CIVIL ENGINEERING STUDIES
Illinois Center for Transportation Series No. 09-055
UILU-ENG-2009-2036
ISSN: 0197-9191

EXPANSIVE CHARACTERISTICS OF RECLAIMED ASPHALT PAVEMENT (RAP) USED AS BASE MATERIALS

Prepared By
Derya Deniz
Erol Tutumluer
John S. Popovics
University of Illinois at Urbana-Champaign

Research Report ICT-09-055

A report of the findings of

ICT-R27-27
Expansive Characteristics of Reclaimed Asphalt Pavement (RAP) Used As Base Materials
Illinois Center for Transportation

August 2009

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-ICT-09-055		

4. Title and Subtitle	5. Report Date
Expansive Characteristics of Reclaimed Asphalt Pavement (RAP) Used As Base Materials	August 2009
	6. Performing Organization Code
7. Author(s) Derya Deniz, Erol Tutumluer and John S. Popovics	8. Performing Organization Report No. ICT-09-055 UILU-ENG-2009-2036
9. Performing Organization Name and Address Illinois Center for Transportation University of Illinois at Urbana Champaign 205 North Mathews Ave. – MC 250 Urbana, Illinois 61801	10. Work Unit (TRAIS)
	11. Contract or Grant No.
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address Illinois Department of Transportation Bureau of Materials and Physical Research 126 East Ash Street Springfield, Illinois 62704	
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Reclaimed asphalt pavement (RAP) is the reprocessed hot-mix asphalt (HMA) pavement material containing asphalt and aggregates. A viable solution for deposing of large quantities of RAP is to incorporate them into base and subbase applications for highway construction. However, RAP materials may contain an expansive aggregate, such as steel slag, that is not allowed in pavement substructure layers in Illinois. Steel slag aggregates are particularly useful in areas where high frictional properties are required, such as HMA surface courses, yet, they may contain free lime and magnesia that may cause the slag to expand when reacted with water. The overall objective of this research project was to determine the expansive properties for RAP materials, especially the materials including recycled steel slag aggregates, with respect to those of the virgin aggregates, and evaluate their potential use as pavement base materials in Illinois. Seventeen RAP materials and virgin aggregates were tested for their expansive characteristics in the laboratory following the ASTM D4792 "Potential Expansion of Aggregates from Hydration Reactions" test method. The specimens in California Bearing Ratio (CBR) test molds were submerged into a high alkali cement water solution (pH of 12) and kept constantly soaked at 70°C to accelerate hydration reactions. The expansion percentage of the CBR specimens and the temperature and pH levels of the solution were measured continuously on a daily basis during the soaking period for a minimum of 7 days and maximum 60 days until the expansion curve flattened or the expansion rate slowed down. Some steel slag aggregates showed considerably high expansion potentials, up to 6.2% swell, due to the hydration of free lime when compared to other virgin aggregates, such as siliceous gravel and crushed dolomite, which had minor or almost no expansion. The RAP materials, which often had lower densities, exhibited more of an initial settlement or contraction before any kind of expansion with time. Two RAP materials, surface RAP with 92% steel slag aggregates and steel slag RAP, gave the maximum expansion amounts 1.69% and 1.46%, respectively. When compared to the high expansion potentials of especially the virgin steel slag aggregates, the RAP materials had much lower tendencies to expand most likely due to an effective asphalt coating around the aggregate which prevents any significant ingress of water into the aggregate.

17. Key Words	18. Distribution Statement
	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

Form DOT F 1700.7 (8-72)　　Reproduction of completed page authorized

ACKNOWLEDGMENT, DISCLAIMER, AND MANUFACTURERS' NAMES

This publication is based on the results of R27-27, Expansive Characteristics of Reclaimed Asphalt Pavement Used as Base Materials. R27-27 was conducted in cooperation with the Illinois Center for Transportation; the Illinois Department of Transportation; and the U.S. Department of Transportation, Federal Highway Administration.

Members of the Technical Review Panel are the following:

Sheila A. Beshears, Chair
Matthew W. Mueller
Mel H. Kirchler
Kurt W. Schmuck
Phil R. Headley
Abdul Z. Dahhan
Sharon L. Haasis

The contents of this report reflect the view 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 views or policies of the Illinois Center for Transportation, the Illinois Department of Transportation, or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

Trademark or manufacturers' names appear in this report only because they are considered essential to the object of this document and do not constitute an endorsement of product by the Federal Highway Administration, the Illinois Department of Transportation, or the Illinois Center for Transportation.

EXECUTIVE SUMMARY

Reclaimed asphalt pavement (RAP) is the reprocessed hot-mix asphalt (HMA) pavement material containing asphalt and aggregates. A viable solution for using large quantities of RAP is to incorporate them into base and subbase applications for highway construction. However, RAP materials may contain an expansive aggregate, such as steel slag, that is not allowed for use in the pavement substructure layers in Illinois. Steel slag aggregates are particularly useful in areas where high frictional properties are required, such as HMA surface courses, yet, they may contain free lime and magnesia that may cause the slag to be expansive when reacted with water. The overall objective of this research project was to determine the expansive properties of RAP materials, especially those including recycled steel slag aggregates, with respect to those of the virgin aggregates, and evaluate their potential use as pavement base materials in Illinois. Seventeen RAP materials and virgin aggregates were tested for their expansive characteristics in the laboratory following the ASTM D4792 "Potential Expansion of Aggregates from Hydration Reactions" test method. The specimens in California Bearing Ratio (CBR) test molds were submerged into a high alkali cement water solution (pH of 12) and kept constantly soaked at 70°C to accelerate hydration reactions. The percentage of expansion of the CBR specimens and the temperature and pH levels of the solution were measured continuously on a daily basis during the soaking period for a minimum of 7 days and maximum of 60 days until the expansion curve flattened or the expansion rate slowed down. Some steel slag aggregates showed considerably high expansion potentials, up to 6.2% swell, due to the hydration of free lime when compared to other virgin aggregates, such as siliceous gravel and crushed dolomite, which had minor or almost no expansion. The RAP materials, which often had lower densities, exhibited more of an initial settlement or contraction before any kind of expansion with time. Two RAP materials, surface RAP with 92% steel slag aggregates and steel slag RAP, gave the maximum expansion amounts 1.69% and 1.46%, respectively. When compared to the high expansion potentials of especially the virgin steel slag aggregates, the RAP materials had much lower tendencies to expand most likely due to an effective asphalt coating around the aggregate which prevents any significant ingress of water into the aggregate.

TABLE OF CONTENTS

CHAPTER 1 INTRODUCTION

1.1 OVERVIEW AND PROBLEM STATEMENT

The use of recycled materials in pavements has become an increasingly widespread practice in recent years. This is especially true for hot-mix asphalt (HMA) and Portland cement concrete (PCC) materials that are milled off the existing road surfaces and recycled for reuse in pavement construction. A viable solution for deposing of these recycled materials is to incorporate them into base and subbase applications for highway construction. Potential savings in construction cost and time have made the use of such recycled HMA and PCC aggregates an attractive alternative to the highway engineer. This practice has been studied by several researchers as well as many state highway agencies (e.g. O'Mahony et al., 1991; Senior et al., 1994; Hudson et al., 1996; Cross et al., 1996; Garg and Thompson 1996; Maher et al., 1997; Simon, 1997; Taha et al., 1999; Bennert et al., 2000; Chini et al., 2001; Taha et al., 2002). Local recycling of construction and demolition debris has also been increasing at an elevated rate.

Most of the recycled materials have been tested with varying degrees of success. However, one of the most promising is the use of iron and steel slag because it is available, economical, and has some excellent aggregate properties. Steel slag, *a by-product of steel making,* has been available as an aggregate in granular base, embankments, engineered fill, highway shoulders, and hot mix asphalt pavement since the 1970s. It is estimated that approximately 7.7 to 8.3 million tons of steel slag are used each year in the U.S. (FHWA Turner Fairbank Highway Research Center). While most of the furnace slag is recycled for use as steel slag aggregate (SSA), excess steel slag from other operations (raker, ladle, clean out, or pit slag) is usually sent to landfills for disposal.

Steel slag consisting of calcium carbonate is broken down to smaller sizes to be used as aggregates in pavement asphalt concrete and base layers. These aggregates are particularly useful in areas where high frictional properties are required, such as HMA surface courses, and good-quality aggregate is scarce. However, steel slag may contain free lime and magnesia, CaO and MgO, that may cause the slag to be expansive when reacted with water. Therefore, steel slag is not generally recommended for use in rigid confined applications.

Reclaimed asphalt pavement (RAP) is the reprocessed HMA pavement material containing asphalt and aggregates. RAP can be obtained from central RAP processing facilities where asphalt pavements are crushed, screened, and stockpiled. Processed RAP consists of high quality, well-graded aggregates coated by asphalt cement. Currently, the use of RAP is not allowed in the pavement substructure layers according to Illinois Department of Transportation (IDOT) specifications. Whether or not this is a major concern for Illinois will need to be decided by first successfully identifying the expansive nature of RAP sources statewide and secondly by establishing guidelines for blending recycled and virgin aggregates for the pavement substructure use. This research project therefore aims to evaluate the steel slag commonly found in RAP materials in Illinois.

1.2 RESEARCH OBJECTIVES

The main objective of this research project is to determine the expansive properties for RAP materials, especially the materials including recycled steel slag aggregates that may be used as pavement base materials in Illinois. Additional objectives are to determine a test method for the expansion of RAP aggregate, the maximum acceptable level of expansion for different RAP aggregate types, properties and blending proportions with virgin aggregates, and the effects that RAP materials may have on pavement performance. The objectives are achieved by linking the pavement performance to the characteristics of unbound layers that are in turn linked to individual aggregate types and properties, i.e., chemical, mineralogical, mechanical, and physical properties, as found in RAP.

1.3 RESEARCH METHODOLOGY

The methodology adopted in this research uses laboratory testing to evaluate the differences in expansion characteristics between recycled and virgin aggregates that would affect the laboratory testing conditions and pavement performance. The following tasks were performed to attain the study's goals:

Task 1: Work with the IDOT Bureau of Materials and Physical Research (BMPR) and the district engineers to gather the types, sources, and properties of recycled materials for use in pavement base/subbase courses in Illinois. Categorize various locally available RAP sources and identify/select the specific RAP materials to be studied in the project for expansive characteristics.

Task 2: Review literature on the pavement base/subbase use of RAP materials, previous research study findings, performance records, and other recent state DOT practices and field experiences. The main focus will be on the volumetric instability and expansive characteristics possibly due to steel slag and/or other materials. Successes, failures, lessons learned, and certain restrictions identified on the use of RAP in the pavement substructure will be compiled.

Task 3: Test both selected RAP materials and related virgin aggregates received from IDOT BMPR and the various Districts in Task 1 for expansion potential in accordance with ASTM D4792-00, "Potential Expansion of Aggregates from Hydration Reactions." The ASTM D4792-00 test method covers the determination of potential volume expansion of densely graded compacted aggregates that contain components susceptible to hydration and consequent volume increase, such as free calcium and magnesium oxides that occur in steel slag and other materials. This test method consists of measuring the volume expansion of compacted specimens following the general procedures of ASTM D1883, the California Bearing Ratio (CBR) test procedure. Compaction is based on maximum density determination using ASTM D698, the standard Proctor test procedure. To accelerate the hydration reaction, specimens are stored in water at 70 ± 3^{o}C (158 ± 5^{o}F) for a minimum of 7 days.

Task 4: After conducting ASTM D4792 tests on the selected IDOT RAP materials, if unsuitably high expansion characteristics are determined that would raise concerns about pavement performance, conduct additional petrographic and chemical analyses. The main purpose of petrographic analysis is to determine mineralogical composition for the types and percentages of minerals in the rock and the microscopic texture, i.e., grain size, grain shape, mineral orientation, grain distribution, boundary relations, degree of alteration, and deformation.

Task 5: Develop a RAP source and material property database based on the expansive characteristics determined from the ASTM D4792 test results to be related to the petrographic and chemical analyses results and the properties of the RAP materials studied. Such an informational database will be useful to efficiently utilize the desired sources of RAP in the State of Illinois. In addition, any criteria applicable to unbound uses of RAP materials such as the maximum acceptable level of expansion for these products, guidelines on blending with virgin aggregates, and the effects that expansive materials may have on pavement performance can be addressed by conveniently referencing such a database.

Task 6: Prepare a final report to include all the research task findings for facilitating practical use of the research results to identify potentially expansive RAP materials.

The intent of this study has been to provide insight into expansion characteristics of RAP materials to be utilized in highway construction in the state of Illinois. The end users will be the IDOT Districts and also project contractors. The expected results are a test method for expansion of RAP materials and a maximum acceptable level of expansion which results in minimal adverse effects to the pavement structure. The findings will offer the opportunity to develop improved specifications and blending guidelines with virgin aggregates that will accommodate the right RAP material for the construction job. The major benefits of optimized RAP selection, resource utilization, and construction cost reductions can be realized in this way.

1.4 REPORT ORGANIZATION

Chapter 2 of this report reviews previous research on RAP and steel slag aggregates used as granular base unbound pavement layer materials. The origins and properties of steel slag aggregates are discussed with examples of their expansion tendencies due to free calcium and magnesium oxides. Steel slag aggregates are also compared with other aggregates for their inherent property variability and suitability for use as pavement granular base. Chapter 3 describes the types and properties of the virgin aggregates and RAP materials selected for testing and the details of the ASTM 4792 test method used for determining in the laboratory expansion characteristics. Chapter 4 presents all the expansion test results detailing the measured material properties and the significant percent expansion values obtained for steel slag aggregates and certain RAP materials. Chapter 4 also presents ASTM criteria for making recommendations on the use of steel slag aggregates and RAP materials in base/subbase layers of constructed pavements. Finally, Chapter 5 summarizes the major findings of the research study and makes recommendations for future research.

CHAPTER 2 PREVIOUS RESEARCH ON RAP AND STEEL SLAG AGGREGATES USED AS GRANULAR BASE

2.1 USE OF RAP AS A GRANULAR BASE MATERIAL

Because a principal constituent of RAP is its mineral aggregates, the overall chemical composition of RAP is similar to that of the mineral aggregates. Asphalt cements only constitute a minor percentage of RAP. The principal elements in asphalt cement molecules are carbon and hydrogen. Concentration of other materials such as sulfur, nitrogen, and oxygen are usually present in very small amounts. Asphalt cements are made up of asphaltenes, resins, and oils. Upon oxidation, the oils convert to resins and asphaltenes where the resins convert to asphaltene type molecules, resulting in age hardening and a higher viscosity binder (Roberts et al., 1996). This change in the chemical composition would influence the unbound layer stiffness and shear strength, and consequently, its performance parameters such as rutting and fatigue cracking.

RAP can be used as granular base or subbase material in pavement structures (e.g., Garg and Thompson, 1996; Maher et al., 1997; Bennert et al., 2000; Chini et al., 2001). Garg and Thompson (1996) conducted a field testing research program to investigate the potential of using RAP as a pavement base. This study demonstrated that the performance of the RAP base was comparable to that of a crushed stone base. A study by Taha et al. (1999) recommended blending granular RAP with virgin aggregates in order to attain the proper bearing strengths since the RAP bearing capacity is usually lower than that of conventional granular aggregate bases. As conventional granular aggregate content increased, dry density and CBR values increased (Taha et al., 1999). Therefore, it is important to characterize and quantify the expected range of RAP properties prior to application.

In addition to the influence of the chemical properties on the unbound layer mechanical properties, RAP has environmental implications with respect to the potential for contamination of ground and surface water systems. The aromatic compound is an organic compound of asphalt cement that has become a great concern since the levels of this aromatic hydrocarbon present in asphalt cement could exceed published soil clean-up standards available in several states. Most binder treatment, required for mechanical reasons, significantly modifies the leaching behavior of a recycled material. A recent study by Hill et al. (2001) has shown that the binder treatment may dilute or amend leachable levels, alter the pH, and reduce the permeability. The addition of alkali binder, however, could introduce some contaminants such as calcium. This study recommended determining optimum binder treatment with regard to type of recycled materials especially when there is a lack of local moisture and performance-related material properties. The environmental impacts to soils or groundwater need to be evaluated when RAP is stockpiled or used as an unbound granular material.

Finally, the degree of expansion for the RAP materials is not well known. Recent experiences with volume changes of up to 10 percent or more have been attributable to hydration of the calcium and magnesium oxides in the recycled steel slag aggregate when water was encountered in the pavement base layer (Collins and Ciesielski, 1994). Depending upon the level of expansion and the material gradation, dense graded aggregate base applications under pavements and structures may have to be avoided.

Since steel slag aggregates (SSA) show a high potential of expansion among recycled materials, more consideration will be given to the description of SSA and the use of SSA in substructure of the pavement in the following sections.

2.2 STEEL SLAG AGGREGATES (SSA)

2.2.1 Origin of Steel Slag Aggregate

Steel slag is a byproduct from either the conversion of iron to steel in a basic oxygen furnace (BOF) or the melting of scrap to make steel in an electric arc furnace (EAF). It is formed through the combination of impurities within the steel by the addition of the fluxing agents into steel-making furnaces (Caijun, 2004). Figure 1 presents an overview of steel slag production in a modern integrated steel plant. Depending on the stage of production, four types of steel slag are produced, i.e., furnace (or tap) slag, raker slag, ladle (or synthetic) slag, and pit (or cleanout) slag. The steel slag produced during the primary stage of steel production is referred to as furnace slag or tap slag. This is the major source of steel slag aggregate. Ladle slag, which contains high amounts of synthetic fluxing agents, is characteristically different than furnace slag and is not generally suitable for processing as steel slag aggregates (Chesner et al., 1998). These different slags must be segregated from furnace slag to avoid contamination of the slag aggregate produced.

The steel slag occurs as a melt and consists of a fused mixture of oxides and silicates, mainly calcium, iron, un-slaked lime and magnesium that solidifies upon cooling. The mineralogical form of the steel slag is highly dependent on the rate of slag cooling in the steel-making process. Table 1 lists the range of compounds present in steel slag from a typical base oxygen furnace determined by x-ray fluorescence or other means (Emery, 1982). Virtually all steel slags fall within these chemical ranges but not all steel slags are suitable as aggregates.

The key for steel slag is the recovery process. The slag from the furnaces is processed to recover all metal to be reused within the manufacturing process. The non-metallic slag which remains can either be sintered and recycled as flux material in the iron and steel furnaces, or crushed and screened for possible aggregate use; this crushed and screened material is called steel slag aggregate.

2.2.2. Properties of Steel Slag Aggregate

Steel slag aggregates are highly angular in shape and have rough surface texture. They have high bulk specific gravity, 3.2 to 3.6, unit weights ranging from 100 to 120 pcf, and moderate water absorption (less than 3 percent). Table 2 lists some typical mechanical properties of steel slag aggregate obtained from basic oxygen furnace (Emery, 1982).

2.2.3 Expansion Tendency of Steel Slag Aggregate

Free calcium and magnesium oxides are not completely consumed in the steel slag, and technical literature generally agrees that the hydration of unslaked lime (CaO) and magnesia (MgO) in contact with moisture is largely responsible for the expansive nature of most steel slags (Collins and Ciesielski, 1994). The free lime hydrates rapidly and can cause large volume changes over a relatively short period of time (weeks), while magnesia hydrates much more slowly and contributes to long-term expansion that may take years to develop. The potential expansion depends on the origin of the slag, grain size and gradation, and the age of the stockpile (Rohde et al., 2003).

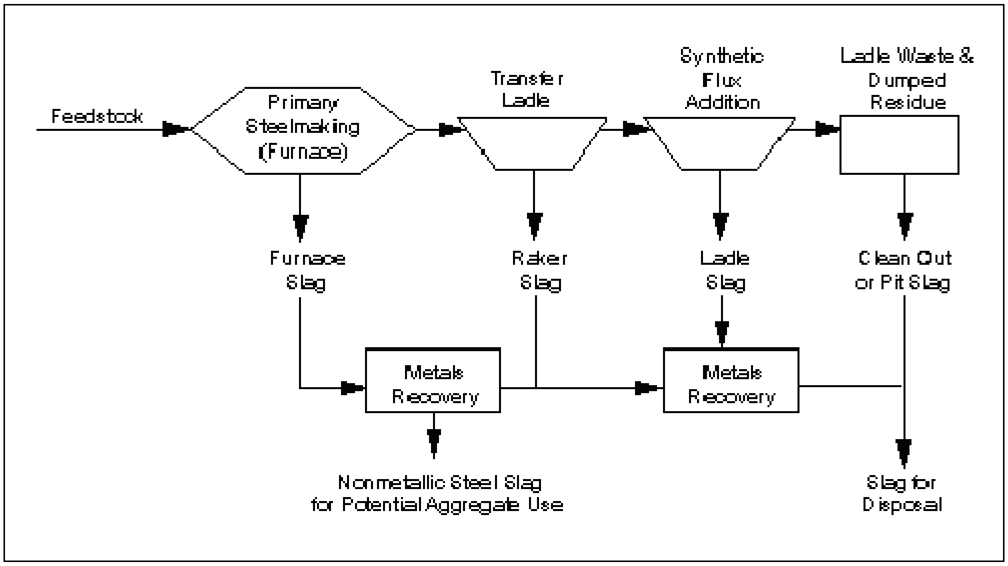


Figure 1. Overview of slag production in modern integrated steel plant (Courtesy of FHWA Turner Fairbank Highway Research Center).

Table 1. Typical Steel Slag Chemical Composition (Emery, 1982)

Constituent	Composition (%)
CaO	40 - 52
SiO_2	10 - 19
FeO	10 - 40 (70 - 80% FeO, 20 - 30% Fe_2O_3)
MnO	5 - 8
MgO	5 - 10
Al_2O_3	1 - 3
P_2O_5	0.5 - 1
S	< 0.1
Metallic Fe	0.5 - 10

Table 2. Typical Mechanical Properties of Steel Slag Aggregate (Emery, 1982)

Property	Value
Los Angeles Abrasion (ASTM C131), %	20 - 25
Sodium Sulfate Soundness Loss (ASTM C88), %	<12
Angle of Internal Friction	40° - 50°
Hardness (measured by Mohr's scale of mineral hardness)*	6 - 7
California Bearing Ratio (CBR), % top size 19 mm (3/4 inch)**	up to 300
Absorption	up to 3%
* Hardness of dolomite measured on same scale is 3 to 4. ** Typical CBR value for crushed limestone is 100%.	

Therefore, steel slag aggregate generally yields difficulties in confined construction applications containing steel slag aggregate due to its expansion tendency.

According to technical literature, this is one reason why steel slag aggregates are not suitable for use in rigid applications.

In the presence of water, the hydrations of free lime (free CaO) and free magnesia (free MgO) make steel slag unstable and liable to expand by the following reactions:

$$\text{free CaO} + H_2O \rightarrow Ca(OH)_2$$

$$\text{free MgO} + H_2O \rightarrow Mg(OH)_2$$

The sources of free lime are a consequence of the slag process when lime is added as a flux. Lime may be added in excess or too late in the process to allow complete assimilation before the taping of slag. The other possibility which exists is some steelmakers add limestone to cool the slag near the end of refining or to produce a more viscous slag that aids in the protection of lining (Saski at al., 1981; British Steel Corporation General Steels Division Research Organization, 1976; Wachsmuth et al. 1981). The source of periclase or MgO in the slag may be from dolomite which is used as a flux or MgO refractory or possibly from the gunning mix used for the protection of the vessel lining (Monaco and Lu, 1996).

Since the hydration of free lime is rapid, it may be locked up within the slag particles and the rate of reaction is significantly reduced. The hydration of free lime in steel slag can be accelerated by several aging methods (Moon et al., 2002). However, the duration of applied aging methods may not be enough to hydrate free MgO since hydration of free MgO takes place over several years. Therefore, failure can be seen after several years if steel slags with inadequate volume stability are used.

2.2.4 Comparison of Steel Slag Aggregate with Crushed Limestone

A study by Maslehuddin et al. (2002) showed that steel slag aggregate had superior mechanical properties when compared to crushed limestone aggregates as listed in Table 3. The water absorption in the steel slag aggregate is less than that of the crushed limestone aggregate. The reduction in the absorption characteristics of steel slag aggregate may be attributed to its impervious nature as compared to the crushed limestone aggregate. Also, the loss on abrasion for crushed limestone aggregate is more than that in the steel slag aggregate. The data presented in Table 3 provide ample evidence of the weak nature of the crushed limestone aggregates compared to steel slag aggregates. Therefore, steel slag aggregate is expected to perform better than the crushed limestone aggregate in terms of improved water absorption, soundness, and abrasion resistance in construction applications.

In general, processed (i.e. crushed) steel slag aggregates are more angular, denser, and harder than comparable natural aggregates. Moreover, steel slag aggregates have high bulk specific gravity and rough surface texture (Kandahl and Hoffman, 1997). Some of these improved shape, texture, and angularity properties make steel slag aggregates sought out especially for use in hot-mix asphalt (HMA) surface friction courses in flexible pavements.

Also, steel slag aggregate has favorable mechanical properties such as good abrasion resistance, good soundness characteristics, and high bearing strength and high elasticity of modulus when compared to limestone aggregate. Therefore, the properties of mechanical strength, stiffness, wear, and water absorption afford an optimistic view of the possibility of using steel slag as a good quality aggregate in bases.

Table 3. Properties of Crushed Limestone and Steel Slag aggregate (Maslehuddin et al., 2002)

Property	Crushed limestone aggregate	Steel slag aggregate
Bulk specific gravity, (Gs)	2.51	3.51
Absorption, %	2.2	0.85
Clay lumps and friable particles, %	0.60	0.067
Magnesium sulfate soundness, %	14.1	0.83
Sodium sulfate soundness, %	1.2	0.35
Chloride, % by weight	0.006	0.006
Sulfate, % by weight	0.20	0.008
pH	–	11.34
Abrasion, %	40.44	18.46

2.2.5 VARIATIONS IN STEEL SLAG AGGREGATE

The physical, chemical, and mineralogical properties of steel slags are typically widely varied. These differences are mainly dependent on:

- steel grade
- the steel-making plant (source)
- specific furnace (BOF or EAF)
- steel slag processing (such as cooling method, crushing, etc.)
- storage conditions

Many grades of steel can be produced, and the properties of the steel slag can change significantly with each grade. For high-grade steels, greater oxygen levels are required in the steel-making process to reduce the high amount of carbon in the steel. This also requires the addition of increased levels of lime and dolime (flux) for the removal of impurities from the steel and increased slag formation according to the recent findings by the FHWA Turner Fairbank Highway Research Center. Hence, increased level of flux causes higher values of volume expansion.

The study by Farrand and Emery (1995) shows that flux and slag practice can significantly affect SSA volume expansion. As seen in Figure 2, Flux Practice A exhibits greater volume expansion as compared with flux practice B since Flux Practice A resulted in slag that was contaminated with lime and dolime. Also, the steel slag aggregate sample obtained from Australia shows very low volume expansion indicating again the effect that slag source can have on the quality of SSA.

Furnace type is another factor that causes variations in chemical and mineralogical properties of steel slag. An Energy Dispersive X-ray Analysis (EDX) study by Bicalho et al. (2008) states that BOF Brazilian steel slag presents a higher content of CaO and MgO compared to Brazillian EAF steel slag, therefore, the BOF steel slag aggregates are expected to have higher values of expansion. It is clear that furnace type has a significant effect on the SSA composition and properties.

Cooling conditions and cooling rate affects the presence and relative amounts of various mineral phases in a given steel slag (Monaco and Lu, 1996; Tossavainen et al., 2006). For example, Ionescu et al. (1998, 2001) clearly indicated how water quenching (one of the cooling methods) of steel slag resulted in products with high contents of glassy material. Also, Lea (1983) noted that the slag passed from a liquid state to a solid without development of a crystalline structure when the cooling was rapid.

The use of steel slag aggregate must be considered on a specific steel-making furnace and processing basis, with recognition of the inherent variability of the slag production and the presence of potentially hydratable free lime and free magnesia. Therefore, slag materials from steel-making facilities must be source separated, and well-defined handling practices must be in place to avoid contamination of the steel slag aggregate. The slag processor must also be aware of the general aggregate requirements of the end user.

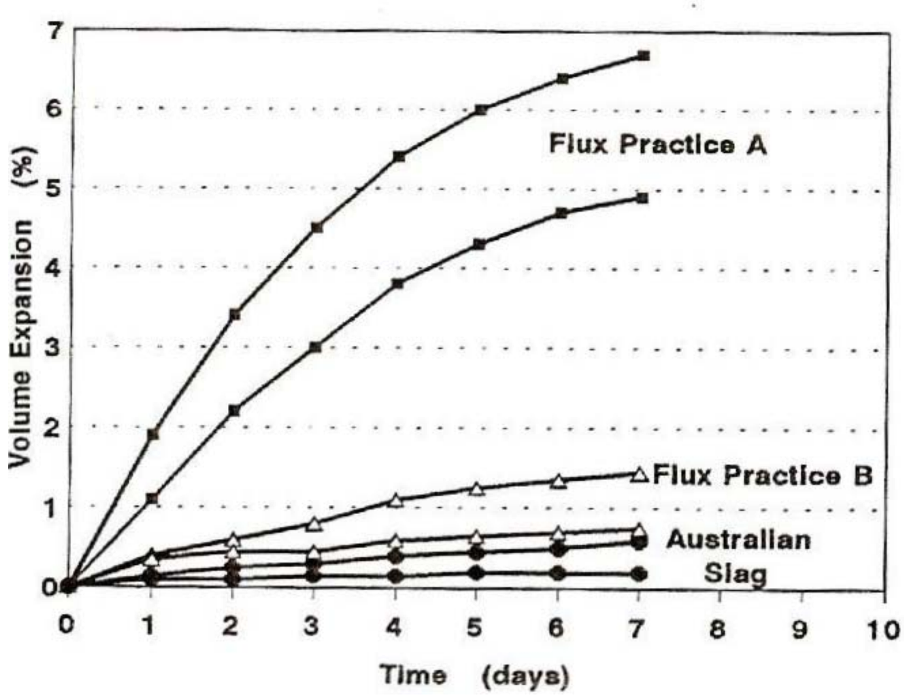


Figure 2. Effect of steelmaking source and flux practice on volume expansion of steel slag aggregates (Farrand and Emery, 1995).

