these 20 sources, 15 fail the corresponding MSS-loss≤20.0% (i.e. MSS agrees with MD); but the remaining 5 pass the MSS requirement (i.e. MSS does not agree with MD). Since the MSS-test has been used by TxDOT as the reference for many years, this could potentially be viewed as contradictory results. However, this need not be a barrier for implementation because the District can set their own limit by using the "as shown in plans" provision.

(b) For those aggregates that have sufficient MSS and MD time history as a result of parallel MD, MSS testing conducted in recent years, an appropriate source-specific MD cutoff value can be selected based on the MSS-MD correlations that could be developed for that specific source. The procedure recommended here can be illustrated using MD and MSS data for the Younsport/O'dell Geer Source (See Figure 3.4). If a district wishes to use this source in a roadway construction project where a MSS limit of 25% is desired, a MD cutoff value of 23% can be implemented for project level testing. For sources that do not provide a tight MD-MSS correlation, sufficient tolerance can be allowed to make sure that the contractor in not unduly penalized. If suitable cut-off values based on MD test are introduced in the specifications and stockpile acceptance/rejection based on the MD-test is allowed, then TxDOT engineers will be able to take advantage of the quick turn around and good repeatability of the MD test to achieve better project level quality control.

(c) Both (a) and (b) above try to achieve better project level quality control by using MD-test as a surrogate to the MSS-test. This approach has two major drawbacks. First, as this research and many other previous research studies have shown, a strong correlation between MSS and MD-test data does not exist. Therefore, development of specifications solely based on the MSS test and then using the MD test as a secondary project level test to check whether the aggregate stockpiles meet the MSS test specification will have limited success. Secondly, there have been no studies that have proven that the MSS test data correlate well with aggregate durability performance in the field. To the contrary, there are many examples of pavement construction projects where low MSS aggregates have performed poorly and high MSS aggregate have performed well. Therefore, it is recommended that the Department take necessary steps to move away from using the MSS-test as a reference. Instead, MD and MSS tests should be considered as two test procedures that evaluate different aspects of aggregate durability. Accordingly, specification limits should be introduced based on both test methods. Aggregates may be categorized into Class I, II, and III based on durability considerations very much the same way they are divided into Classes A, B, C and D for skid resistance considerations. Appropriate limits for aggregate class must be determined based on actual field performance. Project level aggregate quality control, however, will be achieved based on the MD test only.

In order to accomplish the eventual goal of implementing aggregate specifications based on both MD and MSS tests, as a first step, it is necessary to determine how the MD and MSS tests relate to actual field durability performance. Therefore, it is recommended that the department initiate a field monitoring program that observe and document the performance of aggregate with high/medium/low MSS aggregates and high/medium/low MD aggregates. The performance of aggregates with contradictory MD-MSS data (i.e. high MD/low MSS aggregates and low MD/high MSS aggregates) will be of special interest in such a study. Aggregate sources that plot in the second and fourth quadrants (i.e. the two quadrants that are shaded) in Figures 3.1 through 3.3 will be good candidates. Once a sufficiently large database has been developed, the information can be used to separate aggregates with excellent, good, fair and poor durability performance and to identify appropriate MD and MSS limits for separating each category.

REFERENCES

1. Rogers, C.A., Bailey, M.L. and Price, B. "Micro-Deval Test for Evaluating the Quality of Fine Aggregate for Concrete and Asphalt." Transportation Research Record 1301, 1991, pp. 68-76.

2. Senior, S.A., and Rogers, C.A. "Laboratory Tests for Predicting Coarse Aggregate Performance in Ontario." Transportation Research Record 1301, 1991,pp. 97-106.

3. Rogers, Chris "Canadian Experience with the Micro-Deval Test for Aggregates" Latham, J.P. (ed.), Advances in Aggregates and Armourstone Evaluation, Geological Society, London, Engineering Geology Special Publication, 13, 1998, pp. 139-147.

4. Ministry of Transportation, Laboratory Testing Manual, Test Method LS-609, Procedure for the Petrographic Analysis of Coarse Aggregate, Ontario, Canada,1996.

5. Ministry of Transportation, Laboratory Testing Manual, Test Method LS-618, Method of Testing for the Resistance of Coarse Aggregate to Degradation by Abrasion in the Micro-Deval Apparatus. Ontario, Canada, 1997.

6. Kandhal, Prithvi S., and Parker Jr. Frazier, Aggregate Test Related to Asphalt Concrete Performance in Pavements NCHRP Report 405, National Center for Asphalt Technology, Auburn University, Auburn, Alabama, 1998.

7. Cooley, L., Jr.,.Huner, M.S., James, R.H. Micro Deval Testing of Aggregates in the Southeast NCAT Report No. 2002-09, 2002.

8. Phillips, F., Jayawickrama, P.W., Hossain, M.D. and Lehman, T.M. Comparative Analysis of Micro-Deval and Magnesium Sulfate Soundness Tests Project 0-1771Texas Department of Transportation , Austin, Texas, 2000.