2.3 USE OF STEEL SLAG AGGREGATES AS A BASE MATERIAL

Steel slag aggregates have sufficient material properties including favorable frictional properties, high stability, and good durability with resistance to stripping and rutting to be considered as a good performing base material. On the other hand, steel slag aggregates may contain certain amounts of free calcium and magnesium oxides, which can hydrate leading to rapid short-term and long-term expansion, respectively. If the tendency to expand can be controlled by some stabilization techniques, the use of steel slag aggregates will be beneficial, particularly in the substructure layers of pavements.

From a transportation/pavement engineering perspective:

- Steel slag aggregates have high internal friction angles (40 to 45 degrees) that contribute to high stability and California Bearing Ratio (CBR) values, up to 300 percent.
- Steel slag aggregates in bases can be advantageous for pavements subjected to heavy traffic due to the potentially high bearing capacity. The high stiffness of steel slag aggregate enhances good resistance to rutting due to heavy traffic loading.
- Steel slag aggregates exhibit good interlock and provide improved load transfer to weak subgrades because of the rough texture and angular particle shapes.
- Porous aggregates often tend to break down when absorbed liquids freeze and thaw hence decreasing the strength of the aggregate. Steel slag aggregates show better durability and higher performance against freezing-thawing since they have low water absorption properties, and steel slag aggregates are free draining.
- Steel slag aggregates display strong resistance to effects of weathering and erosion.

Steel slag aggregates may contain free lime and magnesia, CaO or MgO, that may cause the slag to expand when reacted with water. Thus, steel slag is not generally recommended for use in confined applications. The conditioning of the steel slag for its use as an aggregate requires it to be crushed, homogenized, weathered, and aged with an appropriate method to enable the hydration of any existing free lime (CaO) and free magnesia (MgO).

Tufa-like precipitates, which result from the exposure of steel slag aggregates to both water and the atmosphere, have been reported in previous literature (Gupta and Kneller, 1993). Tufa is a white, powdery precipitate that consists primarily of calcium carbonate ($CaCO_3$). It occurs in nature and is usually found in water bodies. The tufa precipitates associated with steel slags are attributed to the leachate combining with atmospheric carbon dioxide. The free lime in steel slags can combine with water to produce calcium hydroxide [$Ca(OH_2)$] solution. Upon exposure to atmospheric carbon dioxide, calcite ($CaCO_3$) is precipitated in the form of surficial tufa and powdery sediment in surface water.

$$CaO + CO_2 \rightarrow CaCO_3$$

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

Tufa precipitates have been reported to clog drainage paths in pavement systems creating water retention and soft-pavement conditions (Gupta and Kneller, 1993). Furthermore, frost action on the retained water may result in severe distresses that also cause premature failure of the pavement. Tufa deposition in the pavement structures, therefore, leads to early pavement deterioration and costly maintenance (Gupta et al., 1994). As an example, random cracking and premature failure have been observed in some steel slag-asphalt pavements in Ontario. The failure was found to be due to formation of tufa deposits along the surface and the interface. This affected interfacial bonding and caused excessive expansion of the slag leading to cracking of the mixture (Coomarasamy and Walzak, 1995).

A study by Gupta et al. (1994) shows that the concentration of free lime, water, carbon dioxide, temperature, and humidity are the main elements that control the precipitation of tufaceous deposits in drains and catchment basins of highways. The study also states that the time required and the volume of tufa precipitate may vary among slag types depending on many factors: reactivity of slags, surface area, particle size, pore size distribution, amount of water, and absorption.

Some studies indicate tufa formation is likely to occur in highway subdrain applications if the original (unweathered) total lime content (CaO) of steel slags exceeds 1 percent (Narita et al., 1978; Kneller et al., 1994).

Steel slag is mildly alkaline, with a solution pH generally in the range of 8 to 10. However, the pH of leachate from steel slag can exceed 11, a level that can be corrosive to aluminum or galvanized steel pipes placed in direct contact with the slag.

Especially on low-volume roads, where thin asphalt wearing courses predominate, granular materials play an important role in overall pavement performance. Hence, Rohde et al. (2003) have investigated the use of electric arc furnace (EAF) steel slag as base material for low-volume roads. The results of their study led to the conclusion that the use of EAF slag as pavement base material is possible if the slag is stocked in the open air long enough and that it provides remarkably good technical quality and economic advantages such as higher values of resilient modulus and thinner and cheaper pavements.

Previous research has proven that the steel slag can be safely used for road construction if it is sufficiently slaked. The conventional means of achieving this is to weather the material in stockpiles for a period of time sufficient to ensure the stabilization of potentially expansive systems (Rohde et al. 2003). The minimum stocking time depends on the expansive system content and climatic characteristics (the distributions of temperature and rainfall and the degree of air moisture saturation throughout the year) and ranges from 3 to 12 months (Machado, 2000). Most highway departments require that steel slags be aged or cured for at least 6 months before they are used (Gupta et al. 1994). In Brazil, 6 months of weathering in stockpiles has been adopted for exposing steel slag aggregates to moisture (Institute of Roads Research-Brazilian National Department of Roads, 1990).

Three key steps recommended by Juckes (2003) for the effective use of steel slag aggregates are:

- First, some pretreatment of the slag (such as weathering).
- Secondly, a test that reliably predicts the behavior in use, within a reasonable time. This is commonly an expansion test.
- Thirdly, calibration of the test is necessary so that test results can provide a useful distinction between material which is suitable and that which is not; this is normally achieved by linking laboratory tests to road trials.

Subject to these three steps, steelmaking slag can make a valuable contribution to the need for secondary aggregates (Juckes, 2003).

CHAPTER 3 TESTING OF ILLINOIS RAP MATERIALS FOR EXPANSIVE CHARACTERISTICS

3.1 CHARACTERISTICS OF ILLINOIS RAP MATERIALS FOR USE IN PAVEMENT BASES

The increasing proportions of RAP stockpiles found throughout Illinois make using RAP materials in pavement base/subbase courses economical and worthwhile. The project team gathered information on the types, sources, and properties of both virgin aggregates and RAP materials primarily used in Illinois. The research methodology used evaluated, through laboratory testing, the differences in expansion characteristics between RAP materials and virgin aggregates that would affect the laboratory testing conditions and pavement performance. Accordingly, seven RAP materials and 10 different virgin aggregates were used to conduct tests on and investigate expansion characteristics in the research study.

The following 17 materials were selected by this project's Technical Review Panel (TRP) to be studied for expansive characteristics:

RAP aggregates:

- Surface Binder RAP with 60% Steel Slag Aggregates
- Surface RAP with 92% Steel Slag Aggregates
- ACBF Slag RAP
- Gravel-Crushed Stone RAP (ALL-FRK)
- Gravel RAP (Cur-Cl)
- Steel Slag RAP
- SMA RAP from District 1

Virgin aggregates:

- Porous Steel Slag from District 1
- Nonporous Steel Slag from District 1
- Gravel-Dolomite (Meyer)
- Limestone from R27-1 Research Project
- Dolomite from R27-1 Research Project
- Siliceous Gravel from R27-1 Research Project
- Dolomite Crushed Concrete from District 1
- Gravel Crushed Concrete from District 1
- Steel Slag from District 4
- ACBF Slag from District 8

Each material was received in 40-lb. bags. The steel slag aggregates obtained from District 1, labeled as "Steel Slag Inland," clearly had two different porous structures. By visual inspection, they were separated as porous and nonporous steel slag aggregates as referred to in the above list.

3.2 EXPANSION TEST METHOD (ASTM D4792)

The project team decided early on to test both the selected RAP materials and the virgin aggregates for expansion potential in accordance with ASTM D4792-00, "Potential Expansion of Aggregates from Hydration Reactions." The ASTM D4792-00 test method covers the determination of potential volume expansion of dense graded compacted aggregates that contain components susceptible to hydration and consequent volume increase, such as, free calcium and magnesium oxides that occur in steel slag and other materials. This test method consists of measuring the volume expansion of compacted specimens following the general procedures of ASTM D1883, the California Bearing Ratio (CBR) test procedure. According to the directions given in this expansion test method, the volume expansions of compacted specimens were therefore measured following the general procedures of ASTM D1883, the CBR test procedure.

The compaction method suggested in ASTM D4792-00 is ASTM D698, the standard Proctor test procedure, where three layers are used to place the material in the CBR mold and the compactive effort is applied. However, a modification related to compaction effort was made in the test procedure. Specimens prepared in the CBR molds were compacted in three layers with 56 blows per layer using a modified Proctor hammer with 4-in. (101 mm) contact surface. The compactive effort consistently used in all the expansion tests was therefore in between the standard Proctor (ASTM D698) and the modified Proctor (ASTM D1557) efforts. Considering that granular materials in unbound base/subbase layers are often compacted more closely to the modified Proctor compactive effort, the approach taken was deemed acceptable. Further, expansion test results obtained with both the standard Proctor and the higher compactive effort adopted in this study did not differ significantly for the steel slag RAP material.

Based on how expansion tests were initially conducted following the ASTM D4792 at the IDOT Bureau of Materials and Physical Research (BMPR) and discussions related to the experimental details in a meeting with the project TRP chair, the project team decided to conduct expansion tests on two replicate specimens using the test setup consisting of six CBR mold assemblies submerged in a high alkali cement water solution (pH of 12) to accelerate expansion. Specimens prepared and compacted in the CBR mold would then be kept soaked in the high alkali water at 70°C for up to 20-30 days or until the expansion curve flattens. The water level would be kept at approximately 0.5 to 1.0 in. (13 to 25 mm) above the CBR mold for complete soaking and for allowing minimum surcharge load.

Accordingly, the following test setup and equipment components were gathered at the University of Illinois Advanced Transportation Research and Engineering Laboratory (ATREL) to conduct the ASTM D4792-00 expansion tests:

- 6 CBR molds
- 6 swell plates
- Spacer disks and swell tripods with dial indicators
- Filter paper
- 12 surcharge weight (annular 5 lb. each)
- 1 straightedge

The experiments at ATREL with the six CBR mold assemblies were originally designed for soaking in a water bath type arrangement and heating the high alkali water using a heater and circulator equipment. Nevertheless, no heater and circulator set was allowed for use with acidic or basic solutions for the proper long-term operation and care of these devices. Instead, the project team adopted a large oven at ATREL, similar to the setup used in the laboratory at the IDOT BMPR, to store the individual CBR mold assemblies submerged in metal buckets. The inside oven temperature was adjusted to maintain specimens stored in water at 70 ± 3°C (158 ± 5°F) for a minimum of seven days as per the ASTM D4792. The high alkali solution with pH of 12 was also used to accelerate the hydration reaction.

3.2.1 Sieve Analyses according to ASTM D4792

The samples were passed through the 3-in. (75-mm), ¾-in. (19-mm) and No. 4 (4.75-mm) sieves in accordance with the size classification noted in ASTM D4792. Oversize correction was made when 10% or more was retained on the ¾-in. (19-mm) sieve. After discarding the material retained on the 3-in. (75-mm) sieve, the oversize correction was performed by replacing the material passing through the 3-in (75-mm) sieve and retained on the ¾-in. (19-mm) sieve with an equal amount of material passing the ¾-in. (19-mm) sieve and retained on the No. 4 (4.75-mm). The material for replacement was taken from an unused portion of the sample.

Following the sieve analyses, the samples were mixed twice in a large sample splitter available at ATREL (see Figure 3) to provide a uniform distribution of grain sizes in the samples for the next step of compaction.

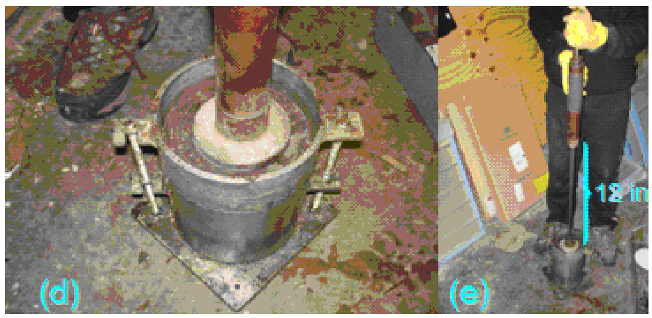
Figure 3. Photos showing the sieve shaker (right) and the sample splitter/mixer (left) at ATREL used in the experiment.

3.2.2 Compaction of Expansion Specimens

The CBR molds specified in Test Method ASTM D1883, Standard Test Method for CBR of Laboratory Compacted Soils, were used to compact the specimens for the expansion tests. The stainless steel molds were 6 in. (152 mm) in diameter and 7 in. (177 mm) high with a perforated base plate found at the bottom and a metal extension collar of at least 2.0 in. (51 mm) in height at the top of the mold. The expansion test specimens to be soaked were prepared according to the following steps also illustrated with photos in Figure 4.

After clamping the mold (with extension collar attached) to the base plate, the spacer disk was inserted over the base plate and a disk of filter paper was placed on top of the spacer disk. Specimens prepared in the molds were compacted in three layers with 56 blows per layer according to the Method C given in ASTM D698 since CBR molds, 6-in. or 152-mm in diameter, shall not be used with Method A or Method B. However, a manual rammer with a 10-lb weight (44.5-N) dropping from a height of 18 in. (457mm) was used to produce a compactive effort of 56,000 ft-lbf/ft^3 (2700 kN-m/m^3) in between the standard (ASTM D698) and modified Proctor (ASTM D1557) efforts.

(a) coating with oil (The CBR molds were coated with a rust preventative - 10W motor oil - according to ASTM D 4792);
(b) placing spacer disk over the base plate and then a filter paper on the disk;
(c) placing material into the mold per layer;



(d) & (e) materials prepared in CBR molds were compacted in three layers with 56 blows per layer by using a 10-lb rammer dropping from a height of 18 in.;

(f) trimming with a straightedge; (g) placing a filter paper on the top;
(h) inverting the CBR mold; (i) removing spacer disk; (j) placing extension collar.

Figure 4. The procedure followed to prepare the expansion test specimens.

After compaction, the extension collar was removed, and the compacted material at the top of the mold was trimmed by means of a straightedge. A disk of coarse filter paper was placed on the trimmed top of the mold, and then a perforated base plate was clamped to the trimmed top of the compacted sample in contact with the filter paper. After the mold was inverted carefully, the perforated base plate at the top was removed. Finally, the spacer disk was removed and the extension collar was placed on the top of the mold.

Note that the moisture-density relationships for the compaction were not determined since there was no need to calculate maximum density and optimum moisture properties for conducting expansion tests. Further, both the virgin aggregates and the RAP materials were quite dry as received, and they were soaked after compaction for the expansion tests. Yet, one modification made in the test procedure was the use of two perforated base plates at the top and bottom of the mold. This was needed to keep the stability of the compacted loose samples while inverting the mold.

After placing the adjustable stem and perforated plate on the compacted specimens in the molds, weights were added to produce a surcharge equal to the overburden of the base material and pavement, approximately 10-lb (44.5-N) as illustrated in Figure 5 according to ASTM D4792. The CBR mold assemblies were then placed in the buckets and the molds were checked for proper horizontal leveling with a bubble. Additional space between the perforated base plate and the bottom level of the bucket was provided by means of small cups as spacers to allow the high alkali solution to wet the bottom of the mold.

(a) swell plate and weights (a surcharge of 10 lbs or 44.5 N);
(b) splacing well plate and weights on the assembly;
(c) placing small cups as spacers at the bottom of the bucket to allow high alkali solution to wet the bottom of the molds;
(d) placing the CBR mold assembly into the metal bucket.

Figure 5. The procedure followed to place the CBR mold assemblies into metal buckets.

3.2.3 Soaking Specimens in High Alkali Solution

Alkali-aggregate reactions are chemical reactions between certain types of aggregates and hydroxyl ions (OH-) associated with alkalis. Alkalis may exist in the environment and when reacted with aggregates, they may produce damaging expansion. There are two main types of reactions: alkali-silica reaction and alkali-carbonate reaction.

Alkali-silica reaction is the most common form of alkali-aggregate reaction that occurs in the presence of certain siliceous aggregates. These aggregates include some granites, gneisses, volcanic rocks, greywackes, argillites, phyllites, hornfels, tuffs, and siliceous limestones. The product of the alkali-silica reaction is a gel that absorbs water and increases in volume.

With the alkali-carbonate reaction, certain "dolomitic limestone aggregates" react with the hydroxyl ions in the cement (or other sources such as de-icing salts) and cause swelling. The mechanism of the reaction is still not well understood with the common agreement that alteration of dolomite to calcite is involved and clay minerals may also have a role in the reaction. It should be noted that limestone aggregates may be susceptible either to alkali-silica reaction, or alkali-carbonate reaction, or a combination of the two.

Soaking aggregates in high alkali solution may therefore cause alkali-aggregate reactions, both alkali-silica and alkali-carbonate reactions, to result in swelling of the sample. According to Bellew and Mitchell (2002), the amount of swelling or expansion depends on:

- the reactivity of the aggregates.
- the alkalinity of the solution.
- the ambient moisture conditions of the sample.

For example, harmful alkali-aggregate reaction in a concrete sample will occur when all the conditions below are satisfied (Bellew and Mitchell 2002)**:**

- the concrete aggregate is reactive.
- the concrete alkali content is high enough to sustain the reaction.
- enough moisture (greater than approximately 85% relative humidity) is present to sustain the reaction.

Most asphalt binder treatments with asphalt binder coating virgin aggregate, such as in RAP materials, significantly modify the leaching behavior of a recycled material. A recent study by Hill et al. (2001) has shown that the binder treatment may dilute or amend leachable levels, alter the pH and reduce the permeability. The addition of alkali binder, however, could introduce some contaminants such as calcium. Also, alkalis may already exist in the environment.

The use of high alkali solution was essential in this research project to accelerate the hydration reaction to determine the worst case of expansion. Accordingly, the specimens were stored in high alkali water at 70 ± 3°C (158 ± 5°F) for a minimum of 7 days according to ASTM D4792. As the amount of alkali content of the solution (high alkali cement) is increased, more expansion should be expected.

The high alkali solution was prepared by mixing high alkali cement with water at a cement to water ratio of w/c = 1/7 to 1/8 to provide a solution pH value of around 13 at room temperature. The high alkali cement used in the solution was obtained from Illinois

Cement Company. It was a high alkali Type I Portland cement with an alkali percentage between 1.1 and 1.2. Figure 6 shows the high alkali solution pH meter measurements taken at room temperature before the buckets were placed in the oven.

Figure 6. Measuring pH value of the high alkali solution at room temperature.

The CBR mold assemblies submerged into metal buckets in high alkali cement water solution were stored in the oven at 70°C (solution temperature). The solution pH values measured at 70°C were typically between 11 and 12. The solution level was kept at approximately 0.5 to 1.0 in. (13 to 25 mm) above the top of the CBR mold for complete soaking and minimum surcharge load. To prevent excessive evaporation, lids were used to cover buckets at all times as shown in Figure 7. Without the lids, too much additional water was required on a daily basis, and the solution temperature could not be properly controlled.

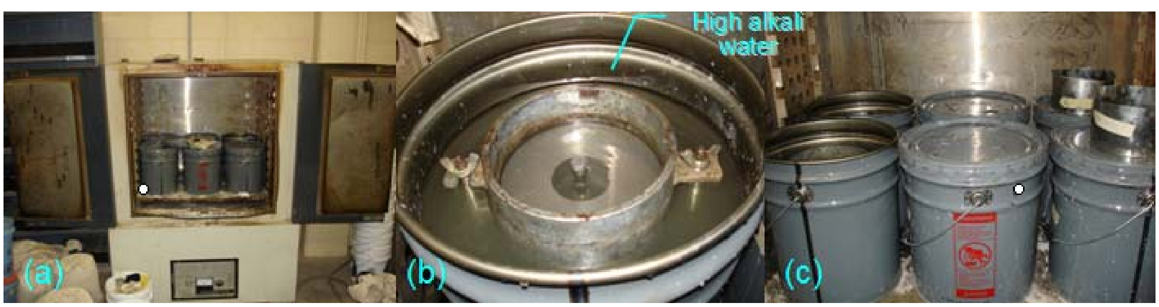


Figure 7. Storage of six specimens soaked in high alkali water in the oven at 70°C.

3.2.4 Collecting Expansion Measurements on a Continuous Basis

Approximately 30 minutes after the specimens were first immersed in the high alkali solution, the initial dial gauge measurements were taken using a dial gauge on a tripod to allow for the thermal expansion of the test apparatus. These were the initial readings based on which the expansion amounts would be determined.

The specimens were kept soaked in the high alkali water at 70°C until the expansion curve flattened. If the curve never flattened and the expansion continued, the test duration and data collection could go up to 60 days. During testing, the water level was always kept approximately at 0.5 to 1.0 in. (13 to 25 mm) above the top of the CBR mold for complete soaking. As illustrated in Figure 8, test data were collected for both the temperature and pH values of the solution in the buckets and the specimen vertical expansion values were continuously recorded and monitored throughout the testing period.

Figure 8. Photos describing continuous data collection of both temperature and pH values of the solution and the specimen expansion values during testing.

Figure 9 captures the additional quality control and maintenance procedures followed throughout the testing period. The solution level in the buckets was always kept constant by adding high alkali water to offset evaporation. The solutions in the buckets were mixed thoroughly to provide uniform pH exposure to the specimens without disturbing the molds and the swell plate positioning. Also, the pH meter used consistently was calibrated every 2 to 4 weeks during the testing period to ensure accurate and dependable pH readings.

(a) keeping the water level constant by adding water each time the daily measurement was taken.
(b) mixing high alkali solution to provide uniform pH and circulation.
(c) calibration of pH meter every 2 to 4 weeks.

Figure 9. The quality control and maintenance procedures followed throughout testing.

CHAPTER 4 EXPANSION TEST RESULTS

To establish the expansion characteristics of Illinois RAP materials for use as base/subbase courses in unbound pavement layers, expansion tests were conducted on both the selected RAP materials and virgin aggregates using the test procedure described in detail in Chapter 3. The test results are presented and evaluated in this Chapter for assessing the differences between the RAP materials and virgin aggregates in order to identify certain trends in the expansion behavior as observed from the laboratory testing and how that would affect pavement performance.

The results obtained from the expansion tests in accordance with ASTM D 4792, "Potential Expansion of Aggregates from Hydration Reactions," include the following:

- Dry density, moisture content, and sieve analysis results, i.e., percentages of material retained on the 3⁄4-in. (19.0-mm) and No. 4 (4.75-mm) sieves and pan.
- A continuous or daily record of the temperature and pH of the solution.
- Graphs and table showing rate-of-expansion for each specimen and the average of the two replicates.
- Graph showing predictive equations developed for the most significant expansion trends.
- Any available criteria applicable to base/subbase use of expansive RAP materials.

In addition, detailed test data of all the materials from the sieve analysis, dry density and moisture content tests can be found in Appendices A, B, and C, respectively. Appendix D gives details on the expansion test temperature and pH measurements. Appendices E and F list the individual test data obtained as cumulative expansion values and those corrected for the initial contraction of the specimens, respectively.

4.1 SIEVE ANALYSIS RESULTS

The samples were passed through the 75-mm (3-in.), 19-mm (3⁄4-in.), and 4.75-mm (No. 4) sieves. Oversize correction was made only for dolomite crushed concrete, gravel crushed concrete, and steel slag RAP. Note that the 4.75-mm (No. 4) sieve is the separator between the coarse and fine aggregates.

Figure 10 shows the cumulative percent passing results of all the 17 materials tested. Note that all the virgin steel slag aggregates, i.e., "nonporous steel slag," "porous steel slag," and "steel slag," typically have low percentages of material passing the 4.75-mm (No. 4) sieve ranging from 4% to 18%. Therefore, virgin steel slag aggregates were generally coarser compared to other materials. On the other hand, "surface binder RAP with 60% steel slag aggregates" has the largest percentage of fine material at 67% followed by the other "surface RAP with 92% steel slag aggregates." This concludes that the steel slag aggregates found in RAP were typically finer than the corresponding virgin steel slag aggregates. The percentages of the fine aggregate for the rest of the materials, except for gravel-dolomite (Meyer) aggregate, were generally around 45%.

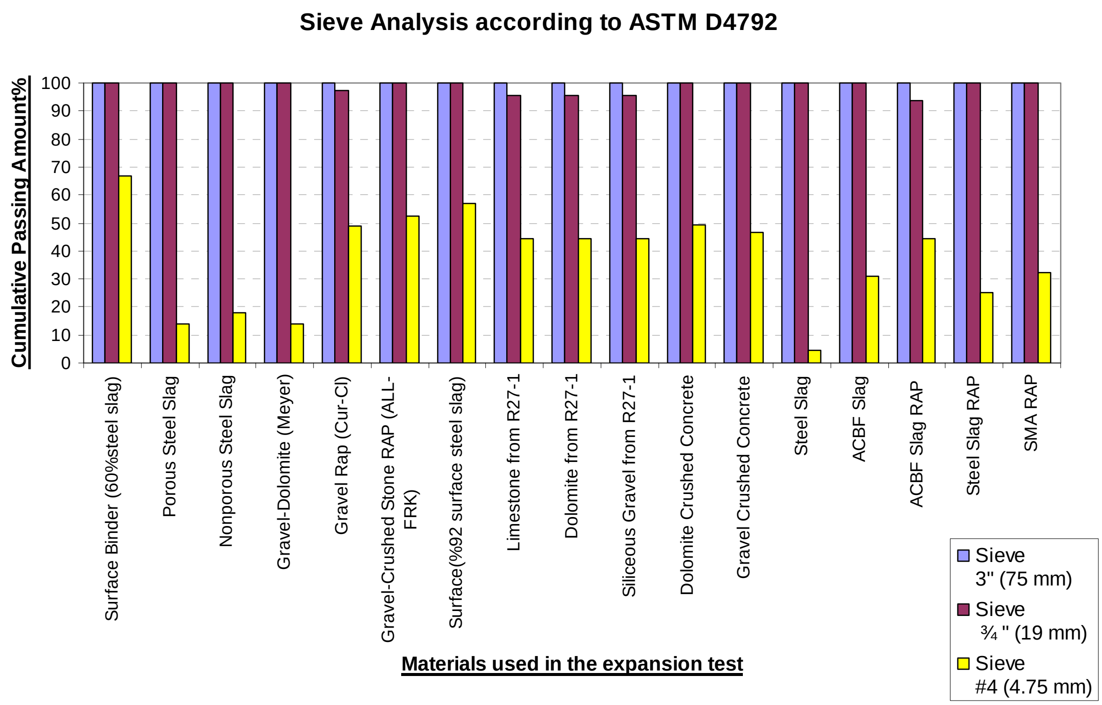


Figure 10. Sieve analysis results of all the materials tested.

4.2 DRY DENSITY AND MOISTURE CONTENT

Figures 11 and 12 present the moisture contents and dry densities for each material as received from IDOT BMPR and the various districts in Illinois, respectively. The results for the two replicate samples of each material are indicated by #1 and #2 in Figures 11 and 12. The moisture content measured for each material replicate sample is mostly less than 1% except for the gravel crushed concrete and dolomite crushed concrete materials, which have moisture content values above 2% (see Figure 11). This is mainly due to the fact that crushed concrete may have trapped water within the concrete paste due to unfinished hydration.

Figure 12 gives the dry densities for all the material replicate samples tested. The virgin steel slag aggregates have dry densities typically around 2.1 g/cm^3 (131 lb/ft^3), which is consistent with the properties given for steel slag aggregates in Chapter 2. On the other hand, steel slag aggregates found in RAP have a unit weight of approximately 1.9 g/cm^3 (119 lb/ft^3). This is expected since RAP materials, a combination of aggregates, liquid asphalt, and air, are commonly lighter than virgin aggregates.

The typical unit weights for steel slag RAP material compacted with the standard Proctor compactive effort are reported around 1.72 g/cm^3 (107 lb/ft^3). Note that this value changes to 1.88 g/cm^3 (117 lb/ft^3) for an effort between the modified and standard Proctor compaction since the higher compactive effort increases the amount of solids in the unit volume or the amount of fine particles filling the voids of the samples.

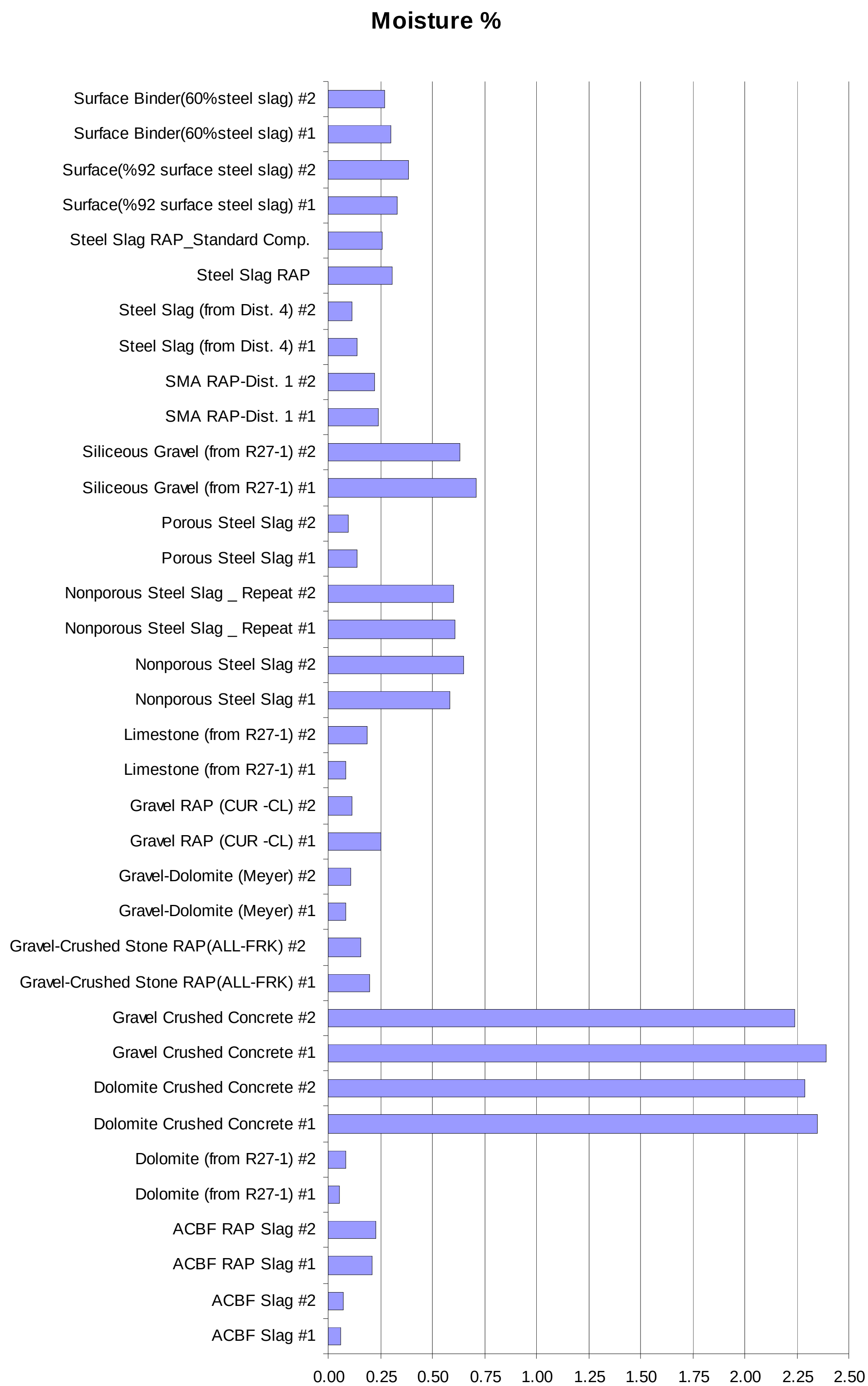


Figure 11. Moisture content values determined for each material replicate sample.

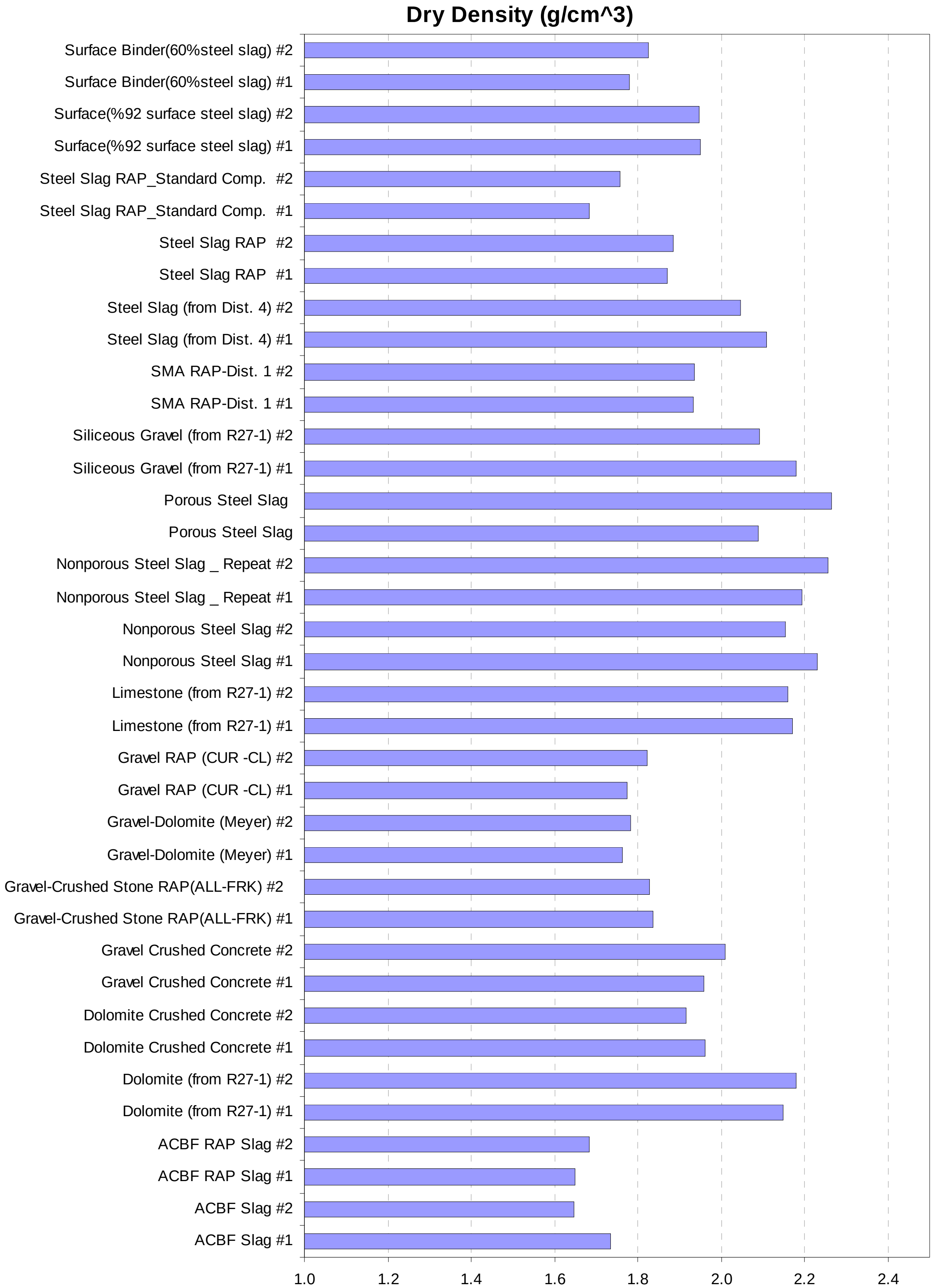


Figure 12. Dry density values determined for each material replicate sample.

4.3 EXPANSION TEST RESULTS (ASTM D4792)

Figure 13 is a typical photo of the daily temperature and pH measurements taken for a specimen submerged in the high alkali water solution. All the recorded solution temperature measurements conformed within the range specified by ASTM D4792, i.e., 67° C to 73°C. At these temperatures, the daily pH value readings were always between 11 and 12. When the temperature increased, the pH values generally tended to slightly decrease when compared to those recorded at the room temperature. To give typical values, Table 4 lists the temperatures in °C with the pH values recorded for the replicate samples of surface RAP material with 92% steel slag aggregates.

Figure 13. Photos showing daily temperature and pH measurements of the high alkali cement water solution used for soaking the specimens.

Table 4. The first 7-day Records of Temperature and pH of the Solution for Surface RAP Material with 92% Steel Slag Aggregates

MATERIAL: Surface RAP (92% surface steel slag)				
	REPLICATE 1		**REPLICATE 2**	
DAY	**Temperature (^oC)**	**pH**	**Temperature (^oC)**	**pH**
	Room	12.2	Room	12.3
1	71.7	11.5	70.8	11.6
2	72.0	11.5	70.6	11.6
3	72.3	11.3	70.0	11.2
4	71.1	11.3	69.5	11.4
5	70.3	11.4	68.7	11.4
6	70.0	11.3	70.1	11.3
7	70.4	11.3	67.7	11.3

Figure 14 presents the complete temperature and pH data for the surface RAP material with 92% of steel slag aggregates taken throughout the expansion test period. Although temperature readings somewhat fluctuate within the range permitted by ASTM D4792, i.e., 67° to 73°C, the pH values recorded for the two replicates are quite consistent. Such consistency was successfully attained as a result of the strict quality control and maintenance procedures, described in Chapter 3, followed throughout expansion testing.

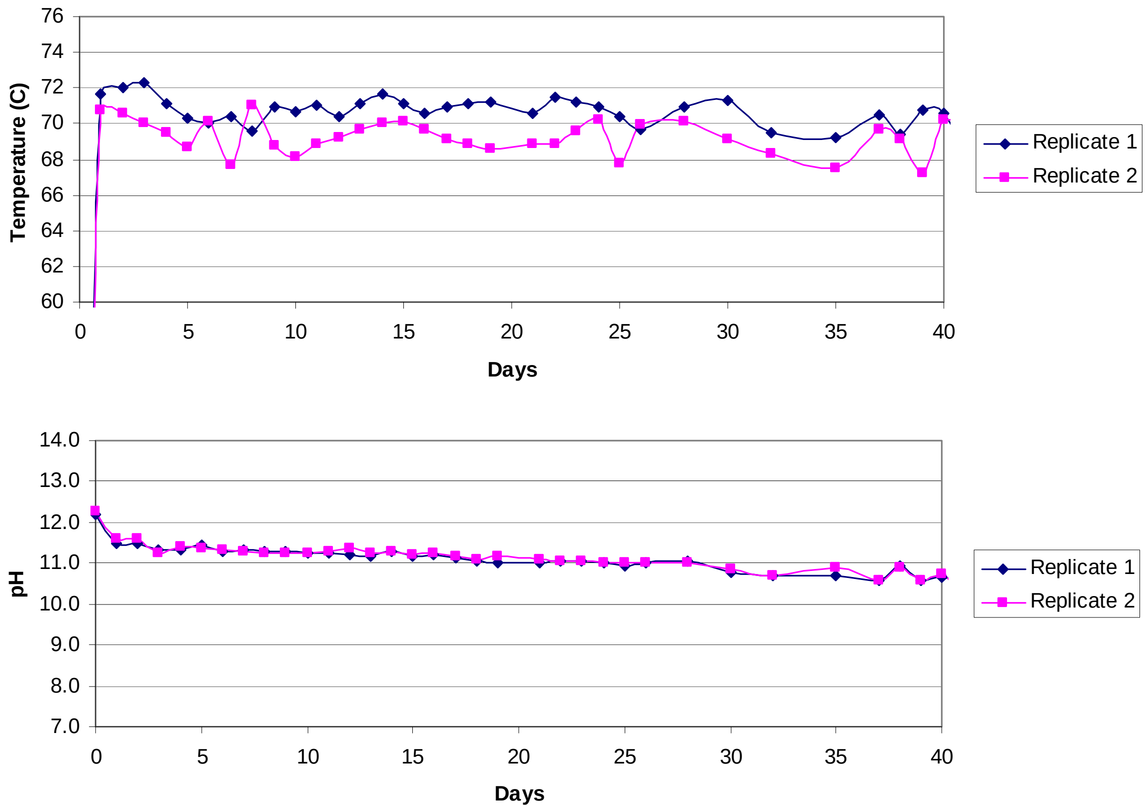


Figure 14. Complete temperature and pH data for surface RAP material with 92% steel slag aggregates recorded during expansion testing.

Table 5 gives the duration of soaking and hence expansion testing for each material tested. Seven-day minimum testing is specified by ASTM D4792 to be usually adequate to evaluate probable expansive behavior. Nevertheless, the expansion tests were generally continued for much longer than 7 days, based on the experience by IDOT BMPR on preliminary expansion test results, to fully assess the expansion trends for longer durations, in one instance for up to 60 days, until a pronounced decrease in the expansion rate was observed.

Figure 15 shows the evolution of net expansion with immersion time for samples. The percent cumulative net expansion from each measurement was calculated by dividing the difference between the current dial gage reading and the base reading by the initial specimen height (4.584 in. or 116.43 mm) and multiplying by 100. A marked increase in expansion rate was commonly observed when specimens were first immersed in the solution. Increasing the immersion time resulted in increased expansion but with smaller expansion rate increases.

Table 5. Typical Durations of Soaking And Expansion Testing for Materials Tested

MATERIAL	Duration of Soaking / Testing (Days)
Surface Binder (60% steel slag) RAP	23
Porous Steel Slag	43
Nonporous Steel Slag[1]	43
Gravel-Dolomite (Meyer)	11
Gravel RAP (CUR -CL)	17
Gravel-Crushed Stone RAP(ALL-FRK)	14
Surface (%92 surface steel slag) RAP	42
Limestone from R27-1 project	13
Dolomite from R27-1 project	22
Siliceous Gravel from R27-1 project	14
Dolomite Crushed Concrete	8
Gravel Crushed Concrete	8
Steel Slag (from District 4)	60
ACBF Slag	32
ACBF RAP Slag	32
Steel Slag RAP	45
Steel Slag RAP with std Proctor compaction[2]	***45***
SMA RAP (from District1)	45

[1] Test repeated twice.

[2] These tests were conducted evaluate effects of currently used intermediate and the Standard Proctor compactive efforts on expansion results.

During the expansion tests, all specimens, but especially the RAP materials, were observed to undergo some initial settlements before any indication of expansion. This is probably due to their more porous nature with lower dry densities; they simply could not tolerate their self weight added on top of the surcharge weight of 10 lbs (44.5 N), equal to the weight of the base material and pavement. This resulted in a contraction instead of expansion as clearly shown with negative percentages in Figure 15. For gravel RAP replicate samples, the highest contraction of over 3% was recorded (see Figure 15). Rohde et al. (2003) stated that this anomaly could be due to deficient compaction because of the lack of fines. Their study suggested using a corrected gradation to achieve accurate results for the expansive nature of the materials.

The upper expansion part of the graph in Figure 15 clearly indicates that the virgin steel slag aggregates show a higher potential of expansion in comparison with other aggregates which have very small or almost no expansion. If one considers the total expansion after all initial settlement (if any) as a means to quantify expansion, nonporous steel slag aggregate gives the maximum expansion as 6.18%, the average of the two replicate sample results. This is followed by porous steel slag aggregate with an average expansion amount of 4.14% and steel slag from District 4 with an average amount of 0.28%. The variation in these expansion values of steel slag aggregates may depend on steel grade, the steel-making plant (source), specific furnace (BOF or EAF), steel slag processing (such as cooling method, crushing, etc.), and storage conditions. Further comparisons and evaluations among the different steel slags could not be made due to insufficient information about their source and properties.

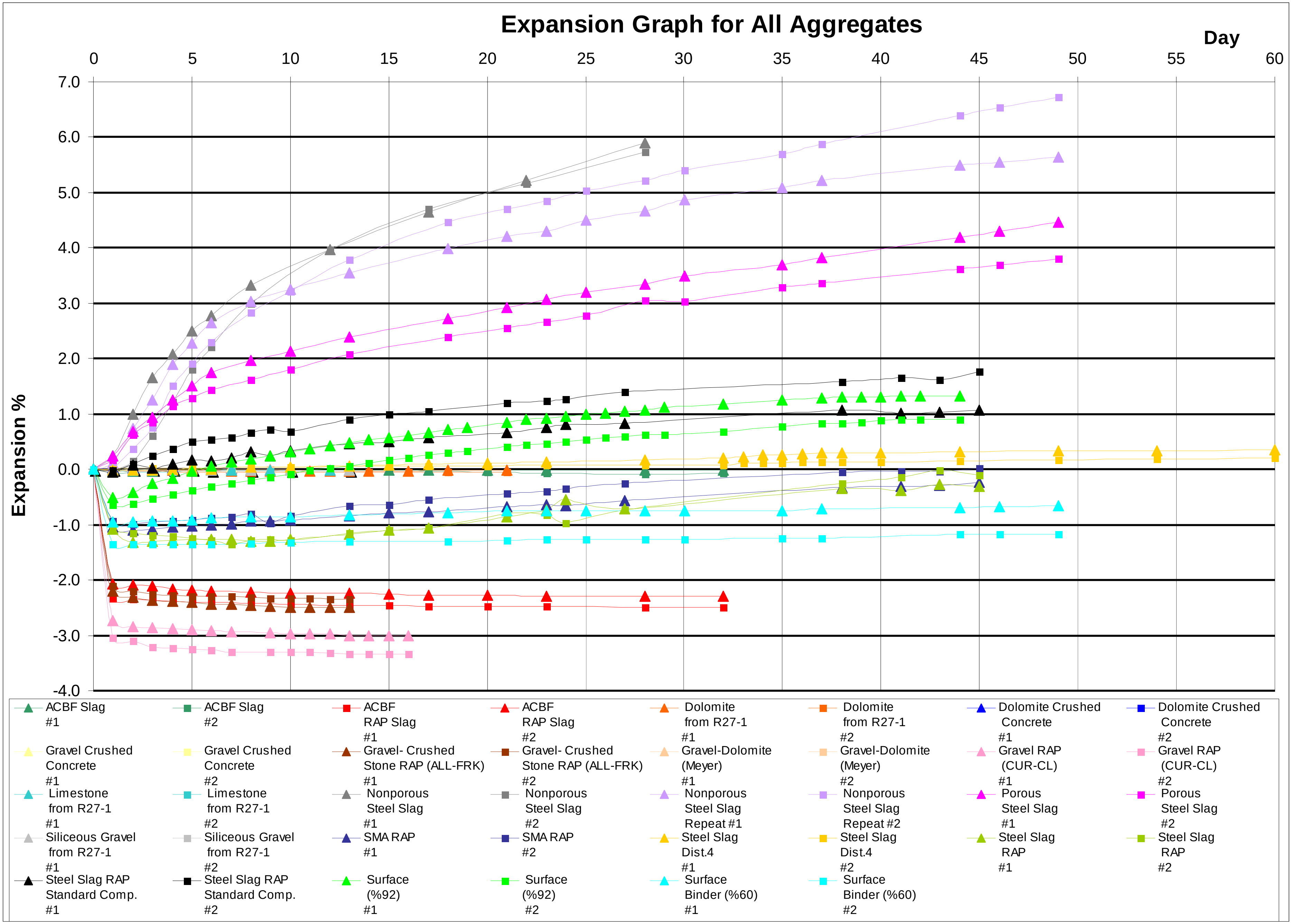


Figure 15. Net expansion values, computed based on first day reading, for all the specimens tested.

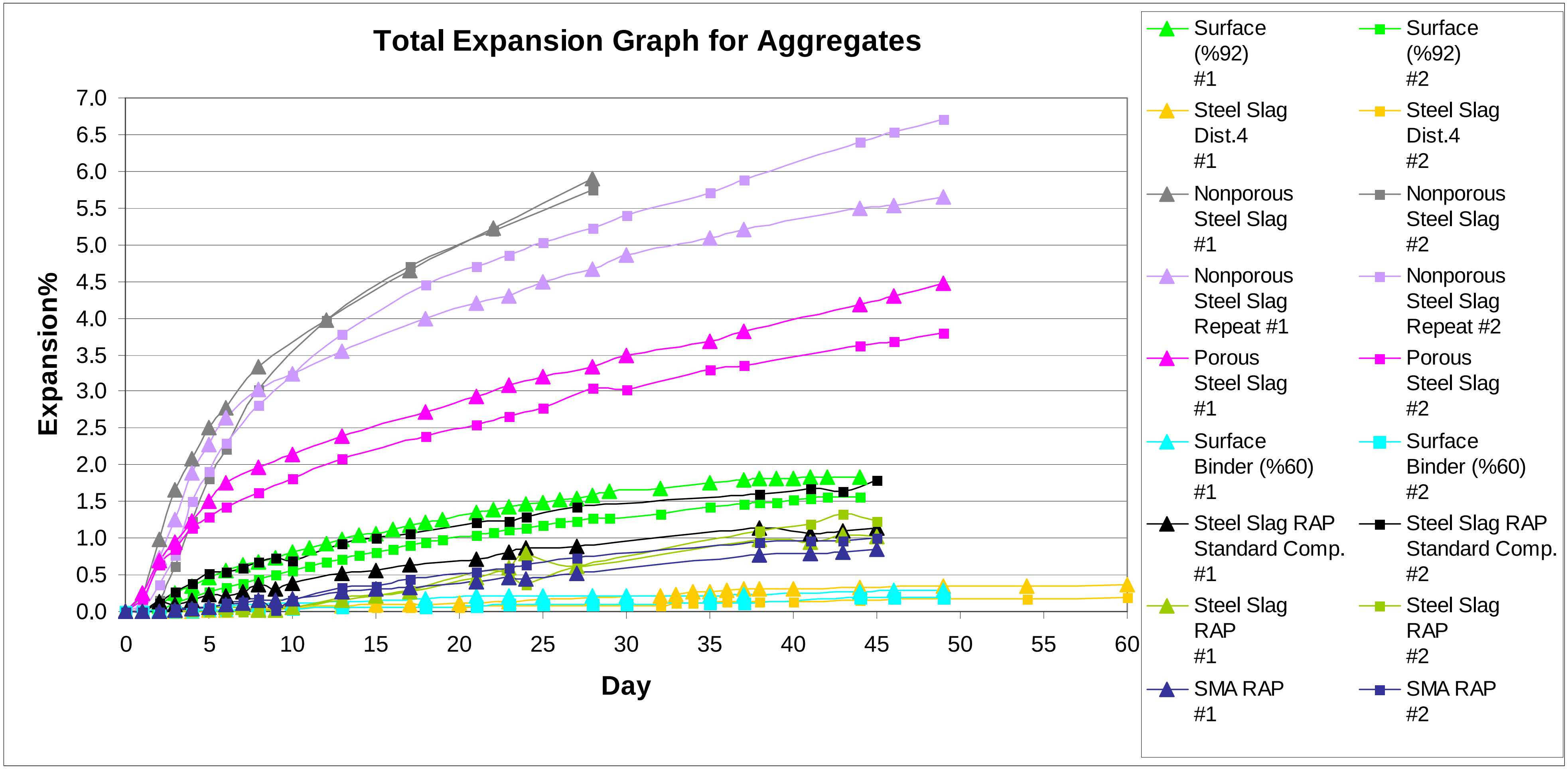


Figure 16. Total expansion values, computed after all initial settlement (if any), for all the specimens tested.

The technical literature generally agrees that the hydration of unslaked lime (CaO) and magnesia (MgO) in contact with moisture is largely responsible for the expansive nature of most steel slags (Collins and Ciesielski, 1994). In addition, free lime has been reported to hydrate rapidly, e.g., in weeks, while free magnesia takes years to develop expansion. Any immediate expansion or volume instability observed in the steel slag aggregates may therefore be more influenced by free lime reactions.

When RAP materials are placed in a pavement base course, the asphalt coating around aggregate particles may prevent to some extent the ingress of water into the aggregate. Accordingly, RAP materials may have less of a tendency to expand compared to virgin aggregates. For example, gravel RAP (CUR-CL), gravel-combined stone RAP (ALL-FRK), and ACBF RAP slag show no expansion over the testing period in Figure 15.

The effect of asphalt coating can be more significant for RAP materials with steel slag aggregates in terms of expansion behavior. Xue et al. (2006) states that steel slags show differences in texture and morphology from natural aggregates, especially in porosity characteristics. Such differences make slag surface texture rougher than those of other natural aggregates, and obviously, this is a major factor that will affect their adhesion ability with asphalt binder. Kandhal and Hoffman (1997) confirm that an effective asphalt coating may seal off the hydration of free calcium and magnesium oxides when steel slag aggregate is used in hot-mix asphalt mixtures. Moreover, a study by Wu at al. (2006) implies that the higher alkali value of steel slag improves the adhesion performance between aggregate and bitumen.

In the light of these findings, Figure 16 shows RAP materials with steel slag aggregates to exhibit a great decrease in expansion behavior when compared to the corresponding virgin steel slag aggregates. This could be due to the high absorption of bitumen and higher alkali value of steel slag aggregates as well as the RAP materials being weathered on the road for many years. For example, nonporous and porous steel slag aggregates exhibit quite high average swell amounts of 6.18% and 4.14%, respectively. However, surface RAP with 92% steel slag aggregates shows an average total expansion amount of only 1.69% after the first day settlement. This value happens to be the highest expansion recorded from all the experiments conducted on RAP materials. Next, SMA RAP also exhibits a significant average total expansion of 0.93% when compared to other aggregates, which have minor (less than 0.04%) or no expansion. Table 6 gives a summary of average total expansion values recorded for all the materials which show noteworthy expansion behavior.

Note that ACBF slag aggregates are more stable volumetrically when compared to steel slag aggregates, showing almost no expansion as indicated in Figure 16. A study by Billingslea (2001) indicates that ACBF is a non-abrasive, non-expansive material. The rough, irregular and angular particles used in the asphalt tend to interlock when compacted, forming a very workable, stable surface with excellent traction. This provides a high resistance to lateral movement (Billingslea, 2001). Gupta et al. (1994) also states that steel slags exhibit a higher potential for producing tufa than ACBF slag. Therefore, the ACBF slag can be conveniently used in highway construction as an aggregate in contrast to steel slag.

Figure 17 shows photos taken during the expansion tests indicating tufa like formation on the spacers which were used to allow water access from the bottom. Tufa is a white, powdery precipitate that consists primarily of calcium carbonate. This tufa precipitate, shown in Figure 17, was observed to form during testing of the steel slag aggregates, which might be related to the existing free lime (CaO) in steel slag aggregates causing expansion.

Table 6. Summary of Average Total Expansion Values for All the Materials which Show Important Expansion Behavior[1]

MATERIAL	Average Total Expansion (%)	Duration of Expansion Test (days)
Virgin Steel Slag Aggregates:		
Nonporous Steel Slag Repeat	6.18	49
Nonporous Steel Slag	5.82	28
Porous Steel Slag	4.14	49
Steel Slag Dist.4	0.28	60
RAP with Steel Slag Aggregates:		
Surface (92%)	1.69	44
Steel Slag RAP Standard Comp.	1.46	45
Steel Slag RAP	1.13	45
Surface Binder (60%)	0.24	49
SMA RAP:	0.93	45

[1] Computed by ignoring initial settlements until the first indication of expansion

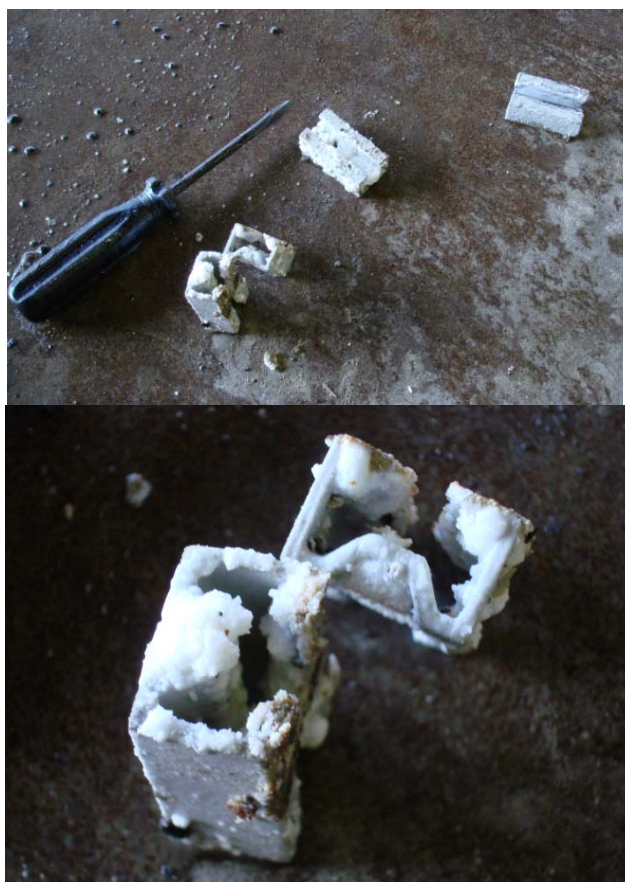


Figure 17. Formation of tufa on the spacers placed between the specimen and the bottom of the bucket.

Table 7 evaluates the effects of compactive efforts for steel slag RAP, surface (92% steel slag aggregates), and surface binder (60% steel slag aggregates) RAP materials for soaking periods of 27 to 49 days. When comparing the results obtained for steel slag RAP, the compactive effort between the standard and modified Proctor efforts adopted in this study led to a somewhat lower expansion amount (see Table 7). Yet, Figure 16 shows the steel slag RAP expansion curves for each compactive effort get closer to each other as the soaking period increases. For example, the difference between the total swell amounts for steel slag RAP conducted by the standard and between the standard and modified compactive efforts decreases from 0.55% to 0.33% at a soaking period of 27 and 45 days, respectively. This is because the standard Proctor compaction effort causes the RAP materials to expand more since the material is looser at a lower compactive effort. Furthermore, when comparing expansion values obtained for surface (92%) and surface binder (60%) RAP materials from the two compactive efforts, the results show good agreement in spite of the fact that the samples compacted with the standard Proctor effort were tested previously at the IDOT BMPR laboratory (see Table 7).

The RAP materials tested so far are more sensitive to compactive effort when compared to virgin aggregates probably because they include somewhat higher amounts of fine aggregates as listed in Table 7 and also indicated by the sieve analysis results in Figure 10. As the fine amount increases, it fills the voids of the sample, thus increases the density, and ultimately enhances the compactibility (Aiban, 2006). Accordingly, as the aggregate particles become coarser, the resulting differences between the different compactive efforts should decrease.

Table 7. Evaluating Effects of Compactive Efforts on Expansion

MATERIAL	Soaking Time (days)	Average Total Expansion (%)		Amount of Fine Aggregate (passing No. 4 or 4.75 mm sieve)
		Standard Proctor	Between Standard and Modified Proctor – used in this study	
Steel Slag RAP	27	1.16	0.61	24.9
Steel Slag RAP	45	1.46	1.13	24.9
Surface (92%)	44	1.50 (from IDOT)	1.69	57
Surface Binder (60%)	49	0.30 (from IDOT)	0.24	66.7

In the technical literature, no clear correlation is established between the expansion test results and field performance. Moreover, according to ASTM D4792, the expansion test results obtained by this standard should not be correlated with field performance, and values obtained do not necessarily indicate expansion that may occur in service conditions. However, another standard, ASTM D2940 "*Standard Specification for Graded Aggregate Material For Bases or Subbases for Highways or Airports,"* states: "aggregates that contain components subject to hydration, such as steel slags, shall be obtained from sources approved by the engineer on the basis of either a satisfactory performance record, or of aging or other treatment known to reduce potential expansion to a satisfactory level, or of expansion values not greater than 0.50% at seven days when tested in accordance with Test Method D4792."

If the compaction effort applied in the current expansion tests conducted based on ASTM D4792 (between the standard and modified Proctor efforts used in this study) is more likely preferred in the field for constructing base/subbase courses, the criteria specified by ASTM D2940 can be conveniently applicable to the expansion test results. Accordingly, Figure 18 shows such a limiting 0.5% expansion criterion drawn as a horizontal line together with a vertical line also drawn at the 7-day evaluation period. Then, it may be concluded that steel slag from District 4, SMA RAP, steel slag RAP, surface binder RAP with 60% steel slag aggregates, and surface RAP with 92% steel slag aggregates (almost) may be used as pavement base course aggregates. On the other hand, porous and nonporous steel slag aggregates should never be used in the bases or subbases without any proper curing that satisfies the limitation specified by ASTM D2940.