APPENDIX
TEX-461-A, DEGRADATION OF COARSE AGGREGATE BY MICRO-DEVAL ABRASION

Use this test method to test coarse aggregate for resistance to abrasion and weathering using the Micro-deval apparatus.

Units of Measurement

The values given in parentheses (if provided) are not standard and may not be exact mathematical conversions. Use each system of units separately. Combining values from the two systems may result in nonconformance with the standard.

The following term is referenced in this test procedure.

Constant weight. Constant weight is defined as aggregates other than limestone rock asphalt are dried at a temperature of 230 ±9°F (110 ±5°C) to a condition such that they will not lose more than 0.1% moisture after 2 hr. of drying. Limestone rock asphalt samples will be dried at a temperature of 140 ±5°F (60 ±3°C) to a condition such that they will not lose more than 0.1% moisture after 2 hr. of drying. Such a condition of dryness can be verified by weighing the sample before and after successive 2-hr. drying periods. In lieu of such determination, samples may be considered to have reached constant weight when they have dried at a temperature of 230 ±9°F (110 ±5°C) for an equal or longer period than that previously found adequate for producing the desired constant condition under equal or heavier loading conditions of the oven.

Apparatus

Use the following apparatus:

Micro-deval Abrasion machine and accessories that meet department specification No. 845-49-40

Standard U.S. sieves and pans, meeting the requirements of "Tex-907-K, Verifying the Accuracy of Wire Cloth Sieves," including:

- 3/4 in. (19.0 mm)
- 1/2 in. (12.5 mm)
- 3/8 in. (9.5 mm)
- 1/4 in. (6.3 mm)
- No. 4 (4.75 mm).

Oven, capable of maintaining a temperature of 230 ±9°F (110 ±5°C)

Balance, accurate and readable to 0.1 g or 0.1% of the mass of the test sample, whichever is greater.

Preparing Sample

Wash and dry the test sample to constant weight. Separate the sample into individual size fractions according to "Tex 401-A, Sieve Analysis of Fine and Coarse Aggregate," and recombine to meet the grading as shown. Dry limestone rock asphalt to constant weight at 140 ±9°F (60 ±5°C).

For bituminous aggregate, use the following standard gradation:

Bituminous Aggregate

Passing	Retained	Wt. (g)
1/2 in. (12.5 mm)	3/8 in. (9.5 mm)	750 ±5
3/8 in. (9.5 mm)	1/4 in. (6.3 mm)	375 ±5
1/4 in. (6.3 mm)	No. 4 (4.75 mm)	375 ±5

For concrete aggregate, use the following standard gradation

Concrete Aggregate

Passing	Retained	Wt. (g)
3/4 in. (19.0 mm)	1/2 in. (12.5 mm)	660 ±5
1/2 in. (12.5 mm)	3/8 in. (9.5 mm)	330 ±5
3/8 in. (9.5 mm)	1/4 in. (6.3 mm)	330 ±5
1/4 in. (6.3 mm)	No. 4 (4.75 mm)	180 ±5

Procedure

The following table outlines the procedure for testing coarse aggregate for resistance to abrasion and weathering using the Micro-deval apparatus.

Testing Coarse Aggregate

Step	Action
1	♦ Prepare a representative 1500 ±5 g sample according to the applicable standard grading. A maximum of 10% of an adjacent size material from the standard grading may be substituted if the sample does not contain appropriate weights. Crush parent material to obtain sizes if necessary. ♦ Record the weight to the nearest 1.0 g, as 'A' under 'Calculations.'
2	♦ Saturate the sample in 0.5 gal. (2000 ±500 mL) of tap water (temperature 68 ±9°F [20 ±5°C]) for a minimum of 1 hr. either in the Micro-deval container or in another suitable container.
3	♦ Place the sample, water, and 5000 ±5 g of stainless steel balls in the Micro-deval container. ♦ Place the Micro-Deval container on the machine.
4	♦ Set the timer and start the machine. ♦ Test concrete aggregate samples at 100 ±5 rpm for 120 ±1 min. ♦ Test bituminous aggregate samples at 100 ±5 rpm for 105 ±1 min. ♦ Record the rpms registered by the tachometer at the end of the test period.
5	♦ Stack a No. 4 (4.75 mm) and a No. 16 (1.18 mm) sieve together and carefully decant the sample over them. Take care to remove the entire sample from the stainless steel jar. ♦ Wash the retained material with water until the wash water is clear and all materials smaller than No. 16 (1.18 mm) pass the sieve.

6

- Remove the stainless steel balls using a magnet or other suitable means.
- Discard material passing the No. 16 (1.18 mm) sieve.

7

- Oven-dry the sample to constant weight at 230 ±9°F (110 ±5°C).
- Oven-dry limestone rock asphalt to constant weight at 140 ±9°F (60 ±5°C).

8

- Weigh the sample to the nearest 1.0 g.
- Record the oven-dry weight as 'B' under 'Calculations.'

Calculations

Calculate the Micro-deval abrasion loss as follows:

$Percent\ loss = (A - B)/A \times 100$

Record to the nearest whole percentage point.