Wang and Emery (2004) proposed a usability criterion for the unconfined applications of a given slag based on its physical properties as follows:

$$F \leq k\frac{(\gamma_s - \gamma_o)}{\gamma_s^2} \times 100\%$$

where F is the hydratable oxide content (CaO and/or MgO) of a given slag; γ_s is the specific gravity of the slag; γ_o is the bulk relative density of the slag; and k is a constant related to the slag's physical properties. When the hydratable oxide content of a given steel slag is less than the right hand term in the above equation, the slag was said to not expand macroscopically when used as a granular material. However, this had to be confirmed through standard slag expansivity testing (Farrand and Emery, 1995).

Figure 19 presents best fit mathematical expressions in dashed lines to predict the observed expansion trends of the tested materials. High correlation coefficient R-square values (0.98 to 0.99) were consistently obtained for most of the 3rd order polynomial best fit models developed. This implies that proper and accurate representations of the actual laboratory expansion trends could be established by means of these predictive models, which may be useful tools for estimating unbound base/subbase layer expansion potentials in the field.

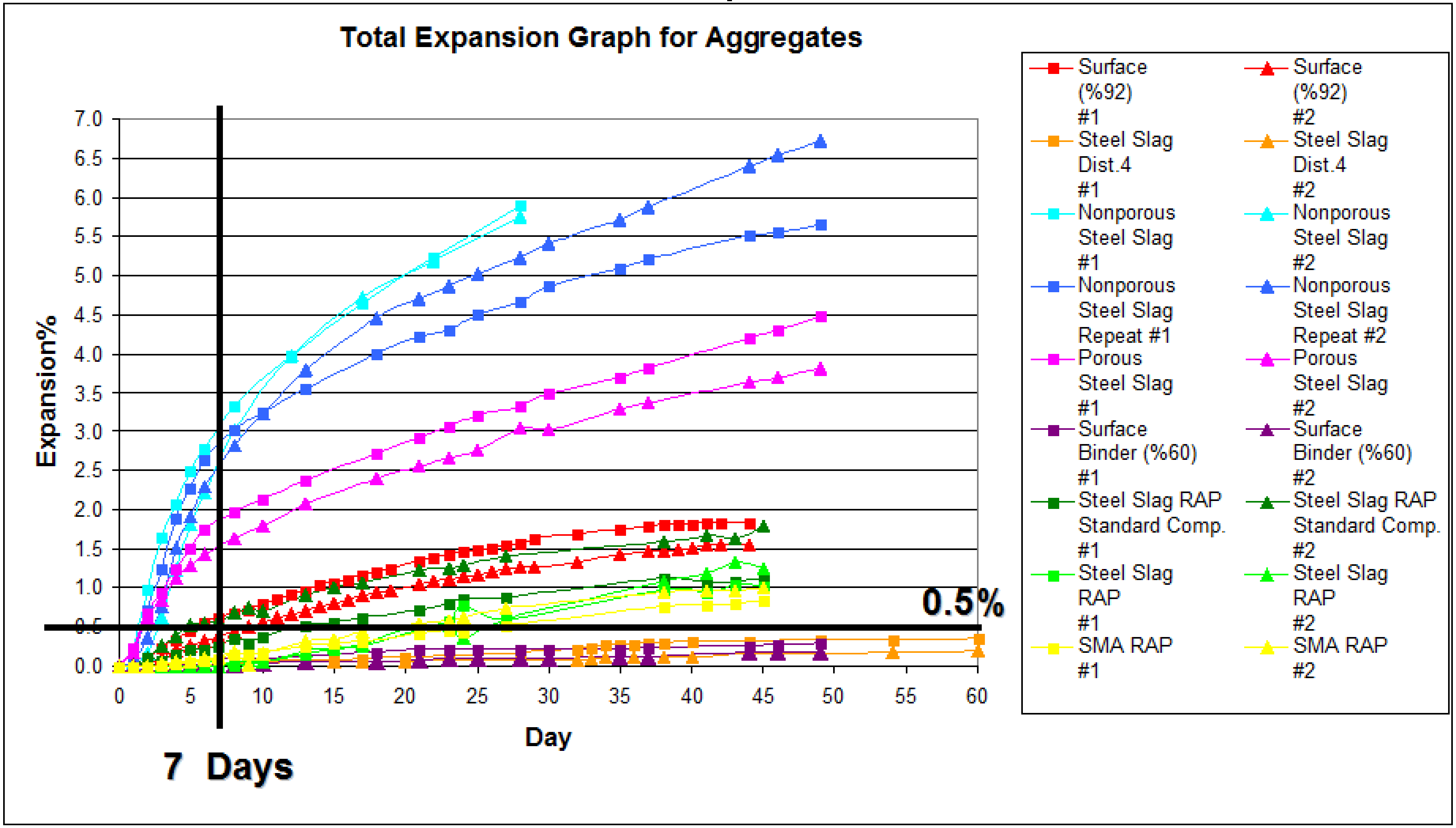


Figure 18. Application of the criterion specified by ASTM D2940 to the total expansion curves of the laboratory tested materials.

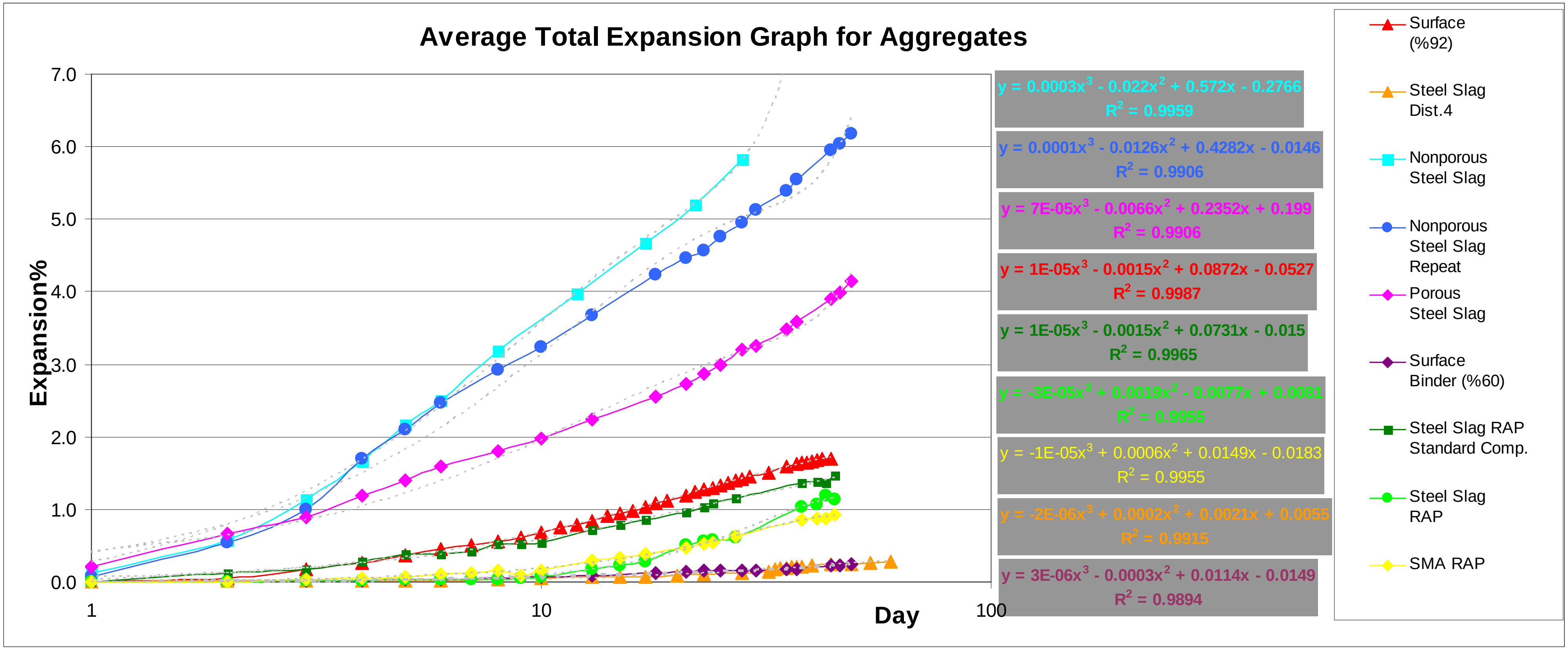


Figure 19. Predictive best fit equations developed for the actual expansion trends of the laboratory tested materials.

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

5.1 SUMMARY AND CONCLUSIONS

The use of recycled materials for pavement construction has increased substantially in recent years. This is especially true for hot-mix asphalt (HMA) and Portland cement concrete (PCC) materials that are recycled from existing interstates and highways. These recycled materials are often blended into the new HMA and PCC mixtures; however, their use as an aggregate base material is also increasing. In some cases, the potential recycled materials will contain an expansive aggregate such as steel slag that is currently not allowed for use in the pavement substructure layers. The degree of expansion for these materials is not well known.

Reclaimed asphalt pavement (RAP) is the reprocessed HMA pavement material containing asphalt and aggregates. RAP can be obtained from central RAP processing facilities where asphalt pavements are crushed, screened, and stockpiled. Processed RAP consists of high quality, well-graded aggregates coated by asphalt cement. Currently, the use of steel slag RAP is not allowed in the pavement substructure layers according to Illinois Department of Transportation (IDOT) specifications. Whether or not this is a major concern for Illinois has been the subject of this research project. The main objective has been to determine the expansive properties for RAP materials, especially the ones including recycled steel slag aggregates that may be used as pavement base materials in Illinois.

Seventeen materials, both virgin aggregates and RAP materials, were identified from the commonly used aggregate and RAP sources statewide and selected for studying their expansive characteristics in the laboratory. ASTM D4792 “Potential Expansion of Aggregates from Hydration Reactions” was determined as the laboratory test method to investigate the maximum acceptable level of expansion for all the selected virgin aggregate and RAP material types, properties, and blending proportions with virgin aggregates, and the effects that RAP materials may have on pavement performance.

In accordance with the ASTM D4792, expansion tests were conducted in CBR molds with the specimens prepared by compacting in three layers, 56 blows in each layer, and using both the standard and modified Proctor hammers. The specimens in CBR molds were submerged into a high alkali cement water solution (pH of 12) and kept continuously soaked at 70°C to accelerate hydration reactions. The percent expansion amounts of the CBR specimens and the temperature and pH levels of the solution were measured continuously on a daily basis during the soaking period for a minimum of 7 days and maximum 60 days until the expansion curve flattened or the expansion rate slowed down.

The expansion test results indicate that some steel slag aggregates showed somewhat high expansion potentials due to the hydration of free lime when compared to other virgin aggregates, such as siliceous gravel and crushed dolomite, which had minor or almost no expansion. The RAP materials, which often had lower densities, exhibited more of an initial settlement or contraction before any kind of expansion with time. Accordingly, considering only the total expansion, after all initial settlement (if any) until expansion started, nonporous steel slag aggregate gave the maximum expansion as 6.18% mainly due to free lime hydration and evidenced by tufa like precipitate formation observed in the test setup. This was followed by porous-surfaced steel slag aggregate, surface RAP with 92% steel slag aggregates, and steel slag RAP (compacted with standard Proctor Hammer) with expansion amounts of 4.14%, 1.69%, and 1.46%, respectively.

The clear conclusion from the expansion test results was that RAP materials have much lower tendencies to expand when compared to the high expansion potentials of especially the virgin steel slag aggregates. Since steel slag surface texture is often rougher than other natural aggregates, their friction properties are superior and they have significantly improved adhesion ability with asphalt binder. Therefore, the significant differences found between the expansion values of the virgin and RAP steel slag aggregates may depend on asphalt coating around the aggregate which may prevent ingress of water into the aggregate as well as on many years of the steel slag RAP materials already being on the road and exposed to the environmental effects.

According to ASTM D2940, "*Standard Specification for Graded Aggregate Material For Bases or Subbases for Highways or Airports,"* aggregates that contain components subject to hydration, such as steel slags, shall be obtained from sources approved by the engineer on the basis of either a satisfactory performance record, or of aging or other treatment known to reduce potential expansion to a satisfactory level, or of expansion values not greater than 0.50% at seven days when tested in accordance with Test Method D 4792." Therefore, if the compaction effort applied in the current expansion tests conducted based on ASTM D4792 (between the standard and modified Proctor efforts used in this study) is more likely preferred in the field for constructing base/subbase courses, the criteria specified by ASTM D2940 can be conveniently applicable to the expansion test results. Then, it may be concluded that the SMA RAP, steel slag RAP, surface binder RAP with 60% steel slag aggregates, and surface RAP with 92% steel slag aggregates (almost) can be used as pavement base course aggregates (see Figure 18). On the other hand, porous and nonporous (virgin) steel slag aggregates should never be used in the bases or subbases without any proper curing that satisfies the limitation specified by ASTM D2940.

5.2 RECOMMENDATIONS FOR FUTURE RESEARCH

After conducting ASTM D4792 tests on the selected virgin and RAP slag aggregates, unsuitably high expansion characteristics were found for some steel slag aggregates that would raise concerns about pavement performance. Therefore, additional petrographic and chemical analyses can be performed to study these expansion properties in a future research study. The main purpose of petrographic analysis is to determine mineralogical composition for the types and percentages of minerals in the rock and the microscopic texture, i.e., grain size, grain shape, mineral orientation, grain distribution, boundary relations, degree of alteration and deformation, etc. Petrographic analysis methodology examines thin sections under transmitted light using a Petrographic microscope. A thin section of 30 micron thickness is made from an aggregate sample and examined using the petrographic microscope.

Polished thin sections can also be analyzed using a scanning electron microscope (SEM). This method provides information on chemical composition of individual grains, which is not available from microscopy studies. For SEM analysis, the polished surface has to be coated with a 100 to 200Å thick carbon layer for charge dissipation, and fitted into a 1-inch-diameter holder. An energy dispersive spectrometer (EDS) attached to a SEM is also often used as an effective approach for in situ determination of the major element composition. The composition of individual mineral grains can be obtained by using a focus electron beam. The bulk or average composition can be obtained by either integrating mineral composition or analyzing the sample using a rastered electron beam (a beam that is large enough to cover multiple grains). For chemical analysis using the EDS, the sample needs to be polished, coated with a 100 to 200Å thick carbon layer for charge dissipation, and fitted into a 1-inch-diameter holder. EDS and SEM can be performed together. The analysis involves standard analysis (calibration) and the analysis of unknowns. The intensities of characteristic x-ray fluorescence of elements in the unknowns are compared to that of the standards with known chemical composition. Such comparison gives the chemical composition of the unknowns to 1% weight level for major elements such as Si, Al, Fe, Ca, Mg, K, and Na.

The expansive characteristics determined from the ASTM D4792 test results can be related to the petrographic and chemical analyses results and the properties of the RAP materials studied. This way, property variations reported by the various analysis results can be successfully linked to potential field performances of the RAP materials when used in unbound pavement layers. An informational database to be established in a future study could be useful to efficiently utilize the desired sources of RAP found in Illinois. In addition, any criteria applicable to unbound uses of RAP materials such as the maximum acceptable level of expansion for these products, guidelines on blending with virgin aggregates, and the effects that expansive materials may have on pavement performance can be addressed by conveniently referencing such a database.

Moreover, the relationship between steel slag mineralogical composition and processing parameters such as cooling rates and furnace types can be evaluated, and the effects of these processing parameters on reactivity and the expansion potential of steel slags can be investigated in a future study with the goal of producing high quality aggregates for highway construction.

REFERENCES

Aiban, S. A., "Utilization of Steel Slag Aggregate for Road Bases," *Journal of Testing and Evaluation*, Vol. 34, No. 1, 2006.

American Society for Testing and Materials, Standard Specification D4792-00, *Potential Expansion of Aggregates from Hydration Reactions,* Annual Book of ASTM Standards, Volume 04.03, West Conshohocken, PA, 2001.

American Society for Testing and Materials, Standard Specification D2940-98, *Standard Specification for Graded Aggregate Material For Bases or Subbases for Highways or Airports,* ASTM International, West Conshohocken, PA, www.astm.org.

American Society for Testing and Materials, Standard Specification D1557-02, *Standard Test Methods for Laboratory Compaction Charecteristics of Soil Using Modified Effort,* ASTM International, West Conshohocken, PA, www.astm.org

Bellew, G., and L. Mitchell, "Preventing Concrete Deterioration Due to Alkali-Aggregate Reaction," NRC Institute for Research in Construction (NRC-IRC) Construction Technology Update No. 52, 2002.

Bennert T., W. J. Papp, A. Maher, and N. Gucunski, "Utilization of Construction and Demolition Debris Under Traffic-Type Loading in Base and Subbase Applications," *Transportation Research Record: Journal of the Transportation Research Board*, No. 1714, National Research Council, Washington D.C., 2000, pp. 33-39.

Bicalho et al., "Study of Brazilian Steel Slag Properties for Road Constructions," In Proceedings of the ASCE Airfield and Highway Pavement Conference, Bellevue, WA, 2008.

Billingslea, A., "*Slag: Mother Nature's By-Product, EIT, Construction and Materials Issues,"* 2001, pp. 176-182.

British Steel Corporation General Steels Division Research Organization, "An Assessment of the Properties of BOS Slag-A Review of the Chemistry, Mineralogy and Physical Properties of the Air Cooled BOS Slags*,"* Produced by the British Steel Corporation, 1976.

Caijun, S., "Steel Slag-Its Production, Processing, Characteristics, and Cementitous Properties," *ASCE Journal of Materials in Civil Engineering.* 16:3 (230), May-June, 2004.

Chesner, W. H., R. J. Collins, and M. H. MacKay, "Users Guidelines for Waste and By-Product Materials in Pavement Construction," Report No. FHWA-RD-97-148, Commack: Chesner Engineering, P.C., April 1998.

Chini, A., S. Kuo, J. Armaghani, and J. Duxbury, "Test for Recycled Concrete Aggregate in Accelerated Test Track," *Journal of Transportation Engineering*, American Society of Civil Engineers, Vol. 127, No. 6, 2001, pp. 486-492.

Collins, R. J. and S. K. Ciesielski, *"*Recycling and Use of Waste Materials and By-Products in Highway Construction*,"* National Cooperative Highway Research Program Synthesis of Highway Practice 199, Transportation Research Board, Washington, D.C., 1994.

Coomarasamy and T. L. Walzak, "Effects of Moisture on Surface Chemistry of Steel Slags and Steel Slag-Asphalt Paving Mixes," *Transportation Research Record: Journal of the Transportation Research Record*, No. 1492, National Research Council, Washington, D.C., 1995, pp. 85-95.

Cross, S., M. Abu-Zeid, J. B. Wojakowski, and Fager. "Long Term Performance of Recycled Portland Cement Concrete in Pavement," *Transportation Research Record:*

Journal of the Transportation Research Board, No. 1652, National Research Council, Washington, D.C., 1996, pp. 115-123.

Emery, J. J., "Slag Utilization in Pavement Construction," Extending Aggregate Resources, ASTM Special Technical Publication 774, American Society for Testing and Materials, Washington, D.C., 1982.

Farrand, B. and J. Emery, "Recent Improvements in Quality of Steel Slag Aggregate," *Transportation Research Record: Journal of the Transportation Research Board*, No. 1486, National Research Council, Washington, D.C., 1995, pp. 137-141.

FHWA Turner Fairbank Highway Research Center, www.fhwa.dot.gov/Pavement/recycling/.

Garg, N., and M. R. Thompson, "Lincoln Avenue Reclaimed Asphalt Pavement Base Project," *Transportation Research Record: Journal of the Transportation Research Board,* No. 1547, National Research Council, Washington D.C., 1996, pp. 89-95.

Gupta et al., "Characterization of Base and Subbase Iron and Steel Slag Aggregates Causing Deposition of Calcareous Tufa in Drains," *Transportation Research Record: Journal of the Transportation Research Board*, No.1434, National Research Council, Washington, D.C., 1994, pp. 8-16.

Gupta, J. D. and W. A. Kneller, "Precipitate Potential of Highway Subbase Aggregates," Report No. FHWA/OH-94/004, Prepared for the Ohio Department of Transportation, Nov 1993.

Hill, A. R., A. R. Dawson, and M. Mundy, "Utilization of Aggregate Materials in Road Construction and Bulk Fill," *Journal of Resources, Conservation and Recycling*, Vol. 32, Issue 3-4, Jul 2001, pp 305-320.

Hudson, W. R. and A. Saeed, "Evaluation and the Use of Waste and Reclaimed Materials in Roadbase Construction," CTR 1348-2F Final Report, FHWA/TX-97/1348-2F, Research Report 1348-2F, 1996, 203 p.

Institute of Roads Research, Brazilian National Department of Roads, "Using Mineralogical and Industrial Wastes in Road Paving," (in Portuguese), Rio de Janeiro, 1990.

Ionescu, D., T. R. Meadowcroft, and P. V. Barr, "Hydration Potential of High Iron Level Glasses: Criteria for the Recycling of Steel Slag as a Portland Cement Additive," ICSTI/Ironmaking Conference Proceedings, 1998, pp. 1245-1254.

Ionescu, D., T. R. Meadowcroft, and P. V. Barr, "Early-age Hydration Kinetics of Steel Slags," *Advances in Cement Research,* 13 (1), 2001, pp. 21-30.

Juckes, L. M., "The Volume Stability of Modern Steelmaking Slags, Mineral Processing and Extractive Metallurgy," Vol.112, Dec 2003.

Kandahl, P. S. and G. L. Hoffman, "Evaluation of Steel Slag Fine Aggregate in Hot-Mix Asphalt Mixtures," *Transportation Research Record: Journal of the Transportation Research Board,* No. 1583, National Research Council, Washington, D.C., 1997, pp. 18-36.

Kneller, W. A., J. Gupta, M. L. Borkowski, and D. Dollimore, "Determination of Original Free Lime Content of Weathered Iron and Steel Slags by Thermogravimetric Analysis," *Transportation Research Record: Journal of the Transportation Research Board*, No. 1434, National Research Council, Washington, D.C., 1994, pp. 17-22.

Lea, F .M., "*The Chemistry of Cement and Concrete*," Third Ed., Edward Arnold, London, 1983, 459 p.

Machado, A. T. "A Comparative Study of Test Methods for Evaluating Steel Slag Expansion," (in Portuguese). M.Sc. Thesis. University of São Paulo, Brazil, 2000.

Maher, M. H. and W. Popp, "Recycled Asphalt Pavement as a Base and Subbase Material," ASTM STP 1275, American Society of Testing and Materials, New Orleans, 1997, pp. 42-53.

Maslehuddin, M., M. Alfarabi, M. Sharif, M. I. Shameem, and M. S. Barry, "Comparison of Properties of Steel Slag and Crushed Limestone Aggregate Concretes," *Construction and Building Materials*, 17, 2003, pp.105-112.

Monaco and W-K. Lu, "The Properties of Steel Slag Aggregates and Their Dependence on Melt Shop Practice," Steelmaking Conference Proceedings, 1996, pp. 701-711.

Narita, K., T. Onoye, and Z. Takata. "On the Weathering Mechanisms of LD Converted Slag," (in Japanese), Koba Steel Ltd., Japan, 1978.

O'Mahony, M. M. and G. W. E. Milligan, "Use of Recycled Materials in Subbase Layers," *Transportation Research Record: Journal of the Transportation Research Board*, No. 1310, National Research Council, Washington D.C., 1991, pp. 73-80.

Roberts, F. L., P. S. Kandhal, E. R. Brown, D.-Y. Lee, and T. W. Kennedy, "*Hot Mix Asphalt Materials, Mixture Design, and Construction*," Second Edition, NAPA Education Foundation, MD, 1996, pp. 102-114.

Rohde at al., "Electric Arc Furnace Steel Slag Base Material for Low-Volume Roads," *Transportation Research Record: Journal of the Transportation Research Board*, No. 1819, National Research Council, Washington, D. C., 2003, pp. 201-207.

Saski F. et al., "Method of Identifying Minerals in Blast Furnace and BOF Slags by Optical Microscopy," Nippon Steel Technical Report No. 17, 1981, pp.1-8.

Senior, S. A., S. I. Szoke, and C. A. Rogers, "Ontario's Experience with Reclaimed Materials for Use in Aggregates," Presented at the International Road Federation Conference, Calgary, Alberta, 1994.

Simon, M. "User Guidelines for Waste and By Product Materials in Pavement Construction," Turner-Fairbank Highway Research Center, Federal Highway Administration, FHWA-RD-97-148, McLean, VA, 1997.

Taha, R., A. AI-Harthy, K. AI-Shamsi, and M. AI-Zubeidi, "Cement Stabilization of Reclaimed Asphalt Pavement Aggregate for Road Bases and Subbases," *Journal of Materials in Civil Engineering*, American Society of Civil Engineers, Vol. 14, No. 3, 2002, pp. 239-245.

Taha, R., G. Ali, A. Basma, and O. Al-Turk, "Evaluation of Reclaimed Asphalt Pavement Aggregate in Road Bases and Subbases," *Transportation Research Record: Journal of the Transportation Research Board*, No. 1652, National Research Council, Washington, D.C., 1999, pp. 264-269.

Tossavainen, M. et al., "Characteristics of Steel Slag under Different Cooling Conditions," Waste Management, 2006.

Wachsmuth, F. et al., "Contribution to the Structure of BOF slags and Its Influence on their Volume Stability," Canadian Metallurgical Quarterly, No. 3, Vol. 20, 1981, pp. 279-284.

Wang, G. and J. Emery, "Technology of Slag Utilization in Highway Construction," Environmental Benefits of In-situ Material Recycling and Strengthening Session-Annual Conference, Transportation Association of Canada, 2004.

Wu, S., Y. Xue, Q. Ye, and Y. Chen, "Utilization of Steel Slag as Aggregates for Stone Mastic Asphalt (SMA) Mixtures," *Building and Environment*, 2007, pp. 42: 2580-5.

Xue, Y., S. Wu, H. Hou, and J. Zha, "Experimental Investigation of Basic Oxygen Furnace Slag Used as Aggregate in Asphalt Mixture," *Journal of Hazardous Materials,* B138, 2006, pp. 261-268.

APPENDIX A: SIEVE ANALYSES OF THE MATERIALS USED IN THE EXPANSION TESTS

Material	Retained on 3" (lb)	Retained on 3/4" (lb)	Retained on #4 (lb)	Retained on pan (lb)	Total (lb)	Over-correction	Retained on #200 (lb)	Retained on pan (lb)
Surface Binder(60%steel slag)	0	0	11.5	23	34.5	No	N.A	N.A
Porous Steel Slag	0	0	30.5	5	35.5	No	N.A	N.A
Nonporous Steel Slag	0	0	32.5	7	39.5	No	N.A	N.A
Gravel-Dolomite (Meyer)	0	0	34.5	5.5	40	No	N.A	N.A
Gravel Rap (Cur-Cl)	0	1	19.5	19.5	40	No	N.A	N.A
Gravel-Crushed Stone RAP (ALL-FRK)	0	0	15	16.5	31.5	No	N.A	N.A
Surface(%92 surface steel slag)	0	0	21.5	28.5	50	No	N.A	N.A
Limestone from R27-1	0	2.2	25.7	22.1	50	No	19.1	2
Dolomite from R27-1	0	2.2	25.7	22.1	50	No	19.1	2
Siliceous Gravel from R27-1	0	2.2	25.7	22.1	50	No	19.1	2
Dolomite Crushed Concrete	0	0	14.5	14	28.5	Yes	N.A	N.A
Gravel Crushed Concrete	0	0	16.3	14.3	30.5	Yes	N.A	N.A
Steel Slag	0	0	33.7	1.6	35.3	No	1.4	0.1
ACBF Slag	0	0	25.0	11.3	36.3	No	10.5	0.8
ACBF Slag RAP	0	2.6	21.0	18.9	42.5	No	18.6	0.3
Steel Slag RAP	0	0.0	46.7	15.5	62.2	Yes	N.A	N.A
SMA RAP	0	0.0	27.0	13.0	40.0	No	N.A	N.A

CUMULATIVE Passing Material %	Sieve 3" (75 mm)	Sieve ¾ " (19 mm)	Sieve #4 (4.75 mm)
Surface Binder (60%steel slag)	100.0	100.0	66.7
Porous Steel Slag	100.0	100.0	14.1
Nonporous Steel Slag	100.0	100.0	17.7
Gravel-Dolomite (Meyer)	100.0	100.0	13.8
Gravel Rap (Cur-Cl)	100.0	97.5	48.8
Gravel-Crushed Stone RAP (ALL-FRK)	100.0	100.0	52.4
Surface(%92 surface steel slag)	100.0	100.0	57.0
Limestone from R27-1	100.0	95.6	44.2
Dolomite from R27-1	100.0	95.6	44.2
Siliceous Gravel from R27-1	100.0	95.6	44.2
Dolomite Crushed Concrete	100.0	100.0	49.1
Gravel Crushed Concrete	100.0	100.0	46.7
Steel Slag	100.0	100.0	4.4
ACBF Slag	100.0	100.0	31.1
ACBF Slag RAP	100.0	93.9	44.4
Steel Slag RAP	100.0	100.0	24.9
SMA RAP	100.0	100.0	32.5

APPENDIX B: DRY DENSITY OF EACH MATERIAL USED IN THE EXPANSION TESTS

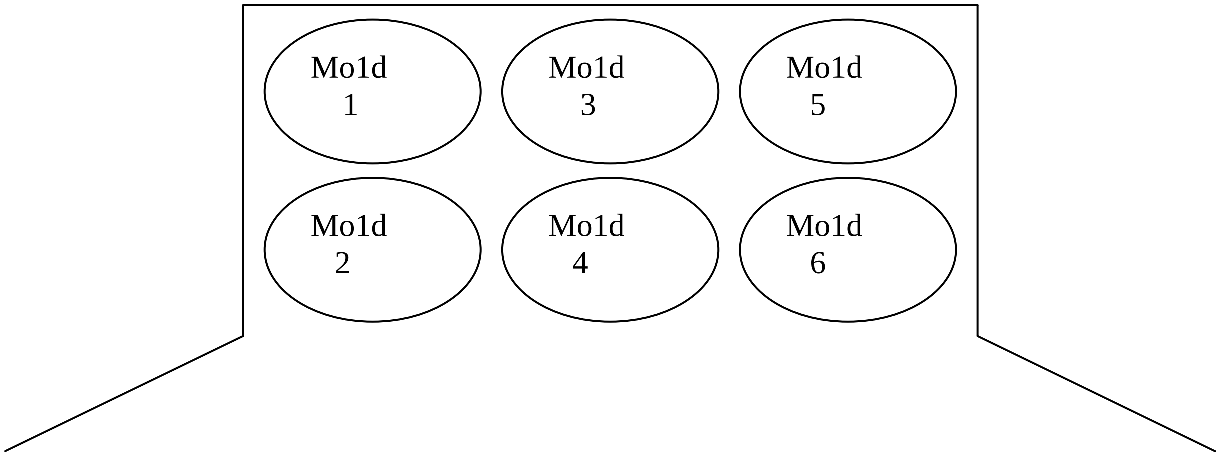
	Material	Weight (g) of mold+soil+base plate	Weight (g) of soil	Dry density (g / cm^3)
CBR mold #3	ACBF Slag #1	12502.6	3682.6	1.73
CBR mold #4	ACBF Slag #2	12317.8	3497.8	1.65
CBR mold #5	ACBF RAP Slag #1	12322	3502	1.65
CBR mold #6	ACBF RAP Slag #2	12395.4	3575.4	1.68
CBR mold #3	Dolomite (from R27-1) #1	13383.3	4563.3	2.15
CBR mold #4	Dolomite (from R27-1) #2	13447.4	4627.4	2.18
CBR mold #1	Dolomite Crushed Concrete #1	12983.1	4163.1	1.96
CBR mold #2	Dolomite Crushed Concrete #2	12886.7	4066.7	1.91
CBR mold #3	Gravel Crushed Concrete #1	12978.7	4158.7	1.96
CBR mold #4	Gravel Crushed Concrete #2	13087.2	4267.2	2.01
CBR mold #3	Gravel-Crushed Stone RAP(ALL-FRK) #1	12718	3898	1.84
CBR mold #4	Gravel-Crushed Stone RAP(ALL-FRK) #2	12705.4	3885.4	1.83
CBR mold #1	Gravel-Dolomite (Meyer) #1	12563.6	3743.6	1.76
CBR mold #2	Gravel-Dolomite (Meyer) #2	12607.1	3787.1	1.78
CBR mold #1	Gravel RAP (CUR -CL) #1	12588.7	3768.7	1.77
CBR mold #2	Gravel RAP (CUR -CL) #2	12690.9	3870.9	1.82
CBR mold #1	Limestone (from R27-1) #1	13432.4	4612.4	2.17
CBR mold #2	Limestone (from R27-1) #2	13408.5	4588.5	2.16
CBR mold #3	Nonporous Steel Slag #1	13556	4736	2.23
CBR mold #4	Nonporous Steel Slag #2	13397.6	4577.6	2.16
CBR mold #1	Nonporous Steel Slag _ Repeat #1	13480.3	4660.3	2.19
CBR mold #2	Nonporous Steel Slag _ Repeat #2	13611.5	4791.5	2.26
CBR mold #4	Porous Steel Slag	13254.4	4434.4	2.09
CBR mold #3	Porous Steel Slag	13628.3	4808.3	2.26
CBR mold #1	Siliceous Gravel (from R27-1) #1	13449.6	4629.6	2.18
CBR mold #2	Siliceous Gravel (from R27-1) #2	13262.8	4442.8	2.09
CBR mold #3	SMA RAP-Dist. 1 #1	12924.1	4104.1	1.93
CBR mold #4	SMA RAP-Dist. 1 #2	12933.6	4113.6	1.94
CBR mold #1	Steel Slag (from Dist. 4) #1	13301.4	4481.4	2.11
CBR mold #2	Steel Slag (from Dist. 4) #2	13163.4	4343.4	2.04
CBR mold #1	Steel Slag RAP #1	12792.9	3972.9	1.87
CBR mold #2	Steel Slag RAP #2	12822.4	4002.4	1.88
CBR mold #5	Steel Slag RAP_Standard Comp. #1	12395.8	3575.8	1.68
CBR mold #6	Steel Slag RAP_Standard Comp. #2	12551.7	3731.7	1.76
CBR mold #5	Surface(92% surface steel slag) #1	12958.7	4138.7	1.95
CBR mold #6	Surface(92% surface steel slag) #2	12955.3	4135.3	1.95
CBR mold #5	Surface Binder(60%steel slag) #1	12599.8	3779.8	1.78
CBR mold #6	Surface Binder(60%steel slag) #2	12695.3	3875.3	1.82
Empty mold+base plate (g) =		8820		
Volume of mold (excluding extension collar and excluding the space placed by spacer disk) (in^3) = 129.610				

APPENDIX C: MOISTURE CONTENTS OF EACH MATERIAL USED IN THE EXPANSION TESTS

CAN #	Material	Weight of Empty can (g)	Weight of Can+Soil (g)	After oven, Weight of Can+Soil (g)	Moisture %
CAN 2	ACBF Slag #1	132.7	640.2	639.9	0.06
CAN 1	ACBF Slag #2	142.3	674.3	673.9	0.08
CAN 3	ACBF RAP Slag #1	132.1	792.1	790.7	0.21
CAN 5	ACBF RAP Slag #2	134.8	488.7	487.9	0.23
CAN 5	Dolomite (from R27-1) #1	134.7	501.2	501	0.05
CAN 4	Dolomite (from R27-1) #2	138.7	734.5	734	0.08
CAN 1	Dolomite Crushed Concrete #1	142.2	909	891	2.35
CAN 2	Dolomite Crushed Concrete #2	132.9	810.2	794.7	2.29
CAN 3	Gravel Crushed Concrete #1	132.3	651.2	638.8	2.39
CAN 4	Gravel Crushed Concrete #2	138.8	593.6	583.4	2.24
CAN 3	Gravel-Crushed Stone RAP(ALL-FRK) #1	132.1	883	881.5	0.20
CAN 6	Gravel-Crushed Stone RAP(ALL-FRK) #2	134.3	455.6	455.1	0.16
CAN 1	Gravel-Dolomite (Meyer) #1	141.9	375.5	375.3	0.09
CAN 2	Gravel-Dolomite (Meyer) #2	132.2	585.8	585.3	0.11
CAN 1	Gravel RAP (CUR -CL) #1	141.8	573.6	572.5	0.25
CAN 2	Gravel RAP (CUR -CL) #2	132.1	563.7	563.2	0.12
CAN 5	Limestone (from R27-1) #1	135	598.6	598.2	0.09
CAN 5	Limestone (from R27-1) #2	135	515.7	515	0.18
CAN 6	Nonporous Steel Slag #1	134.9	856.3	852.1	0.58
CAN 1	Nonporous Steel Slag #2	143.1	757.4	753.4	0.65
CAN 1	Nonporous Steel Slag _ Repeat #1	142.4	914.7	910	0.61
CAN 2	Nonporous Steel Slag _ Repeat #2	133.1	895.2	890.6	0.60
CAN 6	Porous Steel Slag #1	134.8	790.7	789.8	0.14
CAN 5	Porous Steel Slag #2	135.8	648.4	647.9	0.10
CAN 4	Siliceous Gravel (from R27-1) #1	138.6	743.3	739	0.71
CAN 5	Siliceous Gravel (from R27-1) #2	135	975.3	970	0.63
CAN 3	SMA RAP-Dist. 1 #1	132.9	716.4	715	0.24
CAN 1	SMA RAP-Dist. 1 #2	142	683.4	682.2	0.22
CAN 6	Steel Slag (from Dist. 4) #1	135	639.7	639	0.14
CAN 3	Steel Slag (from Dist. 4) #2	132.3	670.5	669.9	0.11
CAN 4	Steel Slag RAP	139.6	628.9	627.4	0.31
CAN 2	Steel Slag RAP_Standard Comp.	133.1	592.7	591.5	0.26
CAN 5	Surface(92% surface steel slag) #1	134.7	703.5	701.6	0.33
CAN 3	Surface(92% surface steel slag) #2	132	393	392	0.38
CAN 3	Surface Binder(60%steel slag) #1	133.3	1132.7	1129.7	0.30
CAN 4	Surface Binder(60%steel slag) #2	140	833.8	831.9	0.27

APPENDIX D: EXPANSION TESTS – DAILY MEASUREMENTS

Placement of the molds in the oven given below:



NOTES:

Height of mold = 4.58 in.

DAY	DATE	CBR MOLD #1 Material #1	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)	CBR MOLD #2 Material #2	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)
1	01/13/08	Gravel-Dolomite (Meyer)	41.7	12.1	42.6	50		Gravel-Dolomite (Meyer)	40.3	12.1	41.7	84.5	
2	01/14/08	Gravel-Dolomite (Meyer)	70.4	11.3	67.2	49.5	-0.5	Gravel-Dolomite (Meyer)	69.4	11.4	66	84	-0.5
3	01/15/08	Gravel-Dolomite (Meyer)	69.5	11.4	66	49.75	0.3	Gravel-Dolomite (Meyer)	70.2	11.5	65.3	84	0.0
4	01/16/08	Gravel-Dolomite (Meyer)	70.4	11.4	67.1	50	0.3	Gravel-Dolomite (Meyer)	70.1	11.4	67.7	84	0.0
5	01/17/08	Gravel-Dolomite (Meyer)	70.7	11.4	62.3	50.25	0.3	Gravel-Dolomite (Meyer)	70.5	11.4	66.8	84.25	0.3
6	01/18/08	Gravel-Dolomite (Meyer)	70.7	11.3	66.7	50.25	0.0	Gravel-Dolomite (Meyer)	69.7	11.3	65.5	84.25	0.0
7	01/19/08	Gravel-Dolomite (Meyer)	70.6	11.3	66.3	50.5	0.3	Gravel-Dolomite (Meyer)	70	11.4	65.6	84.5	0.3
8	01/20/08	Gravel-Dolomite (Meyer)	70.3	11.3	66.4	50.5	0.0	Gravel-Dolomite (Meyer)	70.1	11.3	65.9	84.5	0.0
9	01/21/08	Gravel-Dolomite (Meyer)	71.1	11.2	67.9	50.5	0.0	Gravel-Dolomite (Meyer)	70.3	11.3	66.6	84.5	0.0
10	01/22/08	Gravel-Dolomite (Meyer)	70	11.2	65.8	50.5	0.0	Gravel-Dolomite (Meyer)	69.6	11.3	66	84.5	0.0
11	01/23/08	Gravel-Dolomite (Meyer)	70.8	11.2	65.9	50.5	0.0	Gravel-Dolomite (Meyer)	70.5	11.3	64.7	84.5	0.0
12	01/24/08	Gravel RAP (CUR -CL)	25.9	11.9	21.1	219		Gravel RAP (CUR -CL)	21	11.7	22	183.25	
13	01/25/08	Gravel RAP (CUR -CL)	70.3	11.6	65.8	94	-125.0	Gravel RAP (CUR -CL)	70.1	11.5	66.9	44	-139.3
14	01/26/08	Gravel RAP (CUR -CL)	71.1	11.4	66.5	89	-5.0	Gravel RAP (CUR -CL)	70.8	11.5	66.6	41	-3.0
15	01/27/08	Gravel RAP (CUR -CL)	71.1	11.5	68.2	87.5	-1.5	Gravel RAP (CUR -CL)	70.9	11.6	65.6	36.25	-4.8
16	01/28/08	Gravel RAP (CUR -CL)	70.7	11.4	66.5	87	-0.5	Gravel RAP (CUR -CL)	71.4	11.4	67.9	35.25	-1.0
17	01/29/08	Gravel RAP (CUR -CL)	71.1	11.5	67.7	86	-1.0	Gravel RAP (CUR -CL)	70.3	11.5	67.4	34.25	-1.0
18	01/30/08	Gravel RAP (CUR -CL)	70.8	11.3	67.7	85.25	-0.8	Gravel RAP (CUR -CL)	70.7	11.4	66.3	33.25	-1.0
19	01/31/08	Gravel RAP (CUR -CL)	71.1	11.4	66.8	84.25	-1.0	Gravel RAP (CUR -CL)	70.1	11.5	65.7	32.25	-1.0
20	02/01/08	Gravel RAP (CUR -CL)						Gravel RAP (CUR -CL)					
21	02/02/08	Gravel RAP (CUR -CL)	71.6	11.3	68.5	84	-0.3	Gravel RAP (CUR -CL)	71.7	11.4	67	32.25	0.0
22	02/03/08	Gravel RAP (CUR -CL)	71.6	11.4	66.8	82.75	-1.3	Gravel RAP (CUR -CL)	71.5	11.3	67.9	31.5	-0.8
23	02/04/08	Gravel RAP (CUR -CL)	71.9	11.4	68.2	82.5	-0.3	Gravel RAP (CUR -CL)	71.8	11.6	65.8	31.5	0.0
24	02/05/08	Gravel RAP (CUR -CL)	71.5	11.4	67.8	82.5	0.0	Gravel RAP (CUR -CL)	71	11.5	66.3	31	-0.5
25	02/06/08	Gravel RAP (CUR -CL)	71.5	11.4	68	81.25	-1.3	Gravel RAP (CUR -CL)	71.2	11.5	66.1	30.5	-0.5

DAY	DATE	CBR MOLD #1						CBR MOLD #2					
		Material #1	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)	Material #2	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)
26	02/07/08	Gravel RAP (CUR -CL)	69.6	11.4	65.8	81.25	0.0	Gravel RAP (CUR -CL)	70.5	11.5	65.1	30.5	0.0
27	02/08/08	Gravel RAP (CUR -CL)	71.2	11.3	67.7	81	-0.3	Gravel RAP (CUR -CL)	70	11.4	66.2	30.5	0.0
28	02/09/08	Gravel RAP (CUR -CL)	69.5	11.4	64.4	81	0.0	Gravel RAP (CUR -CL)	69,5	11.5	64.4	30.5	0.0
29	02/10/08												
30	02/11/08	Limestone from R27-1	19.2	12.2	22.4	90		Limestone from R27-1	17.5	12.1	19.4	104	
31	02/12/08	Limestone from R27-1	71.4	11.5	67.6	90	0.0	Limestone from R27-1	69.6	11.5	65.5	103.5	-0.5
32	02/13/08	Limestone from R27-1	71.4	11.4	67.9	89.75	-0.3	Limestone from R27-1	71	11.5	66.7	102	-1.5
33	02/14/08	Limestone from R27-1	71	11.4	67.7	89.75	0.0	Limestone from R27-1	69.9	11.4	68.4	102	0.0
34	02/15/08	Limestone from R27-1	71	11.3	67.8	89.75	0.0	Limestone from R27-1	70.5	11.5	66.5	102	0.0
35	02/16/08	Limestone from R27-1	71.3	11.4	67.4	89.75	0.0	Limestone from R27-1	71.3	11.4	67.2	102.25	0.3
36	02/17/08	Limestone from R27-1	71.2	11.5	66.9	89.75	0.0	Limestone from R27-1	71.3	11.5	65.6	102.5	0.3
37	02/18/08	Limestone from R27-1	70.8	11.4	68.2	89.5	-0.3	Limestone from R27-1	70.3	11.5	65.7	102.5	0.0
38	02/19/08	Limestone from R27-1	70.7	11.4	67.9	89.5	0.0	Limestone from R27-1	70.3	11.4	66.2	102.5	0.0
39	02/20/08	Limestone from R27-1	70.7	11.3	67.7	89.25	-0.3	Limestone from R27-1	70.4	11.4	66.7	102.5	0.0
40	02/21/08	Limestone from R27-1	71.1	11.3	67.1	89.25	0.0	Limestone from R27-1	70.1	11.4	66.4	102.5	0.0
41	02/22/08	Limestone from R27-1						Limestone from R27-1					
42	02/23/08	Limestone from R27-1	71.7	11.3	66.8	89.25	0.0	Limestone from R27-1	71.5	11.3	66.2	102.5	0.0
43	02/24/08	Siliceous Gravel from R27-1	Room	12.0	21.2	93.75		Siliceous Gravel from R27-1	Room	12.1	21.2	78.25	
44	02/25/08	Siliceous Gravel from R27-1	70.2	11.3	66.9	93.75	0.0	Siliceous Gravel from R27-1	70.6	11.2	66.8	78.5	0.3
45	02/26/08	Siliceous Gravel from R27-1	71.3	11.1	65.9	94	0.3	Siliceous Gravel from R27-1	70.5	11.2	65.8	78.25	-0.3
46	02/27/08	Siliceous Gravel from R27-1	68.5	11.2	64.1	94.25	0.3	Siliceous Gravel from R27-1	70.1	11.2	64.5	77.75	-0.5
47	02/28/08	Siliceous Gravel from R27-1	71.4	11.1	62.4	93.5	-0.8	Siliceous Gravel from R27-1	70.6	11.0	63.3	77	-0.8
48	02/29/08	Siliceous Gravel from R27-1	71.2	11.0	62.3	93.5	0.0	Siliceous Gravel from R27-1	70.8	11.1	63.5	77	0.0
49	03/01/08	Siliceous Gravel from R27-1	71.4	11.1	62.7	93.25	-0.3	Siliceous Gravel from R27-1	71.4	11.1	64.2	77	0.0
50	03/02/08	Siliceous Gravel from R27-1						Siliceous Gravel from R27-1					
51	03/03/08	Siliceous Gravel from R27-1	71.1	11.0	62.4	93.25	0.0	Siliceous Gravel from R27-1	70.9	11.0	63.1	76.75	-0.3

DAY	DATE	CBR MOLD #1						CBR MOLD #2					
		Material #1	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)	Material #2	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)
52	03/04/08	Siliceous Gravel from R27-1						Siliceous Gravel from R27-1					
53	03/05/08	Siliceous Gravel from R27-1	71.5	10.8	64.5	93.25	0.0	Siliceous Gravel from R27-1	70.6	10.8	63.2	76.75	0.0
54	03/06/08	Siliceous Gravel from R27-1						Siliceous Gravel from R27-1					
55	03/07/08	Siliceous Gravel from R27-1						Siliceous Gravel from R27-1					
56	03/08/08	Siliceous Gravel from R27-1	70.6	11.0	62	93	-0.3	Siliceous Gravel from R27-1	70.2	11.0	61.3	76.75	0.0
57	03/09/08												
58	03/10/08	Dolomite Crushed Concrete	Room	12.1	25.2	88.25		Dolomite Crushed Concrete	Room	12.0	23.9	82	
59	03/11/08	Dolomite Crushed Concrete	70.8	11.5	65.6	89	0.8	Dolomite Crushed Concrete	70.1	11.3	67.3	82.5	0.5
60	03/12/08	Dolomite Crushed Concrete	67.8	11.3	65.4	89	0.0	Dolomite Crushed Concrete	65.4	11.4	63	82	-0.5
61	03/13/08	Dolomite Crushed Concrete	71.7	11.5	66.5	89	0.0	Dolomite Crushed Concrete	71.8	11.3	66.8	82	0.0
62	03/14/08	Dolomite Crushed Concrete	71.7	11.1	68.9	89	0.0	Dolomite Crushed Concrete	71.2	11.4	65.4	82	0.0
63	03/15/08	Dolomite Crushed Concrete	33.1	12.3	33.2	89.5	0.5	Dolomite Crushed Concrete	33.6	12.4	30.6	83	1.0
64	03/16/08	Dolomite Crushed Concrete						Dolomite Crushed Concrete					
65	03/17/08	Dolomite Crushed Concrete	18.5	12.7	18.5	89.5	0.0	Dolomite Crushed Concrete	18.3	12.8	18.3	83	0.0
66	03/18/08												
67	03/19/08												
68	03/20/08												
69	03/21/08												
70	03/22/08												
71	03/23/08												
72	03/24/08												
73	03/25/08	Steel Slag- Dist. 4	Room	12.7	23.7	93.5		Steel Slag- Dist. 4	Room	12.7	21.6	64	
74	03/26/08	Steel Slag- Dist. 4	70.7	11.1	67.1	93	-0.5	Steel Slag- Dist. 4	69.4	11.2	65.8	64.5	0.5
75	03/27/08	Steel Slag- Dist. 4	70.5	11.1	66.3	93	0.0	Steel Slag- Dist. 4	68.7	11.2	64.6	65	0.5
76	03/28/08	Steel Slag- Dist. 4	68.2	11.1	65.4	93	0.0	Steel Slag- Dist. 4	70.7	11.2	66.9	65	0.0
77	03/29/08	Steel Slag- Dist. 4	71.2	11.3	65	93.25	0.3	Steel Slag- Dist. 4	72	11.2	66.5	65.25	0.3

DAY	DATE	CBR MOLD #1 Material #1	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)	CBR MOLD #2 Material #2	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)
78	03/30/08	Steel Slag- Dist. 4	71.5	11.3	65.3	93.5	0.3	Steel Slag- Dist. 4	71.7	11.2	67.2	65.25	0.0
79	03/31/08	Steel Slag- Dist. 4	72	11.3	66.1	94	0.5	Steel Slag- Dist. 4	71.4	11.1	68.1	65.25	0.0
80	04/01/08	Steel Slag- Dist. 4						Steel Slag- Dist. 4					
81	04/02/08	Steel Slag- Dist. 4	71.9	11.3	64.9	95	1.0	Steel Slag- Dist. 4	71.5	11.3	64.2	65.5	0.3
82	04/03/08	Steel Slag- Dist. 4						Steel Slag- Dist. 4					
83	04/04/08	Steel Slag- Dist. 4	71.4	11.1	64.7	95.5	0.5	Steel Slag- Dist. 4	71.1	11.2	66.1	66	0.5
84	04/05/08	Steel Slag- Dist. 4						Steel Slag- Dist. 4					
85	04/06/08	Steel Slag- Dist. 4						Steel Slag- Dist. 4					
86	04/07/08	Steel Slag- Dist. 4	72	11.2	65.9	96.5	1.0	Steel Slag- Dist. 4	70.9	11.2	65.7	66.5	0.5
87	04/08/08	Steel Slag- Dist. 4						Steel Slag- Dist. 4					
88	04/09/08	Steel Slag- Dist. 4	71.6	11.3	65.9	97	0.5	Steel Slag- Dist. 4	71.7	11.1	66	66.5	0.0
89	04/10/08	Steel Slag- Dist. 4						Steel Slag- Dist. 4					
90	04/11/08	Steel Slag- Dist. 4	71.7	11.1	66.3	97.5	0.5	Steel Slag- Dist. 4	71.6	11.2	66.2	66.5	0.0
91	04/12/08	Steel Slag- Dist. 4						Steel Slag- Dist. 4					
92	04/13/08	Steel Slag- Dist. 4						Steel Slag- Dist. 4					
93	04/14/08	Steel Slag- Dist. 4	71.3	11.0	64.8	98.5	1.0	Steel Slag- Dist. 4	71.5	11.1	67.2	66.5	0.0
94	04/15/08	Steel Slag- Dist. 4						Steel Slag- Dist. 4					
95	04/16/08	Steel Slag- Dist. 4						Steel Slag- Dist. 4					
96	04/17/08	Steel Slag- Dist. 4		11.08	65.3	99.5	1.0	Steel Slag- Dist. 4		11.1	66.5	67.5	1.0
97	04/18/08	Steel Slag- Dist. 4						Steel Slag- Dist. 4					
98	04/19/08	Steel Slag- Dist. 4						Steel Slag- Dist. 4					
99	04/20/08	Steel Slag- Dist. 4						Steel Slag- Dist. 4					
100	04/21/08	Steel Slag- Dist. 4						Steel Slag- Dist. 4					
101	04/22/08	Steel Slag- Dist. 4		11.0	66.4	101.5	2.0	Steel Slag- Dist. 4		11.1	67.2	67.5	0.0
102	04/23/08	Steel Slag- Dist. 4						Steel Slag- Dist. 4					
103	04/24/08	Steel Slag- Dist. 4						Steel Slag- Dist. 4					

DAY	DATE	CBR MOLD #1 Material #1	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)	CBR MOLD #2 Material #2	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)
104	04/25/08	Steel Slag- Dist. 4						Steel Slag- Dist. 4					
105	04/26/08	Steel Slag- Dist. 4	67.1	11.0	65.5	103	1.5	Steel Slag- Dist. 4	68.2	11.1	66.9	67.5	0.0
106	04/27/08	Steel Slag- Dist. 4	72.2	11.0	63.2	104	1.0	Steel Slag- Dist. 4	71.8	11.2	66.9	69	1.5
107	04/28/08	Steel Slag- Dist. 4	71.6	10.9	62.6	105.5	1.5	Steel Slag- Dist. 4	72.1	11.2	65.9	69.25	0.3
108	04/29/08	Steel Slag- Dist. 4	71.1	11.1	62.2	105.5	0.0	Steel Slag- Dist. 4	71.9	11.3	65.2	69.5	0.3
109	04/30/08	Steel Slag- Dist. 4	70.2	11.1	61.6	106.25	0.8	Steel Slag- Dist. 4	72.3	11.2	66.8	69.75	0.3
110	05/01/08	Steel Slag- Dist. 4	68.8	10.9	65	107	0.8	Steel Slag- Dist. 4	67.7	11.3	62.8	70	0.3
111	05/02/08	Steel Slag- Dist. 4	70.1	11.0	62.3	107	0.0	Steel Slag- Dist. 4	68.1	11.3	63.2	70	0.0
112	05/03/08	Steel Slag- Dist. 4						Steel Slag- Dist. 4					
113	05/04/08	Steel Slag- Dist. 4	71.5	11.1	61.8	107.5	0.5	Steel Slag- Dist. 4	72.3	11.1	67.1	70	0.0
114	05/05/08	Steel Slag- Dist. 4						Steel Slag- Dist. 4					
115	05/06/08	Steel Slag- Dist. 4						Steel Slag- Dist. 4					
116	05/07/08	Steel Slag- Dist. 4						Steel Slag- Dist. 4					
117	05/08/08	Steel Slag- Dist. 4	72.7	10.9	61.8	108	0.5	Steel Slag- Dist. 4	72.2	11.2	64.8	71	1.0
118	05/09/08	Steel Slag- Dist. 4						Steel Slag- Dist. 4					
119	05/10/08	Steel Slag- Dist. 4						Steel Slag- Dist. 4					
120	05/11/08	Steel Slag- Dist. 4						Steel Slag- Dist. 4					
121	05/12/08	Steel Slag- Dist. 4						Steel Slag- Dist. 4					
122	05/13/08	Steel Slag- Dist. 4	71.1	11.0	60	108.5	0.5	Steel Slag- Dist. 4	72.1	11.1	67.6	71.75	0.8
123	05/14/08	Steel Slag- Dist. 4						Steel Slag- Dist. 4					
124	05/15/08	Steel Slag- Dist. 4						Steel Slag- Dist. 4					
125	05/16/08	Steel Slag- Dist. 4						Steel Slag- Dist. 4					
126	05/17/08	Steel Slag- Dist. 4						Steel Slag- Dist. 4					
127	05/18/08	Steel Slag- Dist. 4	71	11.1	60.2	109	0.5	Steel Slag- Dist. 4	72.2	11.2	64.5	72.25	0.5
128	05/19/08	Steel Slag- Dist. 4						Steel Slag- Dist. 4					

DAY	DATE	CBR MOLD #1 Material #1	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)	CBR MOLD #2 Material #2	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)
129	05/20/08	Steel Slag- Dist. 4						Steel Slag- Dist. 4					
130	05/21/08	Steel Slag- Dist. 4						Steel Slag- Dist. 4					
131	05/22/08	Steel Slag- Dist. 4						Steel Slag- Dist. 4					
132	05/23/08	Steel Slag- Dist. 4						Steel Slag- Dist. 4					
133	05/24/08	Steel Slag- Dist. 4	There was almost no water left			109.5	0.5	Steel Slag- Dist. 4	71.1	11.0	66.2	73	0.8
134	05/25/08												
135	05/26/08	Nonporous Steel Slag _ 2nd Repeat	Room	12.5	33.4	98		Nonporous Steel Slag _2nd Repeat	Room	12.4	31.3	161.5	
136	05/27/08	Nonporous Steel Slag _ 2nd Repeat	71	11.2	66.3	103	5.0	Nonporous Steel Slag _2nd Repeat	70.1	11.1	67.9	163.25	1.8
137	05/28/08	Nonporous Steel Slag _ 2nd Repeat	72.1	11.1	68.5	131.5	28.5	Nonporous Steel Slag _2nd Repeat	71.8	11.1	67.7	178.5	15.3
138	05/29/08	Nonporous Steel Slag _ 2nd Repeat	71.9	11.2	65.5	155.25	23.8	Nonporous Steel Slag _2nd Repeat	71.8	11.2	66.6	196.5	18.0
139	05/30/08	Nonporous Steel Slag _ 2nd Repeat	72	11.2	66.6	185	29.8	Nonporous Steel Slag _2nd Repeat	70.1	11.1	68.4	230.5	34.0
140	05/31/08	Nonporous Steel Slag _ 2nd Repeat	72.1	11.1	67.1	202.25	17.3	Nonporous Steel Slag _2nd Repeat	71.4	11.0	68.8	249	18.5
141	06/01/08	Nonporous Steel Slag _ 2nd Repeat	72	11.1	66.6	219	16.8	Nonporous Steel Slag _2nd Repeat	72.1	11.1	68.7	267	18.0
142	06/02/08	Nonporous Steel Slag _ 2nd Repeat						Nonporous Steel Slag _2nd Repeat					
143	06/03/08	Nonporous Steel Slag _ 2nd Repeat	72.1	11.1	67.2	237	18.0	Nonporous Steel Slag _2nd Repeat	71.5	11.2	66.8	291	24.0
144	06/04/08	Nonporous Steel Slag _ 2nd Repeat						Nonporous Steel Slag _2nd Repeat					
145	06/05/08	Nonporous Steel Slag _ 2nd Repeat	72.2	11.0	68.3	246.75	9.8	Nonporous Steel Slag _2nd Repeat	72.1	11.1	68.2	309	18.0
146	06/06/08	Nonporous Steel Slag _ 2nd Repeat						Nonporous Steel Slag _2nd Repeat					
147	06/07/08	Nonporous Steel Slag _ 2nd Repeat						Nonporous Steel Slag _2nd Repeat					
148	06/08/08	Nonporous Steel Slag _ 2nd Repeat	72	11.1	67.9	261	14.3	Nonporous Steel Slag _2nd Repeat	71.7	11.1	68.6	335	26.0
149	06/09/08	Nonporous Steel Slag _ 2nd Repeat						Nonporous Steel Slag _2nd Repeat					
150	06/10/08	Nonporous Steel Slag _ 2nd Repeat						Nonporous Steel Slag _2nd Repeat					

DAY	DATE	CBR MOLD #1						CBR MOLD #2					
		Material #1	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)	Material #2	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)
151	06/11/08	Nonporous Steel Slag _ 2nd Repeat						Nonporous Steel Slag _2nd Repeat					
152	06/12/08	Nonporous Steel Slag _ 2nd Repeat						Nonporous Steel Slag _2nd Repeat					
153	06/13/08	Nonporous Steel Slag _ 2nd Repeat				281	20.0	Nonporous Steel Slag _2nd Repeat				366	31.0
154	06/14/08	Nonporous Steel Slag _ 2nd Repeat						Nonporous Steel Slag _2nd Repeat					
155	06/15/08	Nonporous Steel Slag _ 2nd Repeat						Nonporous Steel Slag _2nd Repeat					
156	06/16/08	Nonporous Steel Slag _ 2nd Repeat				291	10.0	Nonporous Steel Slag _2nd Repeat				377	11.0
157	06/17/08	Nonporous Steel Slag _ 2nd Repeat						Nonporous Steel Slag _2nd Repeat					
158	06/18/08	Nonporous Steel Slag _ 2nd Repeat				295	4.0	Nonporous Steel Slag _2nd Repeat				384	7.0
159	06/19/08	Nonporous Steel Slag _ 2nd Repeat						Nonporous Steel Slag _2nd Repeat					
160	06/20/08	Nonporous Steel Slag _ 2nd Repeat				304	9.0	Nonporous Steel Slag _2nd Repeat				392	8.0
161	06/21/08	Nonporous Steel Slag _ 2nd Repeat						Nonporous Steel Slag _2nd Repeat					
162	06/22/08	Nonporous Steel Slag _ 2nd Repeat						Nonporous Steel Slag _2nd Repeat					
163	06/23/08	Nonporous Steel Slag _ 2nd Repeat				312	8.0	Nonporous Steel Slag _2nd Repeat				401	9.0
164	06/24/08	Nonporous Steel Slag _ 2nd Repeat						Nonporous Steel Slag _2nd Repeat					
165	06/25/08	Nonporous Steel Slag _ 2nd Repeat				321	9.0	Nonporous Steel Slag _2nd Repeat				409	8.0
166	06/26/08	Nonporous Steel Slag _ 2nd Repeat						Nonporous Steel Slag _2nd Repeat					
167	06/27/08	Nonporous Steel Slag _ 2nd Repeat						Nonporous Steel Slag _2nd Repeat					
168	06/28/08	Nonporous Steel Slag _ 2nd Repeat						Nonporous Steel Slag _2nd Repeat					
169	06/29/08	Nonporous Steel Slag _ 2nd Repeat						Nonporous Steel Slag _2nd Repeat					
170	06/30/08	Nonporous Steel Slag _ 2nd Repeat				331	10.0	Nonporous Steel Slag _2nd Repeat				423	14.0
171	07/01/08	Nonporous Steel Slag _ 2nd Repeat						Nonporous Steel Slag _2nd Repeat					

DAY	DATE	CBR MOLD #1						CBR MOLD #2					
		Material #1	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)	Material #2	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)
172	07/02/08	Nonporous Steel Slag _ 2nd Repeat				337	6.0	Nonporous Steel Slag _2nd Repeat				431	8.0
173	07/03/08	Nonporous Steel Slag _ 2nd Repeat						Nonporous Steel Slag _2nd Repeat					
174	07/04/08	Nonporous Steel Slag _ 2nd Repeat						Nonporous Steel Slag _2nd Repeat					
175	07/05/08	Nonporous Steel Slag _ 2nd Repeat						Nonporous Steel Slag _2nd Repeat					
176	07/06/08	Nonporous Steel Slag _ 2nd Repeat						Nonporous Steel Slag _2nd Repeat					
177	07/07/08	Nonporous Steel Slag _ 2nd Repeat						Nonporous Steel Slag _2nd Repeat					
178	07/08/08	Nonporous Steel Slag _ 2nd Repeat						Nonporous Steel Slag _2nd Repeat					
179	07/09/08	Nonporous Steel Slag _ 2nd Repeat				350	13.0	Nonporous Steel Slag _2nd Repeat				455	24.0
180	07/10/08	Nonporous Steel Slag _ 2nd Repeat						Nonporous Steel Slag _2nd Repeat					
181	07/11/08	Nonporous Steel Slag _ 2nd Repeat	71.5	11.0	65.1	352	2.0	Nonporous Steel Slag _2nd Repeat	71.3	11.0	64.7	461	6.0
182	07/12/08	Nonporous Steel Slag _ 2nd Repeat						Nonporous Steel Slag _2nd Repeat					
183	07/13/08	Nonporous Steel Slag _ 2nd Repeat						Nonporous Steel Slag _2nd Repeat					
184	07/14/08	Nonporous Steel Slag _ 2nd Repeat	71.6	10.9	64.5	357	5.0	Nonporous Steel Slag _2nd Repeat	71.2	10.9	66.6	469.5	8.5
185	07/15/08	Steel Slag RAP_Standard Comp.		11.7	36.3	240.75		Steel Slag RAP_Standard Comp.		11.6	35.2	323.75	
186	07/16/08	Steel Slag RAP_Standard Comp.	72.3	10.8	66.4	238	-2.8	Steel Slag RAP_Standard Comp.	72.2	11.3	67.9	323	-0.8
187	07/17/08	Steel Slag RAP_Standard Comp.	72.9	11.0	65.5	244.0	6.0	Steel Slag RAP_Standard Comp.	72.6	11.2	64.7	328.0	5.0
188	07/18/08	Steel Slag RAP_Standard Comp.	72.6	11.3	69.2	242.0	-2.0	Steel Slag RAP_Standard Comp.	71.3	11.2	67.1	335.0	7.0
189	07/19/08	Steel Slag RAP_Standard Comp.	71.1	11.1	67.3	245.5	3.5	Steel Slag RAP_Standard Comp.	72.2	11.2	67.5	341.0	6.0
190	07/20/08	Steel Slag RAP_Standard Comp.	70.4	11.3	65.9	248.5	3.0	Steel Slag RAP_Standard Comp.	72.3	11.2	68.3	347.0	6.0
191	07/21/08	Steel Slag RAP_Standard Comp.	72.6	10.7	67.5	248.0	-0.5	Steel Slag RAP_Standard Comp.	72.5	11.1	68.1	348.0	1.0
192	07/22/08	Steel Slag RAP_Standard Comp.	71.4	11.0	66.9	250.0	2.0	Steel Slag RAP_Standard Comp.	71.6	11.2	66.7	350.0	2.0
193	07/23/08	Steel Slag RAP_Standard Comp.	72.1	11.1	67	255.0	5.0	Steel Slag RAP_Standard Comp.	72.2	11.2	67	354.0	4.0
194	07/24/08	Steel Slag RAP_Standard Comp.	72.5	12.0	64.7	252.0	-3.0	Steel Slag RAP_Standard Comp.	72	11.3	66.5	357.0	3.0

DAY	DATE	CBR MOLD #1						CBR MOLD #2					
		Material #1	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)	Material #2	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)
195	07/25/08	Steel Slag RAP_Standard Comp.	72.6	11.2	68.3	256.0	4.0	Steel Slag RAP_Standard Comp.	72.1	11.2	67.9	355.0	-2.0
196	07/26/08	Steel Slag RAP_Standard Comp.						Steel Slag RAP_Standard Comp.					
197	07/27/08	Steel Slag RAP_Standard Comp.						Steel Slag RAP_Standard Comp.					
198	07/28/08	Steel Slag RAP_Standard Comp.	72.4	11.0	69.1	262.0	6.0	Steel Slag RAP_Standard Comp.	72.1	11.0	68.9	365.0	10.0
199	07/29/08	Steel Slag RAP_Standard Comp.						Steel Slag RAP_Standard Comp.					
200	07/30/08	Steel Slag RAP_Standard Comp.	72.5	11.0	69.8	264.0	2.0	Steel Slag RAP_Standard Comp.	71.8	11.0	68.1	369.0	4.0
201	07/31/08	Steel Slag RAP_Standard Comp.						Steel Slag RAP_Standard Comp.					
202	08/01/08	Steel Slag RAP_Standard Comp.	72.6	11.2	66	267.0	3.0	Steel Slag RAP_Standard Comp.	72.1	11.1	67.6	372.0	3.0
203	08/02/08	Steel Slag RAP_Standard Comp.						Steel Slag RAP_Standard Comp.					
204	08/03/08	Steel Slag RAP_Standard Comp.						Steel Slag RAP_Standard Comp.					
205	08/04/08	Steel Slag RAP_Standard Comp.						Steel Slag RAP_Standard Comp.					
206	08/05/08	Steel Slag RAP_Standard Comp.	72.8	11.1	67	271.0	4.0	Steel Slag RAP_Standard Comp.	71.5	11.1	66	379.0	7.0
207	08/06/08	Steel Slag RAP_Standard Comp.						Steel Slag RAP_Standard Comp.					
208	08/07/08	Steel Slag RAP_Standard Comp.	72.4	11.0	67.2	275.0	4.0	Steel Slag RAP_Standard Comp.	72.2	11.0	67.3	380.0	1.0
209	08/08/08	Steel Slag RAP_Standard Comp.	70	11.1	67.1	278.0	3.0	Steel Slag RAP_Standard Comp.	72.1	11.2	66.8	382.0	2.0
210	08/09/08	Steel Slag RAP_Standard Comp.						Steel Slag RAP_Standard Comp.					
211	08/10/08	Steel Slag RAP_Standard Comp.						Steel Slag RAP_Standard Comp.					
212	08/11/08	Steel Slag RAP_Standard Comp.	68.8	11.1	60	279.0	1.0	Steel Slag RAP_Standard Comp.	71.8	11.0	64.8	388.0	6.0
213	08/12/08	Steel Slag RAP_Standard Comp.						Steel Slag RAP_Standard Comp.					
214	08/13/08	Steel Slag RAP_Standard Comp.						Steel Slag RAP_Standard Comp.					
215	08/14/08	Steel Slag RAP_Standard Comp.						Steel Slag RAP_Standard Comp.					
216	08/15/08	Steel Slag RAP_Standard Comp.						Steel Slag RAP_Standard Comp.					
217	08/16/08	Steel Slag RAP_Standard Comp.						Steel Slag RAP_Standard Comp.					
218	08/17/08	Steel Slag RAP_Standard Comp.						Steel Slag RAP_Standard Comp.					
219	08/18/08	Steel Slag RAP_Standard Comp.						Steel Slag RAP_Standard Comp.					
220	08/19/08	Steel Slag RAP_Standard Comp.						Steel Slag RAP_Standard Comp.					

DAY	DATE	CBR MOLD #1						CBR MOLD #2					
		Material #1	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)	Material #2	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)
221	08/20/08	Steel Slag RAP_Standard Comp.						Steel Slag RAP_Standard Comp.					
222	08/21/08	Steel Slag RAP_Standard Comp.						Steel Slag RAP_Standard Comp.					
223	08/22/08	Steel Slag RAP_Standard Comp.	70.5	10.7	52.9	290	11.0	Steel Slag RAP_Standard Comp.	71.2	11.3	57.9	396	8.0
224	08/23/08	Steel Slag RAP_Standard Comp.						Steel Slag RAP_Standard Comp.					
225	08/24/08	Steel Slag RAP_Standard Comp.						Steel Slag RAP_Standard Comp.					
226	08/25/08	Steel Slag RAP_Standard Comp.	70.8	10.0	65.5	287	-3.0	Steel Slag RAP_Standard Comp.	72.1	10.9	65.5	400	4.0
227	08/26/08	Steel Slag RAP_Standard Comp.						Steel Slag RAP_Standard Comp.					
228	08/27/08	Steel Slag RAP_Standard Comp.	71.3	10.1	64.6	288	1.0	Steel Slag RAP_Standard Comp.	72.1	10.8	66.6	398	-2.0
229	08/28/08	Steel Slag RAP_Standard Comp.						Steel Slag RAP_Standard Comp.					
230	08/29/08	Steel Slag RAP_Standard Comp.	72.6	10.0	65.9	290	2.0	Steel Slag RAP_Standard Comp.	71.9	10.7	66.7	405	7.0

DAY	DATE	CBR MOLD #3						CBR MOLD #4					
		Material #3	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)	Material #4	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)
1	01/13/08												
2	01/14/08												
3	01/15/08												
4	01/16/08												
5	01/17/08												
6	01/18/08												
7	01/19/08												
8	01/20/08												
9	01/21/08												
10	01/22/08												
11	01/23/08												
12	01/24/08												
13	01/25/08												
14	01/26/08												
15	01/27/08												
16	01/28/08												
17	01/29/08												
18	01/30/08												
19	01/31/08												
20	02/01/08												
21	02/02/08	Gravel-Crushed Stone RAP (ALL-FRK)	20	12.3	24.9	239		Gravel-Crushed Stone RAP (ALL-FRK)	19.7	12.3	25.3	214	
22	02/03/08	Gravel-Crushed Stone RAP (ALL-FRK)	71.4	11.4	67.8	138	-101.0	Gravel-Crushed Stone RAP (ALL-FRK)	69.8	11.5	66.6	117.25	-96.8
23	02/04/08	Gravel-Crushed Stone RAP (ALL-FRK)	72.1	11.3	68.8	133	-5.0	Gravel-Crushed Stone RAP (ALL-FRK)	70.6	11.4	64.3	113	-4.3
24	02/05/08	Gravel-Crushed Stone RAP (ALL-FRK)	71.8	11.3	67.6	130.25	-2.8	Gravel-Crushed Stone RAP (ALL-FRK)	69.1	11.3	64.7	110.5	-2.5

DAY	DATE	CBR MOLD #3						CBR MOLD #4					
		Material #3	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)	Material #4	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)
25	02/06/08	Gravel-Crushed Stone RAP (ALL-FRK)	71.7	11.4	65.1	129.5	-0.8	Gravel-Crushed Stone RAP (ALL-FRK)	69,1	11.4	62.8	110	-0.5
26	02/07/08	Gravel-Crushed Stone RAP (ALL-FRK)	71	11.4	64.7	128.5	-1.0	Gravel-Crushed Stone RAP (ALL-FRK)	68.2	11.4	60.8	109.25	-0.8
27	02/08/08	Gravel-Crushed Stone RAP (ALL-FRK)	71.2	11.2	67.4	127.5	-1.0	Gravel-Crushed Stone RAP (ALL-FRK)	69.7	11.2	65	108.75	-0.5
28	02/09/08	Gravel-Crushed Stone RAP (ALL-FRK)	70.2	11.3	64.5	127.25	-0.3	Gravel-Crushed Stone RAP (ALL-FRK)	68.6	11.1	65.5	108.75	0.0
29	02/10/08	Gravel-Crushed Stone RAP (ALL-FRK)	71.4	11.2	64.8	126.5	-0.8	Gravel-Crushed Stone RAP (ALL-FRK)	70.3	11.2	64	108.5	-0.3
30	02/11/08	Gravel-Crushed Stone RAP (ALL-FRK)	70.9	11.1	66.8	125.5	-1.0	Gravel-Crushed Stone RAP (ALL-FRK)	68.4	11.2	63.8	107.5	-1.0
31	02/12/08	Gravel-Crushed Stone RAP (ALL-FRK)	70.5	11.2	66.9	125	-0.5	Gravel-Crushed Stone RAP (ALL-FRK)	68.6	11.3	60.3	107	-0.5
32	02/13/08	Gravel-Crushed Stone RAP (ALL-FRK)	70.7	11.2	66.1	125	0.0	Gravel-Crushed Stone RAP (ALL-FRK)	69.5	11.2	64.7	107	0.0
33	02/14/08	Gravel-Crushed Stone RAP (ALL-FRK)	71	11.2	66	125	0.0	Gravel-Crushed Stone RAP (ALL-FRK)	69.9	11.2	63.9	106.5	-0.5
34	02/15/08	Gravel-Crushed Stone RAP (ALL-FRK)	71.1	11.2	64	124.5	-0.5	Gravel-Crushed Stone RAP (ALL-FRK)	69.2	11.2	63.3	106	-0.5
35	02/16/08	Dolomite from R27-1	Room	11.7	24.3	77.75		Dolomite from R27-1	Room	12.0	21.7	114	
36	02/17/08	Dolomite from R27-1	71.4	11.5	67.1	77.5	-0.3	Dolomite from R27-1	70.1	11.6	63.2	112.75	-1.3
37	02/18/08	Dolomite from R27-1	71.6	11.4	68.4	77.5	0.0	Dolomite from R27-1	69.4	11.6	64.4	112.25	-0.5
38	02/19/08	Dolomite from R27-1	71.1	11.4	68.1	77.25	-0.3	Dolomite from R27-1	69,1	11.5	64.2	112.25	0.0
39	02/20/08	Dolomite from R27-1	70.7	11.3	67.7	77	-0.3	Dolomite from R27-1	68.9	11.4	64	112	-0.3
40	02/21/08	Dolomite from R27-1	70.8	11.3	66.2	77	0.0	Dolomite from R27-1	68	11.3	63.9	112	0.0
41	02/22/08	Dolomite from R27-1						Dolomite from R27-1					
42	02/23/08	Dolomite from R27-1	71.7	11.3	67.8	76.5	-0.5	Dolomite from R27-1	69.7	11.4	63.7	112	0.0
43	02/24/08	Dolomite from R27-1	70.6	11.2	66.6	76.5	0.0	Dolomite from R27-1	67.8	11.3	64	112	0.0
44	02/25/08	Dolomite from R27-1	70.9	11.2	67.2	76.5	0.0	Dolomite from R27-1	69.5	11.2	65.2	112	0.0
45	02/26/08	Dolomite from R27-1	71.6	11.2	67.1	77.25	0.8	Dolomite from R27-1	69.4	11.3	65.3	111.75	-0.3
46	02/27/08	Dolomite from R27-1	70.7	11.2	67.4	76.5	-0.8	Dolomite from R27-1	68.7	11.3	64.5	111.5	-0.3

DAY	DATE	CBR MOLD #3 Material #3	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)	CBR MOLD #4 Material #4	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)
47	02/28/08	Dolomite from R27-1	71.2	11.3	62	76.5	0.0	Dolomite from R27-1	68.5	11.3	61.1	111.5	0.0
48	02/29/08	Dolomite from R27-1	70.7	11.1	63.1	76.5	0.0	Dolomite from R27-1	69.6	11.3	62.8	111.5	0.0
49	03/01/08	Dolomite from R27-1	71.8	11.1	64.5	76.5	0.0	Dolomite from R27-1	70	11.1	65.2	111.5	0.0
50	03/02/08	Dolomite from R27-1						Dolomite from R27-1					
51	03/03/08	Dolomite from R27-1	71.3	11.1	63.2	76.5	0.0	Dolomite from R27-1	68.4	11.0	63.1	111.5	0.0
52	03/04/08	Dolomite from R27-1						Dolomite from R27-1					
53	03/05/08	Dolomite from R27-1	70.9	10.8	66.7	76.75	0.3	Dolomite from R27-1	68.9	11.0	63.3	111.5	0.0
54	03/06/08	Dolomite from R27-1						Dolomite from R27-1					
55	03/07/08	Dolomite from R27-1						Dolomite from R27-1					
56	03/08/08	Dolomite from R27-1	70.5	11.1	64.7	76.75	0.0	Dolomite from R27-1	67	11.2	60.6	111.5	0.0
57	03/09/08												
58	03/10/08	Gravel Crushed Concrete	Room	12.1	23.0	52		Gravel Crushed Concrete	Room	12.2	23.1	135	
59	03/11/08	Gravel Crushed Concrete	70.6	11.7	63.2	52.25	0.3	Gravel Crushed Concrete	69.5	11.6	62.9	135.75	0.8
60	03/12/08	Gravel Crushed Concrete	70.6	11.3	68.1	52.25	0.0	Gravel Crushed Concrete	70	11.5	65.6	135.5	-0.3
61	03/13/08	Gravel Crushed Concrete	71.6	11.2	68.5	52.25	0.0	Gravel Crushed Concrete	70.7	11.3	66.3	135.25	-0.3
62	03/14/08	Gravel Crushed Concrete	71.1	11.3	66.9	52.5	0.3	Gravel Crushed Concrete	70.1	11.4	64.5	135.5	0.3
63	03/15/08	Gravel Crushed Concrete	34.3	12.1	34.3	53.25	0.8	Gravel Crushed Concrete	33.2	12.4	33.2	136.25	0.8
64	03/16/08	Gravel Crushed Concrete						Gravel Crushed Concrete					
65	03/17/08	Gravel Crushed Concrete	18.2	12.7	18.2	53.75	0.5	Gravel Crushed Concrete	18.2	12.6	18.5	136.75	0.5
66	03/18/08												
67	03/19/08												
68	03/20/08												
69	03/21/08												
70	03/22/08												
71	03/23/08												

DAY	DATE	CBR MOLD #3						CBR MOLD #4					
		Material #3	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)	Material #4	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)
72	03/24/08												
73	03/25/08	ACBF Slag	Room	12.5	21.1	203		ACBF Slag	Room	12.4	19.8	106	
74	03/26/08	ACBF Slag	69.7	11.2	65.5	201.25	-1.8	ACBF Slag	69.2	11.1	65.3	103	-3.0
75	03/27/08	ACBF Slag	68.1	11.3	65	201.5	0.3	ACBF Slag	69.1	11.0	63.8	103.5	0.5
76	03/28/08	ACBF Slag	69.2	11.3	65.1	201.5	0.0	ACBF Slag	68.5	11.3	64.5	104	0.5
77	03/29/08	ACBF Slag	71.7	11.0	68.4	202	0.5	ACBF Slag	70.5	11.2	65.2	104.25	0.3
78	03/30/08	ACBF Slag	71.5	11.1	67.9	202	0.0	ACBF Slag	70.3	11.2	65.1	104.25	0.0
79	03/31/08	ACBF Slag	72.2	11.1	68.1	202.25	0.3	ACBF Slag	70.9	11.2	66.3	104.5	0.3
80	04/01/08	ACBF Slag						ACBF Slag					
81	04/02/08	ACBF Slag	71.2	11.1	67.9	202.5	0.3	ACBF Slag	70.9	11.1	66.5	104.5	0.0
82	04/03/08	ACBF Slag						ACBF Slag					
83	04/04/08	ACBF Slag	71.8	11.1	67.2	202.5	0.0	ACBF Slag	70.5	11.1	66.4	104.5	0.0
84	04/05/08	ACBF Slag						ACBF Slag					
85	04/06/08	ACBF Slag						ACBF Slag					
86	04/07/08	ACBF Slag	71.9	11.1	65.3	202.5	0.0	ACBF Slag	70.5	11.1	66.4	104.5	0.0
87	04/08/08	ACBF Slag						ACBF Slag					
88	04/09/08	ACBF Slag	70.2	11.1	66	202.5	0.0	ACBF Slag	70	11.1	66.6	104.5	0.0
89	04/10/08	ACBF Slag						ACBF Slag					
90	04/11/08	ACBF Slag	72.2	11.0	68.1	202.5	0.0	ACBF Slag	69.7	11.1	65.1	104.5	0.0
91	04/12/08	ACBF Slag						ACBF Slag					
92	04/13/08	ACBF Slag						ACBF Slag					
93	04/14/08	ACBF Slag	71.3	11.1	64.7	202.5	0.0	ACBF Slag	70.3	11.0	66.2	103.25	-1.3
94	04/15/08	ACBF Slag						ACBF Slag					
95	04/16/08	ACBF Slag						ACBF Slag					
96	04/17/08	ACBF Slag		11.1	66.3	202	-0.5	ACBF Slag		11.1	66.6	103	-0.3

DAY	DATE	CBR MOLD #3 Material #3	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)	CBR MOLD #4 Material #4	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)
97	04/18/08	ACBF Slag						ACBF Slag					
98	04/19/08	ACBF Slag						ACBF Slag					
99	04/20/08	ACBF Slag						ACBF Slag					
100	04/21/08	ACBF Slag						ACBF Slag					
101	04/22/08	ACBF Slag		11.0	67.3	202	0.0	ACBF Slag		11.0	66.9	102	-1.0
102	04/23/08	ACBF Slag						ACBF Slag					
103	04/24/08	ACBF Slag						ACBF Slag					
104	04/25/08	ACBF Slag						ACBF Slag					
		ACBF Slag	71.5	11.2	64.9	202.5	0.5	ACBF Slag	69.7	11.1	64	103	1.0
105	04/26/08	Nonporous Steel Slag _ Repeat	Room	12.2	22.4	101.75		Nonporous Steel Slag _ Repeat	Room	12.2	22.2	126.25	
106	04/27/08	Nonporous Steel Slag _ Repeat	71.6	11.2	64.9	113	11.3	Nonporous Steel Slag _ Repeat	69.7	11.2	65	125.5	-0.8
107	04/28/08	Nonporous Steel Slag _ Repeat	72.2	11.2	64	147	34.0	Nonporous Steel Slag _ Repeat	71	11.3	133	133	7.5
108	04/29/08	Nonporous Steel Slag _ Repeat	72	11.0	65.5	178	31.0	Nonporous Steel Slag _ Repeat	70.8	11.2	65.3	154	21.0
109	04/30/08	Nonporous Steel Slag _ Repeat	71.7	11.1	64.2	197	19.0	Nonporous Steel Slag _ Repeat	70.2	11.2	65.3	182	28.0
110	05/01/08	Nonporous Steel Slag _ Repeat	70.4	11.2	64.1	216.5	19.5	Nonporous Steel Slag _ Repeat	70.2	11.2	64.8	209	27.0
111	05/02/08	Nonporous Steel Slag _ Repeat	70.7	11.2	63.9	229	12.5	Nonporous Steel Slag _ Repeat	70.3	11.2	64.2	227	18.0
112	05/03/08	Nonporous Steel Slag _ Repeat						Nonporous Steel Slag _ Repeat					
113	05/04/08	Nonporous Steel Slag _ Repeat	72.1	11.0	67	254.5	25.5	Nonporous Steel Slag _ Repeat	70.6	11.0	64.6	264	37.0
114	05/05/08	Nonporous Steel Slag _ Repeat						Nonporous Steel Slag _ Repeat					
115	05/06/08	Nonporous Steel Slag _ Repeat						Nonporous Steel Slag _ Repeat					
116	05/07/08	Nonporous Steel Slag _ Repeat						Nonporous Steel Slag _ Repeat					
117	05/08/08	Nonporous Steel Slag _ Repeat	72.1	11.1	67	284	29.5	Nonporous Steel Slag _ Repeat	71.1	11.0	66.2	308	44.0
118	05/09/08	Nonporous Steel Slag _ Repeat						Nonporous Steel Slag _ Repeat					
119	05/10/08	Nonporous Steel Slag _ Repeat						Nonporous Steel Slag _ Repeat					
120	05/11/08	Nonporous Steel Slag _ Repeat						Nonporous Steel Slag _ Repeat					

DAY	DATE	CBR MOLD #3 Material #3	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)	CBR MOLD #4 Material #4	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)
121	05/12/08	Nonporous Steel Slag _ Repeat						Nonporous Steel Slag _ Repeat					
122	05/13/08	Nonporous Steel Slag _ Repeat	72.1	11.1	66.1	314.5	30.5	Nonporous Steel Slag _ Repeat	71.5	11.0	67.7	341.5	33.5
123	05/14/08	Nonporous Steel Slag _ Repeat						Nonporous Steel Slag _ Repeat					
124	05/15/08	Nonporous Steel Slag _ Repeat						Nonporous Steel Slag _ Repeat					
125	05/16/08	Nonporous Steel Slag _ Repeat						Nonporous Steel Slag _ Repeat					
126	05/17/08	Nonporous Steel Slag _ Repeat						Nonporous Steel Slag _ Repeat					
127	05/18/08	Nonporous Steel Slag _ Repeat	71.3	11.1	66.4	341	26.5	Nonporous Steel Slag _ Repeat	70.7	11.1	67.2	363	21.5
128	05/19/08	Nonporous Steel Slag _ Repeat						Nonporous Steel Slag _ Repeat					
129	05/20/08	Nonporous Steel Slag _ Repeat						Nonporous Steel Slag _ Repeat					
130	05/21/08	Nonporous Steel Slag _ Repeat						Nonporous Steel Slag _ Repeat					
131	05/22/08	Nonporous Steel Slag _ Repeat						Nonporous Steel Slag _ Repeat					
132	05/23/08	Nonporous Steel Slag _ Repeat						Nonporous Steel Slag _ Repeat					
133	05/24/08	Nonporous Steel Slag _ Repeat	71.7	11.0	67.9	372	31.0	Nonporous Steel Slag _ Repeat	69.9	11.1	66.9	389	26.0
134	05/25/08												
135	05/26/08	Porous Steel Slag _ Repeat	Room	12.5	30.1	157		Porous Steel Slag _ Repeat	Room	12.6	30.1	86	
136	05/27/08	Porous Steel Slag _ Repeat	70.9	11.2	67.1	168.5	11.5	Porous Steel Slag _ Repeat	68.8	11.4	64.6	94	8.0
137	05/28/08	Porous Steel Slag _ Repeat	72.3	11.2	67.6	188.5	20.0	Porous Steel Slag _ Repeat	71.2	11.3	67.2	115	21.0
138	05/29/08	Porous Steel Slag _ Repeat	71.8	11.1	68.4	200.5	12.0	Porous Steel Slag _ Repeat	70.6	11.3	66.6	125	10.0
139	05/30/08	Porous Steel Slag _ Repeat	72.3	11.1	68.7	214	13.5	Porous Steel Slag _ Repeat	71.2	11.3	66.6	138	13.0
140	05/31/08	Porous Steel Slag _ Repeat	72.4	11.1	69.4	226	12.0	Porous Steel Slag _ Repeat	71.8	11.2	66.9	145	7.0
141	06/01/08	Porous Steel Slag _ Repeat	72.4	11.1	69.6	237	11.0	Porous Steel Slag _ Repeat	71.6	11.2	67	151.5	6.5
142	06/02/08	Porous Steel Slag _ Repeat						Porous Steel Slag _ Repeat					
143	06/03/08	Porous Steel Slag _ Repeat	72.5	11.0	69.8	247.5	10.5	Porous Steel Slag _ Repeat	71.1	11.2	67.3	160.5	9.0
144	06/04/08	Porous Steel Slag _ Repeat						Porous Steel Slag _ Repeat					
145	06/05/08	Porous Steel Slag _ Repeat	72.4	11.0	69.3	255	7.5	Porous Steel Slag _ Repeat	71.3	11.1	67.5	168.75	8.3

DAY	DATE	CBR MOLD #3						CBR MOLD #4					
		Material #3	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)	Material #4	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)
146	06/06/08	Porous Steel Slag _ Repeat						Porous Steel Slag _ Repeat					
147	06/07/08	Porous Steel Slag _ Repeat						Porous Steel Slag _ Repeat					
148	06/08/08	Porous Steel Slag _ Repeat	72.6	11.1	68.3	266.5	11.5	Porous Steel Slag _ Repeat	70.5	11.1	67.1	181.5	12.8
149	06/09/08	Porous Steel Slag _ Repeat						Porous Steel Slag _ Repeat					
150	06/10/08	Porous Steel Slag _ Repeat						Porous Steel Slag _ Repeat					
151	06/11/08	Porous Steel Slag _ Repeat						Porous Steel Slag _ Repeat					
152	06/12/08	Porous Steel Slag _ Repeat						Porous Steel Slag _ Repeat					
153	06/13/08	Porous Steel Slag _ Repeat				282	15.5	Porous Steel Slag _ Repeat				196	14.5
154	06/14/08	Porous Steel Slag _ Repeat						Porous Steel Slag _ Repeat					
155	06/15/08	Porous Steel Slag _ Repeat						Porous Steel Slag _ Repeat					
156	06/16/08	Porous Steel Slag _ Repeat				291	9.0	Porous Steel Slag _ Repeat				203	7.0
157	06/17/08	Porous Steel Slag _ Repeat						Porous Steel Slag _ Repeat					
158	06/18/08	Porous Steel Slag _ Repeat				298	7.0	Porous Steel Slag _ Repeat				208	5.0
159	06/19/08	Porous Steel Slag _ Repeat						Porous Steel Slag _ Repeat					
160	06/20/08	Porous Steel Slag _ Repeat				304	6.0	Porous Steel Slag _ Repeat				213	5.0
161	06/21/08	Porous Steel Slag _ Repeat						Porous Steel Slag _ Repeat					
162	06/22/08	Porous Steel Slag _ Repeat						Porous Steel Slag _ Repeat					
163	06/23/08	Porous Steel Slag _ Repeat				310	6.0	Porous Steel Slag _ Repeat				226	13.0
164	06/24/08	Porous Steel Slag _ Repeat						Porous Steel Slag _ Repeat					
165	06/25/08	Porous Steel Slag _ Repeat				317	7.0	Porous Steel Slag _ Repeat				225	-1.0
166	06/26/08	Porous Steel Slag _ Repeat						Porous Steel Slag _ Repeat					
167	06/27/08	Porous Steel Slag _ Repeat						Porous Steel Slag _ Repeat					
168	06/28/08	Porous Steel Slag _ Repeat						Porous Steel Slag _ Repeat					
169	06/29/08	Porous Steel Slag _ Repeat						Porous Steel Slag _ Repeat					
170	06/30/08	Porous Steel Slag _ Repeat				326	9.0	Porous Steel Slag _ Repeat				237	12.0

DAY	DATE	CBR MOLD #3 Material #3	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)	CBR MOLD #4 Material #4	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)
171	07/01/08	Porous Steel Slag _ Repeat						Porous Steel Slag _ Repeat					
172	07/02/08	Porous Steel Slag _ Repeat				332	6.0	Porous Steel Slag _ Repeat				240	3.0
173	07/03/08	Porous Steel Slag _ Repeat						Porous Steel Slag _ Repeat					
174	07/04/08	Porous Steel Slag _ Repeat						Porous Steel Slag _ Repeat					
175	07/05/08	Porous Steel Slag _ Repeat						Porous Steel Slag _ Repeat					
176	07/06/08	Porous Steel Slag _ Repeat						Porous Steel Slag _ Repeat					
177	07/07/08	Porous Steel Slag _ Repeat						Porous Steel Slag _ Repeat					
178	07/08/08	Porous Steel Slag _ Repeat						Porous Steel Slag _ Repeat					
179	07/09/08	Porous Steel Slag _ Repeat				349	17.0	Porous Steel Slag _ Repeat				252	12.0
180	07/10/08	Porous Steel Slag _ Repeat						Porous Steel Slag _ Repeat					
181	07/11/08	Porous Steel Slag _ Repeat	70.9	11.2	66.3	354	5.0	Porous Steel Slag _ Repeat	69.5	11.2	66	255	3.0
182	07/12/08	Porous Steel Slag _ Repeat						Porous Steel Slag _ Repeat					
183	07/13/08	Porous Steel Slag _ Repeat						Porous Steel Slag _ Repeat					
184	07/14/08	Porous Steel Slag _ Repeat	71.5	11.1	67.9	362	8.0	Porous Steel Slag _ Repeat	70.7	11.2	66.3	260.5	5.5
185	07/15/08	Steel Slag RAP		11.7	34.8	211.75		Steel Slag RAP		11.9	33.2	196.75	
186	07/16/08	Steel Slag RAP	72.2	11.0	68.6	162.5	-49.3	Steel Slag RAP	70.7	11.0	65.4	150	-46.8
187	07/17/08	Steel Slag RAP	72.8	11.5	64.2	151.0	-11.5	Steel Slag RAP	71.9	11.1	64.9	144.0	-6.0
188	07/18/08	Steel Slag RAP	72.5	11.1	66.7	152.0	1.0	Steel Slag RAP	70.9	10.9	65.8	142.0	-2.0
189	07/19/08	Steel Slag RAP	71.9	11.1	67.2	153.0	1.0	Steel Slag RAP	71.3	11.0	66.3	141.0	-1.0
190	07/20/08	Steel Slag RAP	72.5	11.1	67.8	154.0	1.0	Steel Slag RAP	72	11.0	67.6	140.0	-1.0
191	07/21/08	Steel Slag RAP	72	11.1	67	154.0	0.0	Steel Slag RAP	71.2	11.0	68.4	138.0	-2.0
192	07/22/08	Steel Slag RAP	72.2	11.0	68.1	154.0	0.0	Steel Slag RAP	71.6	11.0	65.1	135.0	-3.0
193	07/23/08	Steel Slag RAP	72.3	11.2	66.9	152.0	-2.0	Steel Slag RAP	70.9	11.2	66.9	138.0	3.0
194	07/24/08	Steel Slag RAP	72.5	11.2	66.5	152.0	0.0	Steel Slag RAP	71	11.0	66.5	139.0	1.0
195	07/25/08	Steel Slag RAP	72.7	11.2	68.1	154.0	2.0	Steel Slag RAP	71.5	11.2	66.9	138.0	-1.0

DAY	DATE	CBR MOLD #3						CBR MOLD #4					
		Material #3	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)	Material #4	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)
196	07/26/08	Steel Slag RAP						Steel Slag RAP					
197	07/27/08	Steel Slag RAP						Steel Slag RAP					
198	07/28/08	Steel Slag RAP	72.4	11.2	68.6	158.0	4.0	Steel Slag RAP	71.2	11.1	68	144.0	6.0
199	07/29/08	Steel Slag RAP						Steel Slag RAP					
200	07/30/08	Steel Slag RAP	71.9	11.1	68.3	161.0	3.0	Steel Slag RAP	71	11.1	68	146.0	2.0
201	07/31/08	Steel Slag RAP						Steel Slag RAP					
202	08/01/08	Steel Slag RAP	72.3	11.2	67	163.0	2.0	Steel Slag RAP	71.5	11.0	66.5	148.0	2.0
203	08/02/08	Steel Slag RAP						Steel Slag RAP					
204	08/03/08	Steel Slag RAP						Steel Slag RAP					
205	08/04/08	Steel Slag RAP						Steel Slag RAP					
206	08/05/08	Steel Slag RAP	72.6	11.2	66.5	172.0	9.0	Steel Slag RAP	71.4	11.2	66	160.0	12.0
207	08/06/08	Steel Slag RAP						Steel Slag RAP					
208	08/07/08	Steel Slag RAP	72.3	11.1	66.8	178.0	6.0	Steel Slag RAP	71.4	11.1	67.1	159.0	-1.0
209	08/08/08	Steel Slag RAP	72.4	11.2	66.9	187.0	9.0	Steel Slag RAP	71.7	11.3	66.5	152.0	-7.0
210	08/09/08	Steel Slag RAP						Steel Slag RAP					
211	08/10/08	Steel Slag RAP						Steel Slag RAP					
212	08/11/08	Steel Slag RAP	72	11.1	66.5	179.0	-8.0	Steel Slag RAP	71.4	11.2	66	163.0	11.0
213	08/12/08	Steel Slag RAP						Steel Slag RAP					
214	08/13/08	Steel Slag RAP						Steel Slag RAP					
215	08/14/08	Steel Slag RAP						Steel Slag RAP					
216	08/15/08	Steel Slag RAP						Steel Slag RAP					
217	08/16/08	Steel Slag RAP						Steel Slag RAP					
218	08/17/08	Steel Slag RAP						Steel Slag RAP					
219	08/18/08	Steel Slag RAP						Steel Slag RAP					
220	08/19/08	Steel Slag RAP						Steel Slag RAP					

DAY	DATE	CBR MOLD #3						CBR MOLD #4					
		Material #3	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)	Material #4	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)
221	08/20/08	Steel Slag RAP						Steel Slag RAP					
222	08/21/08	Steel Slag RAP						Steel Slag RAP					
223	08/22/08	Steel Slag RAP	71.7	11.2	61.5	196.0	17.0	Steel Slag RAP	69.4	11.2	62	185.0	22.0
224	08/23/08	Steel Slag RAP						Steel Slag RAP					
225	08/24/08	Steel Slag RAP						Steel Slag RAP					
226	08/25/08	Steel Slag RAP	71.7	11.0	66.9	194.0	-2.0	Steel Slag RAP	70.2	11.2	66.3	190.0	5.0
227	08/26/08	Steel Slag RAP						Steel Slag RAP					
228	08/27/08	Steel Slag RAP	72.6	11.0	66.2	199.0	5.0	Steel Slag RAP	71.9	11.1	65.9	196.0	6.0
229	08/28/08	Steel Slag RAP						Steel Slag RAP					
230	08/29/08	Steel Slag RAP	72.8	10.9	66.5	198.0	-1.0	Steel Slag RAP	71.5	11.0	65.5	192.0	-4.0

DAY	DATE	CBR MOLD #5						CBR MOLD #6					
		Material #5	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)	Material #6	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)
1	01/13/08												
2	01/14/08												
3	01/15/08												
4	01/16/08												
5	01/17/08												
6	01/18/08												
7	01/19/08												
8	01/20/08												
9	01/21/08												
10	01/22/08												
11	01/23/08												
12	01/24/08												
13	01/25/08												
14	01/26/08												
15	01/27/08												
16	01/28/08												
17	01/29/08												
18	01/30/08												
19	01/31/08												
20	02/01/08												
21	02/02/08	Surface(%92 surface steel slag)	23.8	12.2	29.2	44.25		Surface(%92 surface steel slag)	20	12.3	27.5	60.5	
22	02/03/08	Surface(%92 surface steel slag)	71.7	11.5	62.5	21.25	-23.0	Surface(%92 surface steel slag)	70.8	11.6	62.6	31	-29.5
23	02/04/08	Surface(%92 surface steel slag)	72	11.5	65.7	24.75	3.5	Surface(%92 surface steel slag)	70.6	11.6	62.2	32	1.0
24	02/05/08	Surface(%92 surface steel slag)	72.3	11.3	67.2	32.5	7.8	Surface(%92 surface steel slag)	70	11.2	66.3	36	4.0
25	02/06/08	Surface(%92 surface steel slag)	71.1	11.3	66.3	37	4.5	Surface(%92 surface steel slag)	69.5	11.4	64.3	40	4.0

DAY	DATE	CBR MOLD #5 Material #5	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)	CBR MOLD #6 Material #6	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)
26	02/07/08	Surface(%92 surface steel slag)	70.3	11.4	61.7	42.5	5.5	Surface(%92 surface steel slag)	68.7	11.4	63.6	43	3.0
27	02/08/08	Surface(%92 surface steel slag)	70	11.3	65	47	4.5	Surface(%92 surface steel slag)	70.1	11.3	64.3	46.25	3.3
28	02/09/08	Surface(%92 surface steel slag)	70.4	11.3	63.8	50.25	3.3	Surface(%92 surface steel slag)	67.7	11.3	62.2	49	2.8
29	02/10/08	Surface(%92 surface steel slag)	69.6	11.3	63.7	52.5	2.3	Surface(%92 surface steel slag)	71	11.3	63.5	51.75	2.8
30	02/11/08	Surface(%92 surface steel slag)	70.9	11.3	63.3	55	2.5	Surface(%92 surface steel slag)	68.8	11.3	65.5	54	2.3
31	02/12/08	Surface(%92 surface steel slag)	70.7	11.3	65.4	58.5	3.5	Surface(%92 surface steel slag)	68.1	11.2	64.5	56.75	2.8
32	02/13/08	Surface(%92 surface steel slag)	71	11.3	65.5	61.25	2.8	Surface(%92 surface steel slag)	68.9	11.3	64.6	59.5	2.8
33	02/14/08	Surface(%92 surface steel slag)	70.4	11.2	65.2	63.75	2.5	Surface(%92 surface steel slag)	69.2	11.4	63.1	61.5	2.0
34	02/15/08	Surface(%92 surface steel slag)	71.1	11.2	67.1	66	2.3	Surface(%92 surface steel slag)	69.7	11.2	65.1	63.5	2.0
35	02/16/08	Surface(%92 surface steel slag)	71.7	11.3	64	69	3.0	Surface(%92 surface steel slag)	70	11.3	62.1	66	2.5
36	02/17/08	Surface(%92 surface steel slag)	71.1	11.2	66.3	70.25	1.3	Surface(%92 surface steel slag)	70.1	11.2	65.7	68.25	2.3
37	02/18/08	Surface(%92 surface steel slag)	70.6	11.2	63.8	72.5	2.3	Surface(%92 surface steel slag)	69.7	11.2	65.3	70.25	2.0
38	02/19/08	Surface(%92 surface steel slag)	70.9	11.1	64.1	74.75	2.3	Surface(%92 surface steel slag)	69.1	11.2	65	72.5	2.3
39	02/20/08	Surface(%92 surface steel slag)	71.1	11.1	64.6	77	2.3	Surface(%92 surface steel slag)	68.9	11.1	64.6	74.5	2.0
40	02/21/08	Surface(%92 surface steel slag)	71.2	11.0	65	79	2.0	Surface(%92 surface steel slag)	68.6	11.2	62.6	75.75	1.3
41	02/22/08	Surface(%92 surface steel slag)						Surface(%92 surface steel slag)					
42	02/23/08	Surface(%92 surface steel slag)	70.6	11.0	64.7	83	4.0	Surface(%92 surface steel slag)	68.9	11.1	63	79	3.3
43	02/24/08	Surface(%92 surface steel slag)	71.5	11.0	63.4	85.25	2.3	Surface(%92 surface steel slag)	68.9	11.1	64	80.75	1.8
44	02/25/08	Surface(%92 surface steel slag)	71.2	11.1	61.7	86.75	1.5	Surface(%92 surface steel slag)	69.6	11.1	63	82	1.3
45	02/26/08	Surface(%92 surface steel slag)	70.9	11.0	63.2	88.5	1.8	Surface(%92 surface steel slag)	70.2	11.0	65.4	83.25	1.3
46	02/27/08	Surface(%92 surface steel slag)	70.4	11.0	64	89.75	1.3	Surface(%92 surface steel slag)	67.8	11.0	62.1	85	1.8
47	02/28/08	Surface(%92 surface steel slag)	69.7	11.0	56.1	90.75	1.0	Surface(%92 surface steel slag)	69.9	11.0	60.4	86.5	1.5
48	02/29/08	Surface(%92 surface steel slag)				92	1.3	Surface(%92 surface steel slag)				88	1.5
49	03/01/08	Surface(%92 surface steel slag)	70.9	11.1	60.3	93.5	1.5	Surface(%92 surface steel slag)	70.1	11.0	61	89.25	1.3
50	03/02/08	Surface(%92 surface steel slag)						Surface(%92 surface steel slag)					

DAY	DATE	CBR MOLD #5						CBR MOLD #6					
		Material #5	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)	Material #6	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)
51	03/03/08	Surface(%92 surface steel slag)	71.3	10.8	64.3	96	2.5	Surface(%92 surface steel slag)	69.1	10.9	62.1	92	2.8
52	03/04/08	Surface(%92 surface steel slag)						Surface(%92 surface steel slag)					
53	03/05/08	Surface(%92 surface steel slag)	69.5	10.7	55.3	98.5	2.5	Surface(%92 surface steel slag)	68.3	10.7	62.3	94.5	2.5
54	03/06/08	Surface(%92 surface steel slag)						Surface(%92 surface steel slag)					
55	03/07/08	Surface(%92 surface steel slag)						Surface(%92 surface steel slag)					
56	03/08/08	Surface(%92 surface steel slag)	69.2	10.7	63.9	102	3.5	Surface(%92 surface steel slag)	67.5	10.9	60.1	99	4.5
57	03/09/08	Surface(%92 surface steel slag)						Surface(%92 surface steel slag)					
58	03/10/08	Surface(%92 surface steel slag)	70.5	10.6	65.3	103.75	1.8	Surface(%92 surface steel slag)	69.7	10.6	64	101.25	2.3
59	03/11/08	Surface(%92 surface steel slag)	69.4	10.9	60.9	104.25	0.5	Surface(%92 surface steel slag)	69.1	10.9	58.5	101.5	0.3
60	03/12/08	Surface(%92 surface steel slag)	70.8	10.6	67.5	104.25	0.0	Surface(%92 surface steel slag)	67.2	10.6	63.6	102.25	0.8
61	03/13/08	Surface(%92 surface steel slag)	70.6	10.7	66.9	104.25	0.0	Surface(%92 surface steel slag)	70.2	10.7	64	103.5	1.3
62	03/14/08	Surface(%92 surface steel slag)	67.9	10.6	65	105	0.8	Surface(%92 surface steel slag)	69.8	10.5	65.2	104.75	1.3
63	03/15/08	Surface(%92 surface steel slag)	30.6			105	0.0	Surface(%92 surface steel slag)	34.1	12.0	29.8	105	0.3
64	03/16/08	Surface(%92 surface steel slag)						Surface(%92 surface steel slag)					
65	03/17/08	Surface(%92 surface steel slag)	17.9			105	0.0	Surface(%92 surface steel slag)	18.1	12.4	17.6	105	0.0
66	03/18/08												
67	03/19/08												
68	03/20/08												
69	03/21/08												
70	03/22/08												
71	03/23/08												
72	03/24/08												
73	03/25/08	ACBF RAP Slag	Room	12.4	25.1	222.25		ACBF RAP Slag	Room	12.5	23	240	
74	03/26/08	ACBF RAP Slag	70.8	11.2	65.9	115.25	-107.0	ACBF RAP Slag	69.4	11.3	66.1	145.25	-94.8
75	03/27/08	ACBF RAP Slag	70.6	11.2	65.7	114.75	-0.5	ACBF RAP Slag	68.6	11.3	64.6	144.5	-0.8

DAY	DATE	CBR MOLD #5						CBR MOLD #6					
		Material #5	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)	Material #6	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)
76	03/28/08	ACBF RAP Slag	67.3	11.3	63.1	114	-0.8	ACBF RAP Slag	67.6	11.3	63.8	143.5	-1.0
77	03/29/08	ACBF RAP Slag	71.5	11.1	68.7	113	-1.0	ACBF RAP Slag	70.5	11.2	65.6	141	-2.5
78	03/30/08	ACBF RAP Slag	71.7	11.1	68.9	112.5	-0.5	ACBF RAP Slag	70.1	11.3	65.1	140	-1.0
79	03/31/08	ACBF RAP Slag	72.3	11.1	69.1	112	-0.5	ACBF RAP Slag	70.5	11.2	65.3	139.5	-0.5
80	04/01/08	ACBF RAP Slag						ACBF RAP Slag					
81	04/02/08	ACBF RAP Slag	72.7	11.1	68.9	111	-1.0	ACBF RAP Slag	70.8	11.2	66.2	138.25	-1.3
82	04/03/08	ACBF RAP Slag						ACBF RAP Slag					
83	04/04/08	ACBF RAP Slag	71.9	11.2	66.9	110.25	-0.8	ACBF RAP Slag	70.7	11.2	66.7	137.5	-0.8
84	04/05/08	ACBF RAP Slag						ACBF RAP Slag					
85	04/06/08	ACBF RAP Slag						ACBF RAP Slag					
86	04/07/08	ACBF RAP Slag	72	11.1	67.7	110	-0.3	ACBF RAP Slag	70.6	11.2	65.4	137.25	-0.3
87	04/08/08	ACBF RAP Slag						ACBF RAP Slag					
88	04/09/08	ACBF RAP Slag	71.8	11.0	67.8	109.5	-0.5	ACBF RAP Slag	70.4	11.1	66.3	136.75	-0.5
89	04/10/08	ACBF RAP Slag						ACBF RAP Slag					
90	04/11/08	ACBF RAP Slag	71.5	11.0	68.3	109	-0.5	ACBF RAP Slag	71	11.1	66.1	136	-0.8
91	04/12/08	ACBF RAP Slag						ACBF RAP Slag					
92	04/13/08	ACBF RAP Slag						ACBF RAP Slag					
93	04/14/08	ACBF RAP Slag	70.6	11.0	66.3	109	0.0	ACBF RAP Slag	70.8	11.1	67	135.5	-0.5
94	04/15/08	ACBF RAP Slag						ACBF RAP Slag					
95	04/16/08	ACBF RAP Slag						ACBF RAP Slag					
96	04/17/08	ACBF RAP Slag		11.3	64	108.5	-0.5	ACBF RAP Slag		11.1	65.1	135	-0.5
97	04/18/08	ACBF RAP Slag						ACBF RAP Slag					
98	04/19/08	ACBF RAP Slag						ACBF RAP Slag					
99	04/20/08	ACBF RAP Slag						ACBF RAP Slag					
100	04/21/08	ACBF RAP Slag						ACBF RAP Slag					

		CBR MOLD #5						CBR MOLD #6					
DAY	DATE	Material #5	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)	Material #6	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)
101	04/22/08	ACBF RAP Slag		11.0	67.6	108	-0.5	ACBF RAP Slag		11.0	62.9	135	0.0
102	04/23/08	ACBF RAP Slag						ACBF RAP Slag					
103	04/24/08	ACBF RAP Slag						ACBF RAP Slag					
104	04/25/08	ACBF RAP Slag						ACBF RAP Slag					
		ACBF RAP Slag	72	11.1	66.4	108	0.0	ACBF RAP Slag	70.5	11.1	65.9	135	0.0
105	04/26/08												
106	04/27/08												
107	04/28/08												
108	04/29/08												
109	04/30/08												
110	05/01/08												
111	05/02/08												
112	05/03/08												
113	05/04/08												
114	05/05/08												
115	05/06/08												
116	05/07/08												
117	05/08/08												
118	05/09/08												
119	05/10/08												
120	05/11/08												
121	05/12/08												
122	05/13/08												
123	05/14/08												
124	05/15/08												

DAY	DATE	CBR MOLD #5						CBR MOLD #6					
		Material #5	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)	Material #6	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)
125	05/16/08												
126	05/17/08												
127	05/18/08												
128	05/19/08												
129	05/20/08												
130	05/21/08												
131	05/22/08												
132	05/23/08												
133	05/24/08												
134	05/25/08												
135	05/26/08	Surface Binder(60%steel slag) _ Repeat	Room	12.3	35.3	212		Surface Binder(60%steel slag) _ Repeat	Room	12.5	34.3	227	
136	05/27/08	Surface Binder(60%steel slag) _ Repeat	71.4	11.3	65.9	168	-44.0	Surface Binder(60%steel slag) _ Repeat	69.7	11.4	65.7	164.5	-62.5
137	05/28/08	Surface Binder(60%steel slag) _ Repeat	72.2	11.2	68.7	168.5	0.5	Surface Binder(60%steel slag) _ Repeat	71.5	11.4	65.1	164.5	0.0
138	05/29/08	Surface Binder(60%steel slag) _ Repeat	71.6	11.2	68	169	0.5	Surface Binder(60%steel slag) _ Repeat	70.8	11.4	64.3	164.5	0.0
139	05/30/08	Surface Binder(60%steel slag) _ Repeat	72.6	11.1	69.6	169.5	0.5	Surface Binder(60%steel slag) _ Repeat	71.1	11.3	67.1	164.5	0.0
140	05/31/08	Surface Binder(60%steel slag) _ Repeat	72.1	11.2	69.5	170.25	0.8	Surface Binder(60%steel slag) _ Repeat	71.2	11.2	66.8	165	0.5
141	06/01/08	Surface Binder(60%steel slag) _ Repeat	71.8	11.2	69.2	171.5	1.3	Surface Binder(60%steel slag) _ Repeat	71.7	11.2	67.3	165	0.0
142	06/02/08	Surface Binder(60%steel slag) _ Repeat						Surface Binder(60%steel slag) _ Repeat					
143	06/03/08	Surface Binder(60%steel slag) _ Repeat	72.9	11.1	70.1	172.25	0.8	Surface Binder(60%steel slag) _ Repeat	71	11.2	66.2	165.5	0.5
144	06/04/08	Surface Binder(60%steel slag) _ Repeat						Surface Binder(60%steel slag) _ Repeat					
145	06/05/08	Surface Binder(60%steel slag) _ Repeat	71.8	11.0	68.6	173	0.8	Surface Binder(60%steel slag) _ Repeat	70.9	11.2	67.1	166.25	0.8

DAY	DATE	CBR MOLD #5						CBR MOLD #6					
		Material #5	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)	Material #6	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)
146	06/06/08	Surface Binder(60%steel slag) _ Repeat						Surface Binder(60%steel slag) _ Repeat					
147	06/07/08	Surface Binder(60%steel slag) _ Repeat						Surface Binder(60%steel slag) _ Repeat					
148	06/08/08	Surface Binder(60%steel slag) _ Repeat	72.8	11.0	70.1	174.25	1.3	Surface Binder(60%steel slag) _ Repeat	71.2	11.2	67.3	167	0.8
149	06/09/08	Surface Binder(60%steel slag) _ Repeat						Surface Binder(60%steel slag) _ Repeat					
150	06/10/08	Surface Binder(60%steel slag) _ Repeat						Surface Binder(60%steel slag) _ Repeat					
151	06/11/08	Surface Binder(60%steel slag) _ Repeat						Surface Binder(60%steel slag) _ Repeat					
152	06/12/08	Surface Binder(60%steel slag) _ Repeat						Surface Binder(60%steel slag) _ Repeat					
153	06/13/08	Surface Binder(60%steel slag) _ Repeat				176	1.8	Surface Binder(60%steel slag) _ Repeat				167	0.0
154	06/14/08	Surface Binder(60%steel slag) _ Repeat						Surface Binder(60%steel slag) _ Repeat					
155	06/15/08	Surface Binder(60%steel slag) _ Repeat						Surface Binder(60%steel slag) _ Repeat					
156	06/16/08	Surface Binder(60%steel slag) _ Repeat				178	2.0	Surface Binder(60%steel slag) _ Repeat				168	1.0
157	06/17/08	Surface Binder(60%steel slag) _ Repeat						Surface Binder(60%steel slag) _ Repeat					
158	06/18/08	Surface Binder(60%steel slag) _ Repeat				178	0.0	Surface Binder(60%steel slag) _ Repeat				169	1.0
159	06/19/08	Surface Binder(60%steel slag) _ Repeat						Surface Binder(60%steel slag) _ Repeat					
160	06/20/08	Surface Binder(60%steel slag) _ Repeat				178	0.0	Surface Binder(60%steel slag) _ Repeat				169	0.0
161	06/21/08	Surface Binder(60%steel slag) _ Repeat						Surface Binder(60%steel slag) _ Repeat					
162	06/22/08	Surface Binder(60%steel slag) _ Repeat						Surface Binder(60%steel slag) _ Repeat					
163	06/23/08	Surface Binder(60%steel slag) _ Repeat				178	0.0	Surface Binder(60%steel slag) _ Repeat				169	0.0
164	06/24/08	Surface Binder(60%steel slag) _ Repeat						Surface Binder(60%steel slag) _ Repeat					

DAY	DATE	CBR MOLD #5						CBR MOLD #6					
		Material #5	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)	Material #6	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)
165	06/25/08	Surface Binder(60%steel slag) _ Repeat				178	0.0	Surface Binder(60%steel slag) _ Repeat				169	0.0
166	06/26/08	Surface Binder(60%steel slag) _ Repeat						Surface Binder(60%steel slag) _ Repeat					
167	06/27/08	Surface Binder(60%steel slag) _ Repeat						Surface Binder(60%steel slag) _ Repeat					
168	06/28/08	Surface Binder(60%steel slag) _ Repeat						Surface Binder(60%steel slag) _ Repeat					
169	06/29/08	Surface Binder(60%steel slag) _ Repeat						Surface Binder(60%steel slag) _ Repeat					
170	06/30/08	Surface Binder(60%steel slag) _ Repeat				178	0.0	Surface Binder(60%steel slag) _ Repeat				170	1.0
171	07/01/08	Surface Binder(60%steel slag) _ Repeat						Surface Binder(60%steel slag) _ Repeat					
172	07/02/08	Surface Binder(60%steel slag) _ Repeat				179	1.0	Surface Binder(60%steel slag) _ Repeat				170	0.0
173	07/03/08	Surface Binder(60%steel slag) _ Repeat						Surface Binder(60%steel slag) _ Repeat					
174	07/04/08	Surface Binder(60%steel slag) _ Repeat						Surface Binder(60%steel slag) _ Repeat					
175	07/05/08	Surface Binder(60%steel slag) _ Repeat						Surface Binder(60%steel slag) _ Repeat					
176	07/06/08	Surface Binder(60%steel slag) _ Repeat						Surface Binder(60%steel slag) _ Repeat					
177	07/07/08	Surface Binder(60%steel slag) _ Repeat						Surface Binder(60%steel slag) _ Repeat					
178	07/08/08	Surface Binder(60%steel slag) _ Repeat						Surface Binder(60%steel slag) _ Repeat					
179	07/09/08	Surface Binder(60%steel slag) _ Repeat				180	1.0	Surface Binder(60%steel slag) _ Repeat				173	3.0
180	07/10/08	Surface Binder(60%steel slag) _ Repeat						Surface Binder(60%steel slag) _ Repeat					
181	07/11/08	Surface Binder(60%steel slag) _ Repeat	69.3			181	1.0	Surface Binder(60%steel slag) _ Repeat	69.2	11.2	65.7	173	0.0
182	07/12/08	Surface Binder(60%steel slag) _ Repeat						Surface Binder(60%steel slag) _ Repeat					
183	07/13/08	Surface Binder(60%steel slag) _ Repeat						Surface Binder(60%steel slag) _ Repeat					

DAY	DATE	CBR MOLD #5						CBR MOLD #6					
		Material #5	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)	Material #6	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)
184	07/14/08	Surface Binder(60%steel slag) _ Repeat	69.8			181.5	0.5	Surface Binder(60%steel slag) _ Repeat	69.7	11.1	65.8	173	0.0
185	07/15/08	SMA RAP-Dist. 1		11.8	37.2	207.15		SMA RAP-Dist. 1		11.8	36.4	451.25	
186	07/16/08	SMA RAP-Dist. 1	72.6	11.1	66.6	159	-48.2	SMA RAP-Dist. 1	70.6	11.0	63.7	408.5	-42.8
187	07/17/08	SMA RAP-Dist. 1	72.2	11.4	66	157.0	-2.0	SMA RAP-Dist. 1	71.9	11.2	66.9	406.0	-2.5
188	07/18/08	SMA RAP-Dist. 1	72.5	11.4	65.6	158.0	1.0	SMA RAP-Dist. 1	71.5	11.3	67.3	408.0	2.0
189	07/19/08	SMA RAP-Dist. 1	71.7	11.2	66.3	159.0	1.0	SMA RAP-Dist. 1	71.2	11.3	67.1	408.5	0.5
190	07/20/08	SMA RAP-Dist. 1	72.5	11.2	67.9	160.0	1.0	SMA RAP-Dist. 1	71.9	11.2	67.7	409.0	0.5
191	07/21/08	SMA RAP-Dist. 1	71.9	11.2	67.1	161.0	1.0	SMA RAP-Dist. 1	70.2	11.3	67	411.0	2.0
192	07/22/08	SMA RAP-Dist. 1	70.7	11.3	66.5	162.0	1.0	SMA RAP-Dist. 1	71.5	11.3	66	412.0	1.0
193	07/23/08	SMA RAP-Dist. 1	71.6	11.2	67.2	164.0	2.0	SMA RAP-Dist. 1	71.8	11.4	66.7	414.0	2.0
194	07/24/08	SMA RAP-Dist. 1	72.5	11.2	66.6	164.0	0.0	SMA RAP-Dist. 1	71.7	11.3	66.6	407.0	-7.0
195	07/25/08	SMA RAP-Dist. 1	72.5	11.3	66.9	165.0	1.0	SMA RAP-Dist. 1	71.4	11.2	66.9	413.0	6.0
196	07/26/08	SMA RAP-Dist. 1						SMA RAP-Dist. 1					
197	07/27/08	SMA RAP-Dist. 1						SMA RAP-Dist. 1					
198	07/28/08	SMA RAP-Dist. 1	72.6	11.1	69.3	169.0	4.0	SMA RAP-Dist. 1	72	11.2	67.9	421.0	8.0
199	07/29/08	SMA RAP-Dist. 1						SMA RAP-Dist. 1					
200	07/30/08	SMA RAP-Dist. 1	72.4	11.2	68.4	171.0	2.0	SMA RAP-Dist. 1	71.3	11.2	67.5	422.0	1.0
201	07/31/08	SMA RAP-Dist. 1						SMA RAP-Dist. 1					
202	08/01/08	SMA RAP-Dist. 1	71.3	11.3	66	172.0	1.0	SMA RAP-Dist. 1	72.3	11.2	66.5	426.0	4.0
203	08/02/08	SMA RAP-Dist. 1						SMA RAP-Dist. 1					
204	08/03/08	SMA RAP-Dist. 1						SMA RAP-Dist. 1					
205	08/04/08	SMA RAP-Dist. 1						SMA RAP-Dist. 1					
206	08/05/08	SMA RAP-Dist. 1	71.5	11.2	66.2	176.0	4.0	SMA RAP-Dist. 1	71.7	11.1	66.6	431.0	5.0
207	08/06/08	SMA RAP-Dist. 1						SMA RAP-Dist. 1					

DAY	DATE	CBR MOLD #5						CBR MOLD #6					
		Material #5	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)	Material #6	Temp (C)	PH	PH temp	Height (0.001in)	Delta Height (0.001in)
208	08/07/08	SMA RAP-Dist. 1	72.5	11.1	67	178.0	2.0	SMA RAP-Dist. 1	71.6	11.2	66.1	433.0	2.0
209	08/08/08	SMA RAP-Dist. 1	73	11.2	67	177.0	-1.0	SMA RAP-Dist. 1	72.3	11.3	66.5	435.0	2.0
210	08/09/08	SMA RAP-Dist. 1						SMA RAP-Dist. 1					
211	08/10/08	SMA RAP-Dist. 1						SMA RAP-Dist. 1					
212	08/11/08	SMA RAP-Dist. 1	71.7	11.2	65.5	181.0	4.0	SMA RAP-Dist. 1	71.6	11.2	65.4	440.0	5.0
213	08/12/08	SMA RAP-Dist. 1						SMA RAP-Dist. 1					
214	08/13/08	SMA RAP-Dist. 1						SMA RAP-Dist. 1					
215	08/14/08	SMA RAP-Dist. 1						SMA RAP-Dist. 1					
216	08/15/08	SMA RAP-Dist. 1						SMA RAP-Dist. 1					
217	08/16/08	SMA RAP-Dist. 1						SMA RAP-Dist. 1					
218	08/17/08	SMA RAP-Dist. 1						SMA RAP-Dist. 1					
219	08/18/08	SMA RAP-Dist. 1						SMA RAP-Dist. 1					
220	08/19/08	SMA RAP-Dist. 1						SMA RAP-Dist. 1					
221	08/20/08	SMA RAP-Dist. 1						SMA RAP-Dist. 1					
222	08/21/08	SMA RAP-Dist. 1						SMA RAP-Dist. 1					
223	08/22/08	SMA RAP-Dist. 1	71.6	11.0	61	192	11.0	SMA RAP-Dist. 1	70.2	11.2	61	449	9.0
224	08/23/08	SMA RAP-Dist. 1						SMA RAP-Dist. 1					
225	08/24/08	SMA RAP-Dist. 1						SMA RAP-Dist. 1					
226	08/25/08	SMA RAP-Dist. 1	70.7	11.0	67.3	193	1.0	SMA RAP-Dist. 1	71.5	11.2	65.9	450	1.0
227	08/26/08	SMA RAP-Dist. 1						SMA RAP-Dist. 1					
228	08/27/08	SMA RAP-Dist. 1	73	11.0	66	194	1.0	SMA RAP-Dist. 1	71.8	11.1	65.9	450	0.0
229	08/28/08	SMA RAP-Dist. 1						SMA RAP-Dist. 1					
230	08/29/08	SMA RAP-Dist. 1	72.5	10.9	66.9	196	2.0	SMA RAP-Dist. 1	71.5	11.0	65.2	452	2.0

APPENDIX E: CUMULATIVE EXPANSION RESULTS

CUMULATIVE EXPANSION %										
DAY	Surface (%92) #1	Surface (%92) #2	Surface (%92) Average	DAY	Steel Slag Dist.4 #1	Steel Slag Dist.4 #2	Steel Slag Dist.4 Average	ACBF Slag #1	ACBF Slag #2	ACBF Slag Average
0	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
1	-0.502	-0.644	-0.573	**1**	-0.011	0.011	0.000	-0.038	-0.065	-0.052
2	-0.425	-0.622	-0.524	**2**	-0.011	0.022	0.005	-0.033	-0.055	-0.044
3	-0.256	-0.534	-0.395	**3**	-0.011	0.022	0.005	-0.033	-0.044	-0.038
4	-0.158	-0.447	-0.303	**4**	-0.005	0.027	0.011	-0.022	-0.038	-0.030
5	-0.038	-0.382	-0.210	**5**	0.000	0.027	0.014	-0.022	-0.038	-0.030
6	0.060	-0.311	-0.125	**6**	0.011	0.027	0.019	-0.016	-0.033	-0.025
7	0.131	-0.251	-0.060	**8**	0.033	0.033	0.033	-0.011	-0.033	-0.022
8	0.180	-0.191	-0.005	**10**	0.044	0.044	0.044	-0.011	-0.033	-0.022
9	0.235	-0.142	0.046	**13**	0.065	0.055	0.060	-0.011	-0.033	-0.022
10	0.311	-0.082	0.115	**15**	0.076	0.055	0.065	-0.011	-0.033	-0.022
11	0.371	-0.022	0.175	**17**	0.087	0.055	0.071	-0.011	-0.033	-0.022
12	0.425	0.022	0.224	**20**	0.109	0.055	0.082	-0.011	-0.060	-0.035
13	0.474	0.065	0.270	**23**	0.131	0.076	0.104	-0.022	-0.065	-0.044
14	0.540	0.120	0.330	**28**	0.175	0.076	0.125	-0.022	-0.087	-0.055
15	0.567	0.169	0.368	**32**	0.207	0.076	0.142	-0.011	-0.065	-0.038
16	0.616	0.213	0.414	**33**	0.229	0.109	0.169			
17	0.665	0.262	0.464	**34**	0.262	0.115	0.188			
18	0.714	0.305	0.510	**35**	0.262	0.120	0.191			

19	0.758	0.333	0.545	**36**	0.278	0.125	0.202			
21	0.845	0.404	0.624	**37**	0.295	0.131	0.213			
22	0.894	0.442	0.668	**38**	0.295	0.131	0.213			
23	0.927	0.469	0.698	**40**	0.305	0.131	0.218			
24	0.965	0.496	0.731	**44**	0.316	0.153	0.235			
25	0.993	0.534	0.764	**49**	0.327	0.169	0.248			
26	1.014	0.567	0.791	**54**	0.338	0.180	0.259			
27	1.042	0.600	0.821	**60**	0.349	0.196	0.273			
28	1.074	0.627	0.851							
29	1.129	0.627	0.878							
32	1.183	0.682	0.933							
35	1.260	0.780	1.020							
37	1.298	0.829	1.063							
38	1.309	0.834	1.072							
39	1.309	0.851	1.080							
40	1.309	0.878	1.093							
41	1.325	0.905	1.115							
42	1.325	0.911	1.118							
44	1.325	0.911	1.118							

DAY	Nonporous Steel Slag #1	Nonporous Steel Slag #2	Nonporous Steel Slag Average	DAY	Nonporous Steel Slag Repeat #1	Nonporous Steel Slag Repeat #2	Nonporous Steel Slag Repeat Average	Porous Steel Slag #1	Porous Steel Slag #2	Porous Steel Slag Average	Surface Binder (%60) #1	Surface Binder (%60) #2	Surface Binder (%60) Average
0	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
1	0.245	-0.016	0.115	**1**	0.109	0.038	0.074	0.251	0.175	0.213	-0.960	-1.363	-1.162
2	0.987	0.147	0.567	**2**	0.731	0.371	0.551	0.687	0.633	0.660	-0.949	-1.363	-1.156
3	1.663	0.605	1.134	**3**	1.249	0.764	1.006	0.949	0.851	0.900	-0.938	-1.363	-1.151
4	2.078	1.216	1.647	**4**	1.898	1.505	1.702	1.243	1.134	1.189	-0.927	-1.363	-1.145
5	2.503	1.805	2.154	**5**	2.274	1.909	2.092	1.505	1.287	1.396	-0.911	-1.353	-1.132
6	2.776	2.198	2.487	**6**	2.640	2.301	2.471	1.745	1.429	1.587	-0.884	-1.353	-1.118
8	3.332	3.005	3.169	**8**	3.032	2.825	2.929	1.974	1.625	1.800	-0.867	-1.342	-1.104
12	3.976	3.965	3.970	**10**	3.245	3.218	3.231	2.138	1.805	1.972	-0.851	-1.325	-1.088
17	4.641	4.696	4.668	**13**	3.556	3.785	3.670	2.389	2.083	2.236	-0.824	-1.309	-1.066
22	5.219	5.165	5.192	**18**	3.992	4.461	4.227	2.727	2.400	2.563	-0.785	-1.309	-1.047
28	5.896	5.732	5.814	**21**	4.210	4.701	4.456	2.923	2.552	2.738	-0.742	-1.287	-1.014
				23	4.298	4.854	4.576	3.076	2.661	2.869	-0.742	-1.265	-1.003
				25	4.494	5.028	4.761	3.207	2.771	2.989	-0.742	-1.265	-1.003
				28	4.668	5.225	4.947	3.338	3.054	3.196	-0.742	-1.265	-1.003
				30	4.865	5.399	5.132	3.490	3.032	3.261	-0.742	-1.265	-1.003
				35	5.083	5.705	5.394	3.687	3.294	3.490	-0.742	-1.243	-0.993
				37	5.214	5.879	5.546	3.818	3.360	3.589	-0.720	-1.243	-0.982
				44	5.497	6.403	5.950	4.188	3.621	3.905	-0.698	-1.178	-0.938
				46	5.541	6.534	6.037	4.298	3.687	3.992	-0.676	-1.178	-0.927
				49	5.650	6.719	6.185	4.472	3.807	4.139	-0.665	-1.178	-0.922

DAY	Steel Slag RAP Standard Comp. #1	Steel Slag RAP Standard Comp. #2	Steel Slag RAP Standard Comp. Average	Steel Slag RAP #1	Steel Slag RAP #2	Steel Slag RAP Average	SMA RAP #1	SMA RAP #2	SMA RAP Average
0	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
1	-0.060	-0.016	-0.038	-1.074	-1.020	-1.047	-1.050	-0.933	-0.991
2	0.071	0.093	0.082	-1.325	-1.151	-1.238	-1.094	-0.987	-1.041
3	0.027	0.245	0.136	-1.303	-1.194	-1.249	-1.072	-0.943	-1.008
4	0.104	0.376	0.240	-1.282	-1.216	-1.249	-1.050	-0.933	-0.991
5	0.169	0.507	0.338	-1.260	-1.238	-1.249	-1.029	-0.922	-0.975
6	0.158	0.529	0.344	-1.260	-1.282	-1.271	-1.007	-0.878	-0.942
7	0.202	0.573	0.387	-1.260	-1.347	-1.303	-0.985	-0.856	-0.921
8	0.311	0.660	0.485	-1.303	-1.282	-1.293	-0.941	-0.813	-0.877
9	0.245	0.725	0.485	-1.303	-1.260	-1.282	-0.941	-0.965	-0.953
10	0.333	0.682	0.507	-1.260	-1.282	-1.271	-0.920	-0.834	-0.877
13	0.464	0.900	0.682	-1.173	-1.151	-1.162	-0.832	-0.660	-0.746
15	0.507	0.987	0.747	-1.107	-1.107	-1.107	-0.789	-0.638	-0.713
17	0.573	1.053	0.813	-1.063	-1.063	-1.063	-0.767	-0.551	-0.659
21	0.660	1.205	0.933	-0.867	-0.802	-0.834	-0.680	-0.442	-0.561
23	0.747	1.227	0.987	-0.736	-0.824	-0.780	-0.636	-0.398	-0.517
24	0.813	1.271	1.042	-0.540	-0.976	-0.758	-0.658	-0.354	-0.506
27	0.834	1.402	1.118	-0.714	-0.736	-0.725	-0.570	-0.245	-0.408
38	1.074	1.576	1.325	-0.344	-0.256	-0.300	-0.330	-0.049	-0.190
41	1.009	1.663	1.336	-0.387	-0.147	-0.267	-0.309	-0.027	-0.168
43	1.031	1.620	1.325	-0.278	-0.016	-0.147	-0.287	-0.027	-0.157
45	1.074	1.772	1.423	-0.300	-0.104	-0.202	-0.243	0.016	-0.113

DAY	Gravel-Dolomite (Meyer) #1	Gravel-Dolomite (Meyer) #2	Gravel-Dolomite (Meyer) Average	DAY	Gravel RAP (CUR-CL) #1	Gravel RAP (CUR-CL) #2	Gravel RAP (CUR-CL) Average	DAY	Gravel-Crushed Stone RAP (ALL-FRK) #1	Gravel-Crushed Stone RAP (ALL-FRK) #2	Gravel- Crushed Stone RAP (ALL-FRK) Average
0	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
1	-0.011	-0.011	-0.011	**1**	-2.727	-3.038	-2.882	**1**	-2.203	-2.111	-2.157
2	-0.005	-0.011	-0.008	**2**	-2.836	-3.103	-2.970	**2**	-2.312	-2.203	-2.258
3	0.000	-0.011	-0.005	**3**	-2.869	-3.207	-3.038	**3**	-2.372	-2.258	-2.315
4	0.005	-0.005	0.000	**4**	-2.880	-3.229	-3.054	**4**	-2.389	-2.269	-2.329
5	0.005	-0.005	0.000	**5**	-2.901	-3.250	-3.076	**5**	-2.411	-2.285	-2.348
6	0.011	0.000	0.005	**6**	-2.918	-3.272	-3.095	**6**	-2.432	-2.296	-2.364
7	0.011	0.000	0.005	**7**	-2.940	-3.294	-3.117	**7**	-2.438	-2.296	-2.367
8	0.011	0.000	0.005	**9**	-2.945	-3.294	-3.120	**8**	-2.454	-2.301	-2.378
9	0.011	0.000	0.005	**10**	-2.972	-3.310	-3.141	**9**	-2.476	-2.323	-2.400
10	0.011	0.000	0.005	**11**	-2.978	-3.310	-3.144	**10**	-2.487	-2.334	-2.411
				12	-2.978	-3.321	-3.150	**11**	-2.487	-2.334	-2.411
				13	-3.005	-3.332	-3.169	**12**	-2.487	-2.345	-2.416
				14	-3.005	-3.332	-3.169	**13**	-2.498	-2.356	-2.427
				15	-3.010	-3.332	-3.171				
				16	-3.010	-3.332	-3.171				

DAY	Limestone from R27-1 #1	Limestone from R27-1 #2	Limestone from R27- Average	DAY	Dolomite from R27-1 #1	Dolomite from R27-1 #2	Dolomite from R27-1 Average	DAY	Siliceous Gravel from R27-1 #1	Siliceous Gravel from R27-1 #2	Siliceous Gravel from R27-1 Average
0	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
1	0.000	-0.011	-0.005	**1**	-0.005	-0.027	-0.016	**1**	0.000	0.005	0.003
2	-0.005	-0.044	-0.025	**2**	-0.005	-0.038	-0.022	**2**	0.005	0.000	0.003
3	-0.005	-0.044	-0.025	**3**	-0.011	-0.038	-0.025	**3**	0.011	-0.011	0.000
4	-0.005	-0.044	-0.025	**4**	-0.016	-0.044	-0.030	**4**	-0.005	-0.027	-0.016
5	-0.005	-0.038	-0.022	**5**	-0.016	-0.044	-0.030	**5**	-0.005	-0.027	-0.016
6	-0.005	-0.033	-0.019	**7**	-0.027	-0.044	-0.035	**6**	-0.011	-0.027	-0.019
7	-0.011	-0.033	-0.022	**8**	-0.027	-0.044	-0.035	**8**	-0.011	-0.033	-0.022
8	-0.011	-0.033	-0.022	**9**	-0.027	-0.044	-0.035	**10**	-0.011	-0.033	-0.022
9	-0.016	-0.033	-0.025	**10**	-0.011	-0.049	-0.030	**13**	-0.016	-0.033	-0.025
10	-0.016	-0.033	-0.025	**11**	-0.027	-0.055	-0.041				
12	-0.016	-0.033	-0.025	**12**	-0.027	-0.055	-0.041				
				13	-0.027	-0.055	-0.041				
				14	-0.027	-0.055	-0.041				
				16	-0.027	-0.055	-0.041				
				18	-0.022	-0.055	-0.038				
				21	-0.022	-0.055	-0.038				

DAY	Dolomite Crushed Concrete #1	Dolomite Crushed Concrete #2	Dolomite Crushed Concrete Average	Gravel Crushed Concrete #1	Gravel Crushed Concrete #2	Gravel Crushed Concrete Average	DAY	ACBF RAP Slag #1	ACBF RAP Slag #2	ACBF RAP Slag Average
0	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
1	0.016	0.011	0.014	0.005	0.016	0.011	**1**	-2.334	-2.067	-2.201
2	0.016	0.000	0.008	0.005	0.011	0.008	**2**	-2.345	-2.083	-2.214
3	0.016	0.000	0.008	0.005	0.005	0.005	**3**	-2.361	-2.105	-2.233
4	0.016	0.000	0.008	0.011	0.011	0.011	**4**	-2.383	-2.160	-2.271
5	0.027	0.022	0.025	0.027	0.027	0.027	**5**	-2.394	-2.182	-2.288
7	0.027	0.022	0.025	0.038	0.038	0.038	**6**	-2.405	-2.192	-2.299
							8	-2.427	-2.220	-2.323
							10	-2.443	-2.236	-2.340
							13	-2.449	-2.241	-2.345
							15	-2.460	-2.252	-2.356
							17	-2.471	-2.269	-2.370
							20	-2.471	-2.280	-2.375
							23	-2.481	-2.291	-2.386
							28	-2.492	-2.291	-2.391
							32	-2.492	-2.291	-2.391

APPENDIX F: CORRECTED CUMULATIVE EXPANSION RESULTS

Only the materials which show significant expansion are shown below.
Note that initial settlements up to the first expansion value are ignored to calculate total expansion.

CUMULATIVE EXPANSION %

DAY	Surface (%92) #1	Surface (%92) #2	Surface (%92)	DAY	Steel Slag Dist.4 #1	Steel Slag Dist.4 #2	Steel Slag Dist.4	DAY	Nonporous Steel Slag #1	Nonporous Steel Slag #2	Nonporous Steel Slag
0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00
1	0.00	0.00	0.00	1	0.00	0.01	0.01	1	0.25	0.00	0.12
2	0.08	0.02	0.05	2	0.00	0.02	0.01	2	0.99	0.16	0.58
3	0.25	0.11	0.18	3	0.00	0.02	0.01	3	1.66	0.62	1.14
4	0.34	0.20	0.27	4	0.01	0.03	0.02	4	2.08	1.23	1.66
5	0.46	0.26	0.36	5	0.01	0.03	0.02	5	2.50	1.82	2.16
6	0.56	0.33	0.45	6	0.02	0.03	0.02	6	2.78	2.21	2.50
7	0.63	0.39	0.51	8	0.04	0.03	0.04	8	3.33	3.02	3.18
8	0.68	0.45	0.57	10	0.05	0.04	0.05	12	3.98	3.98	3.98
9	0.74	0.50	0.62	13	0.08	0.05	0.07	17	4.64	4.71	4.68
10	0.81	0.56	0.69	15	0.09	0.05	0.07	22	5.22	5.18	5.20
11	0.87	0.62	0.75	17	0.10	0.05	0.08	28	5.90	5.75	5.82
12	0.93	0.67	0.80	20	0.12	0.05	0.09				
13	0.98	0.71	0.84	23	0.14	0.08	0.11				
14	1.04	0.76	0.90	28	0.19	0.08	0.13				
15	1.07	0.81	0.94	32	0.22	0.08	0.15				
16	1.12	0.86	0.99	33	0.24	0.11	0.17				
17	1.17	0.91	1.04	34	0.27	0.11	0.19				
18	1.22	0.95	1.08	35	0.27	0.12	0.20				
19	1.26	0.98	1.12	36	0.29	0.13	0.21				
21	1.35	1.05	1.20	37	0.31	0.13	0.22				

22	1.40	1.09	1.24	**38**	0.31	0.13	0.22				
23	1.43	1.11	1.27	**40**	0.32	0.13	0.22				
24	1.47	1.14	1.30	**44**	0.33	0.15	0.24				
25	1.49	1.18	1.34	**49**	0.34	0.17	0.25				
26	1.52	1.21	1.36	**54**	0.35	0.18	0.26				
27	1.54	1.24	1.39	**60**	0.36	0.20	0.28				
28	1.58	1.27	1.42								
29	1.63	1.27	1.45								
32	1.69	1.33	1.51								
35	1.76	1.42	1.59								
37	1.80	1.47	1.64								
38	1.81	1.48	1.64								
39	1.81	1.49	1.65								
40	1.81	1.52	1.67								
41	1.83	1.55	1.69								
42	1.83	1.55	1.69								
44	1.83	1.55	1.69								

CUMULATIVE EXPANSION%

DAY	Nonporous Steel Slag Repeat #1	Nonporous Steel Slag Repeat #2	Nonporous Steel Slag Repeat	Porous Steel Slag #1	Porous Steel Slag #2	Porous Steel Slag	Surface Binder (%60) #1	Surface Binder (%60) #2	Surface Binder (%60)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	0.11	0.04	0.07	0.25	0.17	0.21	0.00	0.00	0.00
2	0.73	0.37	0.55	0.69	0.63	0.66	0.01	0.00	0.01
3	1.25	0.76	1.01	0.95	0.85	0.90	0.02	0.00	0.01
4	1.90	1.51	1.70	1.24	1.13	1.19	0.03	0.00	0.02
5	2.27	1.91	2.09	1.51	1.29	1.40	0.05	0.01	0.03
6	2.64	2.30	2.47	1.75	1.43	1.59	0.08	0.01	0.04
8	3.03	2.83	2.93	1.97	1.63	1.80	0.09	0.02	0.06
10	3.24	3.22	3.23	2.14	1.81	1.97	0.11	0.04	0.07
13	3.56	3.78	3.67	2.39	2.08	2.24	0.14	0.05	0.10
18	3.99	4.46	4.23	2.73	2.40	2.56	0.17	0.05	0.11
21	4.21	4.70	4.46	2.92	2.55	2.74	0.22	0.08	0.15
23	4.30	4.85	4.58	3.08	2.66	2.87	0.22	0.10	0.16
25	4.49	**5.03**	4.76	3.21	2.77	2.99	0.22	0.10	0.16
28	4.67	5.22	4.95	3.34	3.05	3.20	0.22	0.10	0.16
30	4.86	5.40	5.13	3.49	3.03	3.26	0.22	0.10	0.16
35	5.08	5.70	5.39	3.69	3.29	3.49	0.22	0.12	0.17
37	5.21	5.88	5.55	3.82	3.36	3.59	0.24	0.12	0.18
44	5.50	6.40	5.95	4.19	3.62	3.90	0.26	0.19	0.22
46	5.54	6.53	6.04	4.30	3.69	3.99	0.28	0.19	0.23
49	5.65	6.72	6.18	4.47	3.81	4.14	0.29	0.19	0.24

CUMULATIVE EXPANSION%

DAY	Steel Slag RAP Standard Comp. #1	Steel Slag RAP Standard Comp. #2	Steel Slag RAP Standard Comp.	Steel Slag RAP #1	Steel Slag RAP #2	Steel Slag RAP	DAY	SMA RAP #1	SMA RAP #2	SMA RAP
0	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00
1	0.00	0.00	0.00	0.00	0.00	0.00	1	0.00	0.00	0.00
2	0.13	0.11	0.12	0.00	0.00	0.00	2	0.00	0.00	0.00
3	0.09	0.26	0.17	0.02	0.00	0.01	3	0.02	0.04	0.03
4	0.16	0.39	0.28	0.04	0.00	0.02	4	0.04	0.05	0.05
5	0.23	0.52	0.38	0.07	0.00	0.03	5	0.07	0.07	0.07
6	0.22	0.55	0.38	0.07	0.00	0.03	6	0.09	0.11	0.10
7	0.26	0.59	0.43	0.07	0.00	0.03	7	0.11	0.13	0.12
8	0.37	0.68	0.52	0.02	0.07	0.04	8	0.15	0.17	0.16
9	0.31	0.74	0.52	0.02	0.09	0.05	9	0.15	0.02	0.09
10	0.39	0.70	0.55	0.07	0.07	0.07	10	0.17	0.15	0.16
13	0.52	0.92	0.72	0.15	0.20	0.17	13	0.26	0.33	0.29
15	0.57	1.00	0.79	0.22	0.24	0.23	15	0.31	0.35	0.33
17	0.63	1.07	0.85	0.26	0.28	0.27	17	0.33	0.44	0.38
21	0.72	1.22	0.97	0.46	0.55	0.50	21	0.41	0.55	0.48
23	0.81	1.24	1.03	0.59	0.52	0.56	23	0.46	0.59	0.52
24	0.87	1.29	1.08	0.79	0.37	0.58	24	0.44	0.63	0.53
27	0.89	1.42	1.16	0.61	0.61	0.61	27	0.52	0.74	0.63
38	1.13	1.59	1.36	0.98	1.09	1.04	**38**	0.76	0.94	0.85
41	1.07	1.68	1.37	0.94	1.20	1.07	**41**	0.79	0.96	0.87
43	1.09	1.64	1.36	1.05	1.33	1.19	**43**	0.81	0.96	0.88
45	1.13	1.79	1.46	1.03	1.24	1.13	**45**	0.85	1.00	0.93

Illinois Department of Transportation

ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN