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   Using the Portable XRF to Identify/Verify Field Material Properties
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13. Abstract
    In order to investigate the feasibility of rapid identification of chemical compounds or detection of certain additives or contaminants in commonly used construction materials with portable X-ray Fluorescence (XRF), stainless steel, anchor bolt, steel nut, steel washer, portland cement (type I, II, and III), class F fly ash, and aggregates were tested with the Olympus Vanta C series handheld XRF in this study. The same materials were also tested either with a spark spectrometer (for metal samples) or a benchtop XRF device (for non-metal samples) in DOTD materials laboratory. Through a comparison between the results from portable XRF and DOTD materials lab for metal samples, it shows the Olympus Vanta C series handheld XRF was able to detect manganese, nickel, chromium, and molybdenum, but it was not able to detect phosphorus, sulfur, and silicon that have a content value less than 1% in the metal samples. There is a linear relationship between the portable XRF testing results and DOTD materials laboratory testing results for the testing results of element copper, and manganese.

For portland cement and class F fly ash, it was not able to detect magnesium oxide, which might be due to that magnesium is at the edge of the detection limit of Olympus Vanta C series. Portable XRF generally underestimates the content of silicon dioxide, calcium oxide, and ferric oxide, and different correlation/calibrations would be needed for each of the element. However, the portable XRF would not be able to reliably detect light atomic weight element such as aluminum.

For aggregates, portable XRF works fairly well to detect aluminum oxide, silicon oxide, ferric oxide, and calcium oxide. A linear relationship with R2 value of above 0.85 could be established between the portable XRF testing results and DOTD materials laboratory testing results except for the contents of silicon dioxide and aluminum oxide in crushed gravel aggregates that have R2 value of lower than 0.55.

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Abstract

In order to investigate the feasibility of rapid identification of chemical compounds or detection of certain additives or contaminants in commonly used construction materials with portable X-ray Fluorescence (XRF), stainless steel, anchor bolt, steel nut, steel washer, portland cement (type I, II, and III), class F fly ash, and aggregates were tested with the Olympus Vanta C series handheld XRF in this study. The same materials were also tested either with a spark spectrometer (for metal samples) or a benchtop XRF device (for non-metal samples) in DOTD materials laboratory.

Through a comparison between the results from portable XRF and DOTD materials lab for metal samples, it shows the Olympus Vanta C series handheld XRF was able to detect manganese, nickel, chromium, and molybdenum, but it was not able to detect phosphorus, sulfur, and silicon that have a content value less than 1% in the metal samples. There is a linear relationship between the portable XRF testing results and DOTD materials laboratory testing results for the testing results of element copper, and manganese.

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For aggregates, portable XRF works fairly well to detect aluminum oxide, silicon oxide, ferric oxide, and calcium oxide. A linear relationship with R^2 value of above 0.85 could be established between the portable XRF testing results and DOTD materials laboratory testing results except for the contents of silicon dioxide and aluminum oxide in crushed gravel aggregates that have R^2 value of lower than 0.55.

Acknowledgments

The U.S. Department of Transportation, Federal Highway Administration (FHWA), Louisiana Department of Transportation and Development (DOTD), and Louisiana Transportation Research Center (LTRC) financially supported this research project.

The efforts of Norris Rosser, Austin Gueho, and Aaron Brown in the concrete laboratory are greatly appreciated.

Implementation Statement

Portable XRF might be used to detect heavy atomic elements, providing the device has been calibrated with the results from a benchtop XRF or spark spectrometer.

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Introduction

Materials such as cement, concrete, limestone, thermoplastic, steels, glass beads, and bridge coatings must be sent into the central laboratory for testing of properties, such as chloride content of bridge deck cores, silica content of aggregates, chemical composition of cement, and lead content of existing bridge coatings. However, these laboratory tests are time consuming, expensive, or need destructive sampling. The second Strategic Highway Research Program (SHRP2) R06B identified the portable X-ray Fluorescence (XRF) unit as a potential solution to quickly determine some of these properties in the field on in-place materials without sampling delays. Hence, in collaboration with the spark spectrometer and the benchtop XRF at DOTD materials lab, this report investigates the feasibility of using an Olympus Vanta C series handheld XRF as a nondestructive means to test the composition of some common construction materials.

Literature Review

Since X-rays were discovered by Wilhelm Conrad Rontgen at the physics institute of Julius-Maximilians University of Wurzburg in Bavaria in 1895, various research has been inspired and advanced by X-ray physics, including the modern theory of atomic structures and X-ray spectroscopy. Through the development in the past decades, X-ray technology is now playing a very significant role in the advanced characterization of materials [1]. Recently, the development of a portable and hand-held X-ray fluorescence device has provided another option for quick and in-place testing of materials.

In order to assure/control the quality of materials used during construction, routine procedures have been developed by transportation/highway agencies for infrastructure projects. However, concerns have been raised that some procedures are time-consuming, expensive, and unreliable. In order to address these concerns, identifying the most practical applications of handheld spectroscopic equipment for field testing and analysis has been set as the main objective for the second Strategic Highway Research Program (SHRP2) R06B project [2].

During the SHRP2 Reliability project R06B, the Maine Department of Transportation (MaineDOT) used two portable XRF devices (Olympus Vanta C series, and Thermo Fisher Scientific Niton XL3t 950) to test the chloride content in bridge deck cores, presence of recycled engine oil bottoms in asphalt binder, chemical composition of portland cement, arsenic and lead content of glass beads, alloy grade of reinforcing steel, and titanium content of traffic paint [3]. Different sample preparation methods were compared during the chloride content testing. It was found that compacted powder samples produced a linear correlation with the titration results. However, a significantly higher difference was noticed between the readings from core slice samples (not pulverized). It was noticed that the portable XRF (Thermo Fisher Scientific Niton XL3t 950) produced a value of 0.0% Cl when its content was very low. MaineDOT also purchased 10 calibration portland cement samples from the Cement and Concrete Reference Laboratory (CCRL) and generated linear equations for compounds SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, SO_3, and K_2O with the results from portable XRF. These linear equations were later used to predict the compound contents in another eight verification samples. The predicted values from these linear equations were reasonably accurate for compounds Fe_2O_3, CaO, SO_3, and K_2O, but falling away from the XRF testing values for other compounds.

National Concrete Pavement Technology Center at Iowa State University employed a Niton XL3t 900 GOLDD+ analyzer from Thermo Scientific to investigate the feasibility of using a portable XRF device to determine the proportions of fresh concrete [4]. It was found that the device was able to provide reasonable testing results for the raw materials. However, during the testing on fine aggregate, it was noticed that there was a significant difference between the balance values, i.e., the percentage of undetected elements from the portable XRF and laboratory instrument testing results. The balance values were further increased in the mortar tests, which could be due to the detection area and heterogeneity of the mortar samples. It was also noticed that the SO_3 content from portable XRF testing was also significantly higher than the expected levels (typical range).

The Tennessee Department of Transportation (TDOT) performed the silica (SiO_2) content tests in aggregates with the portable XRF to check the aggregate quality. During the testing, different siliceous standards with a SiO_2 concentration of 18% to 60% were obtained from the Cement Concrete Reference Laboratory. Through the comparison with the reference concertation of the standards, it was found the XRF tests overestimated the SiO_2 contents by a factor of 1.0657 [5].

Objective

Portable spectroscopy technologies such as X-Ray Fluorescence (XRF) are proposed for a rapid identification of chemical compounds or detection of certain additives or contaminants in some commonly used construction materials in portland cement concrete, structural coatings, or pavement markings. The ability to provide fast verification in the field of material properties at the source or on the job site prior to incorporation can enhance quality assurance, and therefore alleviate potential issues after the project is complete. Hence, it has been set as the objective of this study to evaluate the efficiency of the portable devices to characterize relevant materials for acceptance and develop a methodology for applications in Louisiana.

Scope

To meet the objectives of this study, a portable XRF was employed to test steel, portland cement, fly ash, and aggregates that were available at DOTD material's laboratory.

Methodology

To investigate the feasibility of using portable XRF to characterize the compositions of commonly used construction materials, the selected materials were tested with the traditional device (spark spectrometer for metal samples, and benchtop XRF device for non-metal samples) at DOTD material's laboratory and the portable Olympus Vanta C series handheld XRF device at LTRC. A comparison study between the testing results was followed to evaluate the efficiency of using portable XRF to characterize the compositions of commonly used construction materials.

Materials

The materials used in this study included stainless steel (A955 Grade 60); anchor bolt (F1554 Grade 105, A193A B7, and F1554 Grade 55); steel nut (A194 Grade 2H, A563 Grade DH, and A194 Grade 8); steel washer (F436 Type 1); portland cement (Type I / II Powder, and Type III Powder); fly ash (Class F Powder); and aggregate (crushed sand, gravel, and stone). Material information and designated sample IDs are shown in Table 1.

Table 1. Tested Materials

Sample ID / Designation	Material	Description
A3-060320	Stainless Steel	A955 Grade 60
B2-090239	Anchor Bolt	F1554 Grade 105
B2-091346	Anchor Bolt	F1554 Grade 105
B2-101824	Anchor Bolt	F1554 Grade 105
B2-103957	Anchor Bolt	F1554 Grade 55
B2-125548	Anchor Bolt	F1554 Grade 55
B2-145239	Anchor Bolt	F1554 Grade 55
B2-150913	Anchor Bolt	F1554 Grade 105
B3-082158	Steel Nut	A194 Grade 2H
B3-083618	Steel Nut	A194 Grade 2H
B3-085958	Steel Nut	A563 Grade DH
B3-102310	Steel Nut	A194 Grade 2H
B3-131602	Steel Nut	A194 Grade 2H
B3-141517	Steel Nut	A194 Grade 2H
B3-150641	Steel Nut	A194 Grade 8
B4-082504	Steel Washer	F436 Type 1
B4-090215	Steel Washer	F436 Type 1
B4-145030	Steel Washer	F436 Type 1
C1	Portland Cement	Type I or Type II Powder
C3	Portland Cement	Type III Powder

C9	Fly Ash	Class F Powder
D4	Aggregate	Sand (Crushed)
D5	Aggregate	Gravel (Crushed)
D6	Aggregate	Stone (Crushed)

Testing Methods

The testing procedures from the Olympus Vanta C series user's manual were followed in this study [6]. The portable XRF device used in this study is shown in Figure 1.

Figure 1. Olympus Vanta C Series

In comparison, all the samples were also tested in DOTD material's laboratory. A Zetium XRF spectrometer and an OBLF GS 1000-II spark spectrometer were employed to test the non-metal samples and metal samples, respectively. The following standards were referred during testing and analysis at DOTD material's laboratory.

- ASTM A194 [Standard Specification for Carbon Steel, Alloy Steel, and Stainless Steel Nuts for Bolts for High Pressure or High Temperature Service, or Both] [7]
- ASTM A955 [Standard Specification for Deformed and Plain Stainless Steel Bars for Concrete Reinforcement] [8]
- ASTM C311 [Standard Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use in Portland-Cement Concrete] [9]
- ASTM C1260 [Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)] [10]
- ASTM F436 [Standard Specification for Hardened Steel Washers Inch and Metric Dimensions] [11]
- ASTM F1554 [Standard Specification for Anchor Bolts, Steel, 36, 55, and 105-ksi Yield Strength] [12]
- AASHTO M85 [Standard Specification for Portland Cement] [13]

- AASHTO T105 [Standard Method of Test for Chemical Analysis of Hydraulic Cement] [14]
- AASHTO M295 [Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete] [15]

Discussion of Results

ASTM A955 Grade 60 Stainless Steel (A3)

One piece of A955 Grade 60 stainless steel was tested in this study and the results are shown in Table 2. It can be observed that manganese, nickel, chromium and molybdenum were detected by the portable XRF device and their contents were very close to the results from DOTD materials laboratory. It should be noted that carbon cannot be detected by the portable XRF due to the detection limit. From Table 2, it can be seen that portable XRF was able to produce a very close result for the content of manganese, copper, nickel, chromium, and molybdenum. However, for elements phosphorus, sulfur, and silicon, portable XRF cannot produce reliable results for their contents. These could be due to that the fluorescence from these light-atomic-weight elements has a very low energy, which would be reabsorbed by the sample or blocked by the air between the detector and the sample, rendering unreliable testing results from portable XRF. It has also been reported that taking measurement under a vacuum or helium atmosphere could help increase X-ray transmission effectiveness significantly when testing light atomic weight elements [16, 17].

Table 2. Testing Results of A955 Grade 60 Stainless Steel

Chemical Component	Portable XRF				DOTD Materials Laboratory (%)
	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average (%)	
Carbon	Out of detection limit				0.066
Manganese	0.990	1.030	1.020	1.01	1.011
Phosphorus	0.092	0.112	0.116	0.11	0.048
Sulfur	0.487	0.394	0.604	0.50	0.002
Silicon	1.061	0.926	1.116	1.03	0.097
Copper	0.335	0.361	0.341	0.35	0.324
Nickel	9.87	9.75	9.82	9.81	10.13
Chromium	17.69	17.62	17.58	17.63	17.01
Molybdenum	2.053	2.042	2.008	2.03	2.03

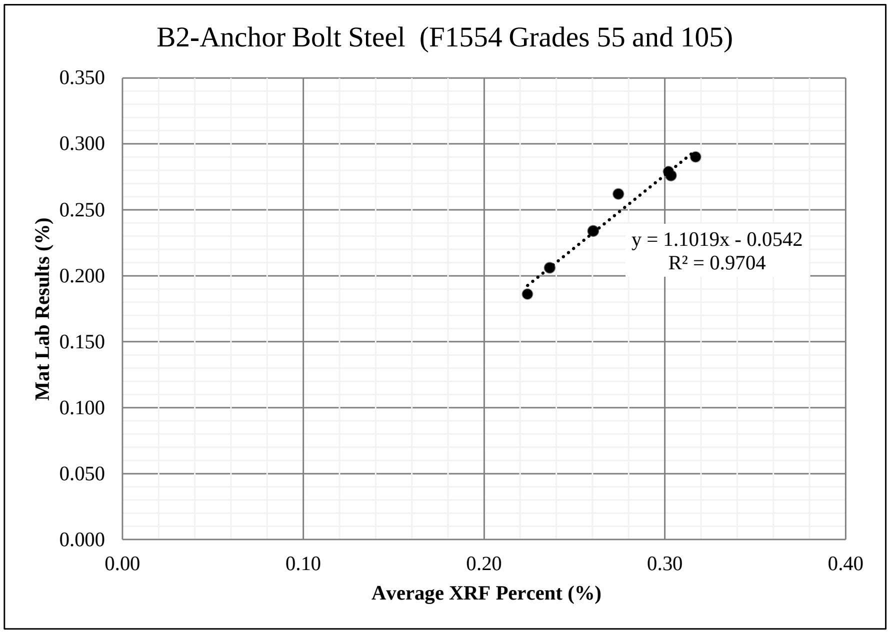
ASTM F1554 Grade 55 and 105 Anchor Bolt (B2)

As stated in ASTM F1554 Table 1, the targeted chemical elements for testing Grades 55 and 105 anchor bolts are phosphorus, sulfur, and copper. As shown in Table 3, show that the 7 tested anchor bolts have been characterized at DOTD materials laboratory with a content of 0.008% to 0.02% and a content of 0.008% to 0.036% for phosphorus and sulfur respectively. However, they were not detected (noted as ND in Table 3) by portable XRF in this study. For element copper, it can be observed in Figure 2 that there is a linear relationship between the portable XRF testing results and DOTD materials laboratory testing results.

Table 3. Testing Results of F1554 Grade 55 and 105 Bolts

Sample ID	Chemical Component	Portable XRF (%)				DOTD Materials Laboratory (%)
		XRF1	XRF2	XRF3	Average	
B2-090239	Phosphorus	ND	ND	ND	ND	0.008
	Sulfur	ND	ND	ND	ND	0.029
	Copper	0.301	0.297	0.312	0.30	0.276
B2-091346	Phosphorus	ND	ND	ND	ND	0.020
	Sulfur	ND	ND	ND	ND	0.032
	Copper	0.293	0.317	0.296	0.30	0.279
B2-101824	Phosphorus	ND	ND	ND	ND	0.016
	Sulfur	ND	ND	ND	ND	0.030
	Copper	0.275	0.276	0.272	0.27	0.262
B2-103957	Phosphorus	ND	ND	ND	ND	0.013
	Sulfur	ND	ND	ND	ND	0.036
	Copper	0.314	0.323	0.314	0.32	0.290
B2-125548	Phosphorus	ND	ND	ND	ND	0.011
	Sulfur	ND	ND	ND	ND	0.032
	Copper	0.242	0.236	0.231	0.24	0.206
B2-145239	Phosphorus	ND	ND	ND	ND	0.009
	Sulfur	ND	ND	ND	ND	0.008
	Copper	0.266	0.257	0.258	0.26	0.234
B2-150913	Phosphorus	ND	ND	ND	ND	0.008
(820052)	Sulfur	ND	ND	ND	ND	0.024
	Copper	0.237	0.226	0.209	0.22	0.186

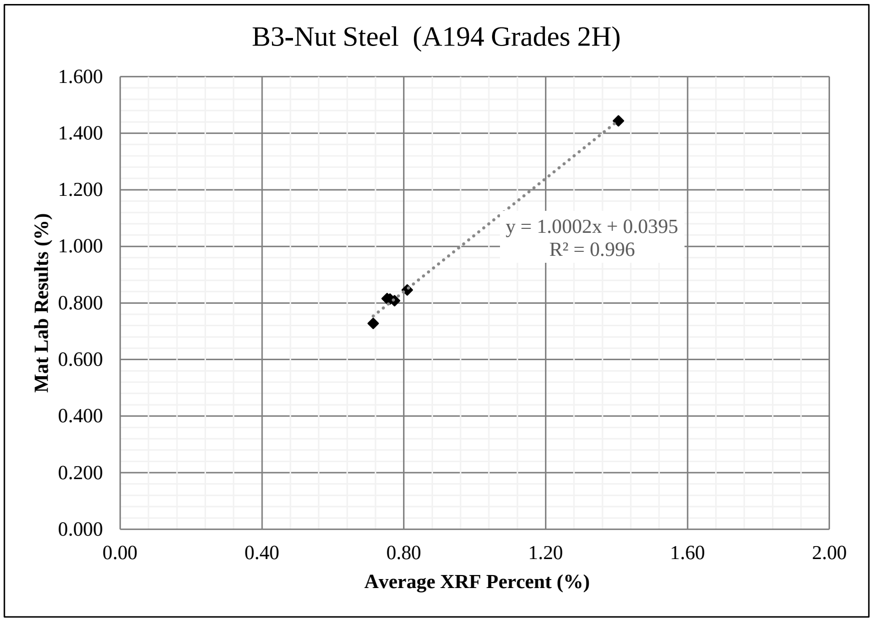
Figure 2. Testing Results of Copper in F1554 Grade 55 and 105 Bolts



ASTM A194 Grade 2H Steel Nut (B3)

According to ASTM A194 Table 1, the chemical elements carbon, manganese, phosphorus, and sulfur will be of the best interest for testing Grade 2H nuts. Hence, after six A194 Grade 2H nuts were tested, the data analysis was focused on the comparison between the detected contents of carbon, manganese, phosphorus, and sulfur from portable XRF and DOTD materials laboratory. The spark spectrometer in DOTD materials laboratory was able to detect carbon, phosphorus, and sulfur in all the six samples, though at relative low content, i.e., less than 0.5%. However, these three elements were not detected by the portable XRF. These could be due to that (1) carbon is beyond the detection limit of portable XRF, and (2) the fluorescence from phosphorus and sulfur has a very low energy which could be reabsorbed by the sample or blocked by the air between the detector and the sample, leading to "not detected" testing results from portable XRF. For element manganese, it can be observed in Figure 3 that a linear relationship could be established between the portable XRF testing results and DOTD materials laboratory testing results. This implies the portable XRF used in this study could not be employed to detect light-atomic-weight elements, but could be employed to detect heavy-atomic-weight elements providing the device has been calibrated with the results from spark spectrometer.

Figure 3. Testing Results of Manganese in A194 Grade 2H Nuts



ASTM F436 Type I Steel Washer (B4)

Based on ASTM F436 Table 1, the targeted chemical elements for testing Type I steel washer are phosphorus and sulfur. From Table 4, it can be seen that phosphorus and sulfur were detected, with a content of 0.008% to 0.019% and a content of 0.009% to 0.027% respectively, in all the three steel washers by the spark spectrometer at DOTD materials laboratory. However, they were not detected by the portable XRF in this study. It is further confirmed that the portable XRF device used in this study was not capable to detect light-atomic-weight elements phosphorus and sulfur.

Table 4. Testing Results of Type I Steel Washers

Sample ID	Chemical Component	Portable XRF (%)				DOTD Materials Laboratory (%)
		XRF1	XRF2	XRF3	Average	
B4-082504	Phosphorus	ND	ND	ND	ND	0.019
	Sulfur	ND	ND	ND	ND	0.027
B4-090215	Phosphorus	ND	ND	ND	ND	0.011
	Sulfur	ND	ND	ND	ND	0.009
B4-145030	Phosphorus	ND	ND	ND	ND	0.008
	Sulfur	ND	ND	ND	ND	0.026

Portland cement Type I/II/III Powder (C1, C3)

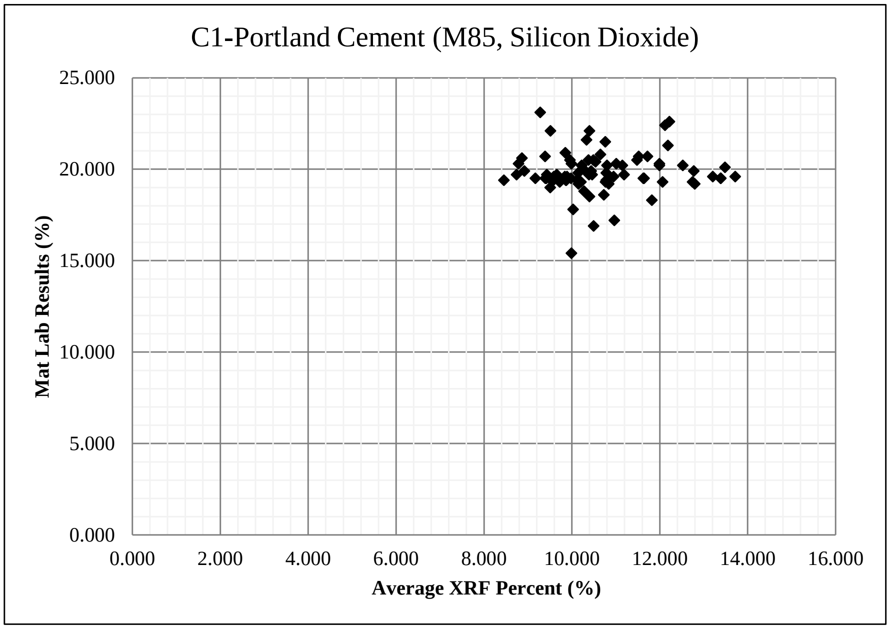
Eighty-seven portland cement Type I/II and three portland cement type III samples have been tested in this study to investigate the feasibility of applying portable XRF for testing cement. In comparison, the same materials were also tested in the DOTD materials laboratory, following the procedures in AASHTO T105 and standard chemical requirements in AASHTO M85. The testing reports from the DOTD materials laboratory show that there are five oxides detected during the laboratory testing, including silicon dioxide, calcium oxide, magnesium oxide, ferric oxide, and aluminum oxide. However, magnesium oxide was not detected by portable XRF in this study. This is probably due to that magnesium is at the edge of the detection capability of Olympus Vanta C series. Though different device was used, similar findings have also been reported by Young et al. (2016) that the handheld XRF was unable to detect elements Mg and Na reliably [18].

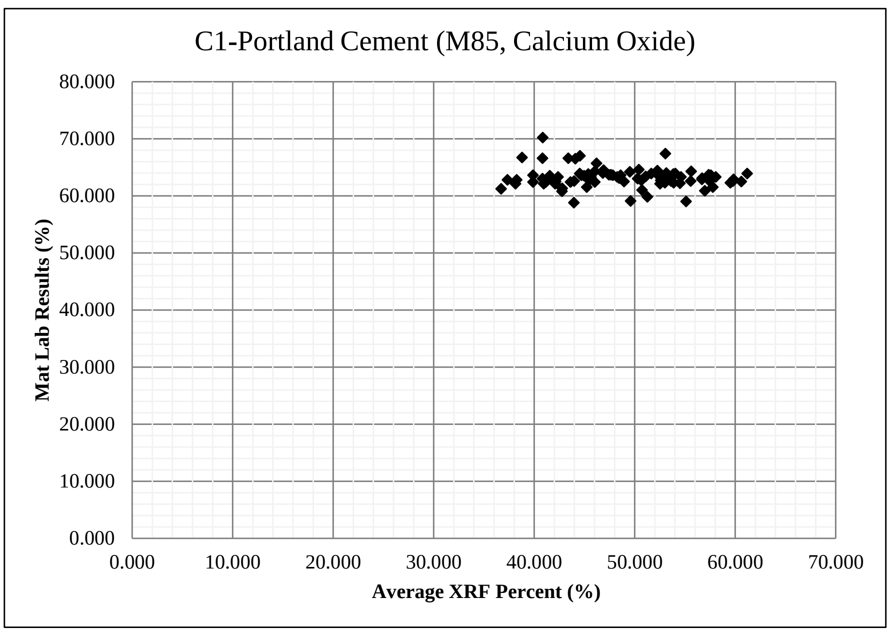
The plotting of the portable XRF testing results and the DOTD materials laboratory testing results for Type I/II portland cement are shown in Figure 4. For silicon dioxide, there are five data points showing a value less than 5% from portable XRF testing and far away from other data points. This could be due to the errors during testing and these five data points were excluded from further statistical analysis. The statistical parameters of the testing results are shown in Table 5. From Figure 4 and Table 5, it can be seen that the portable XRF works fairly well to detect silicon dioxide, calcium oxide, and ferric oxide though different correlation/calibrations would be needed for all of them. However, the testing results of aluminum oxide from portable XRF are more dispersive, which could be due to the lower atomic weight of aluminum and its low content in the samples.

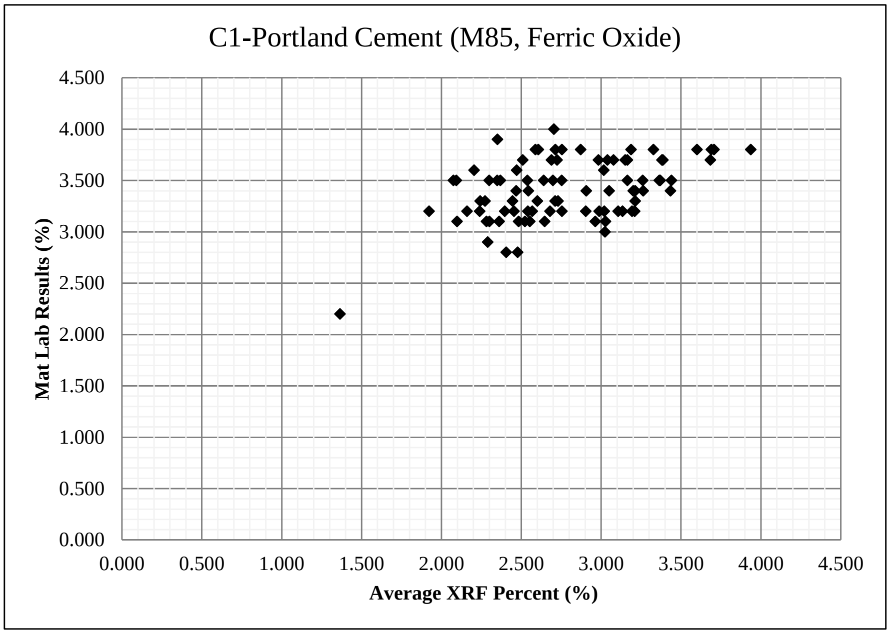
Table 5. Statistical Analysis of Type I/II Portland Cement Testing Results

	Portable XRF (%)		DOTD Materials Laboratory (%)	
	Mean	Standard Deviation	Mean	Standard Deviation
Silicon Dioxide	10.64	1.22	19.83	1.13
Calcium Oxide	48.99	6.27	63.19	1.73
Ferric Oxide	2.78	0.46	3.41	0.30
Aluminum Oxide	1.80	0.40	4.82	0.37

Figure 4. Testing Results of Type I/II Cement from Portable XRF and DOTD Laboratory







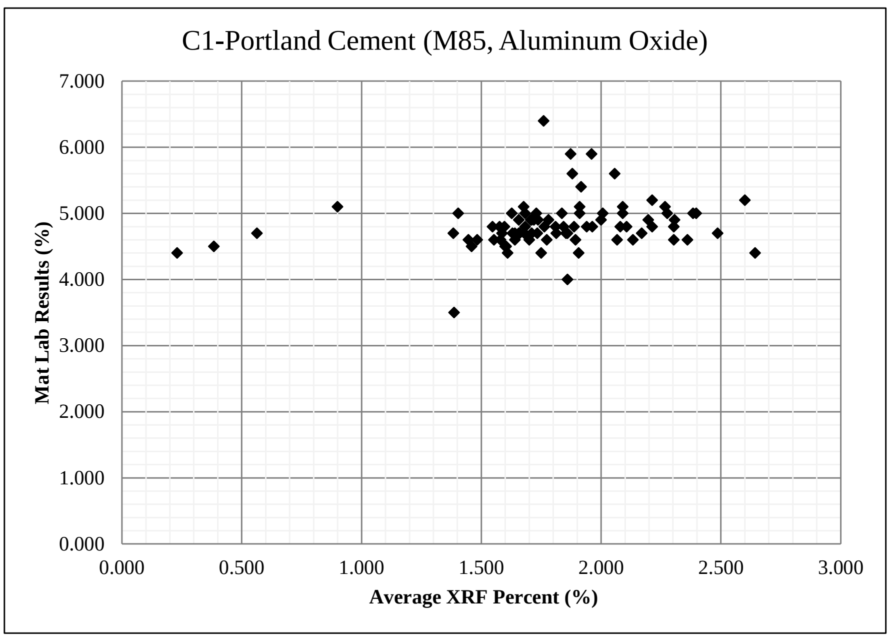
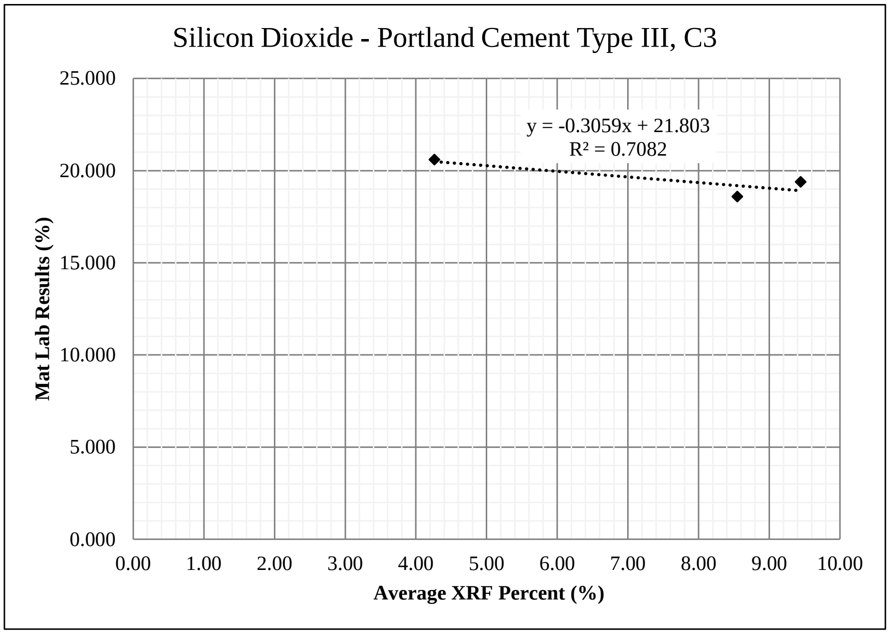
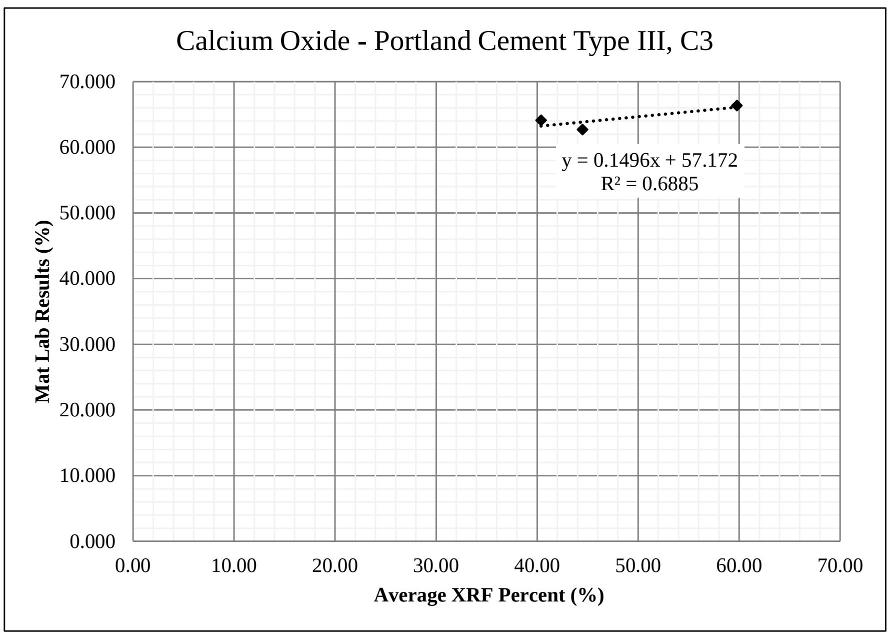
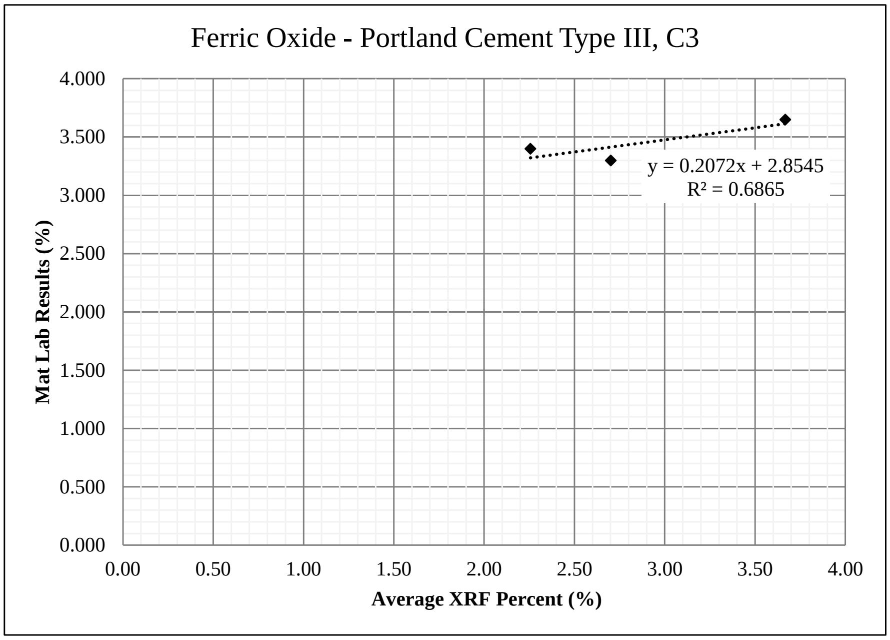


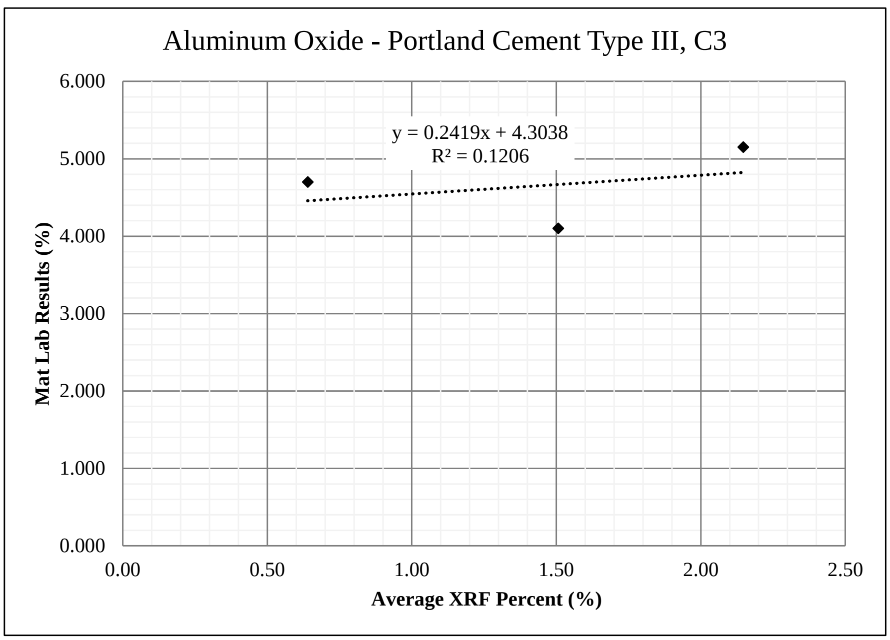
Figure 5 shows the correlations of the portable XRF testing results and the DOTD materials laboratory testing results for Type III portland cement. It is observed that a linear relationship with R^2 value of approximately 0.7 could be established between the portable XRF testing results and the DOTD materials laboratory testing results for silicon oxide, calcium oxide, and ferric oxide. However, the R^2 value drastically reduced to 0.1206 when similar linear relationship is trying to be established for aluminum oxide. This confirms that the portable XRF was not able to detect light weight element reliably.

Figure 5. Correlation of Portable XRF Results and DOTD Laboratory Results









Fly Ash Class F Powder (C9)

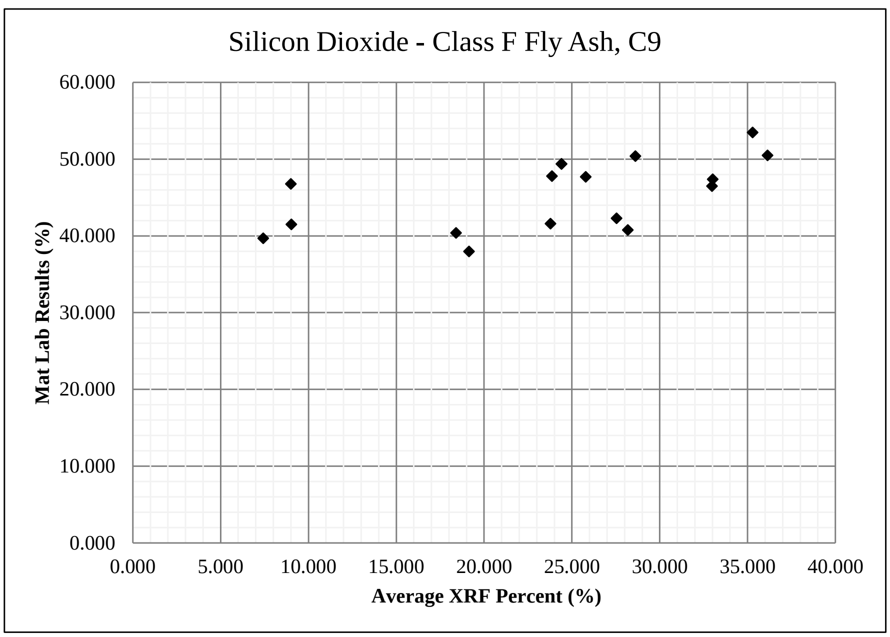
There were 17 class F fly ash samples tested with the portable XRF device in this study. In comparison, the same materials were also tested in the DOTD materials laboratory in accordance with AASHTO M295.

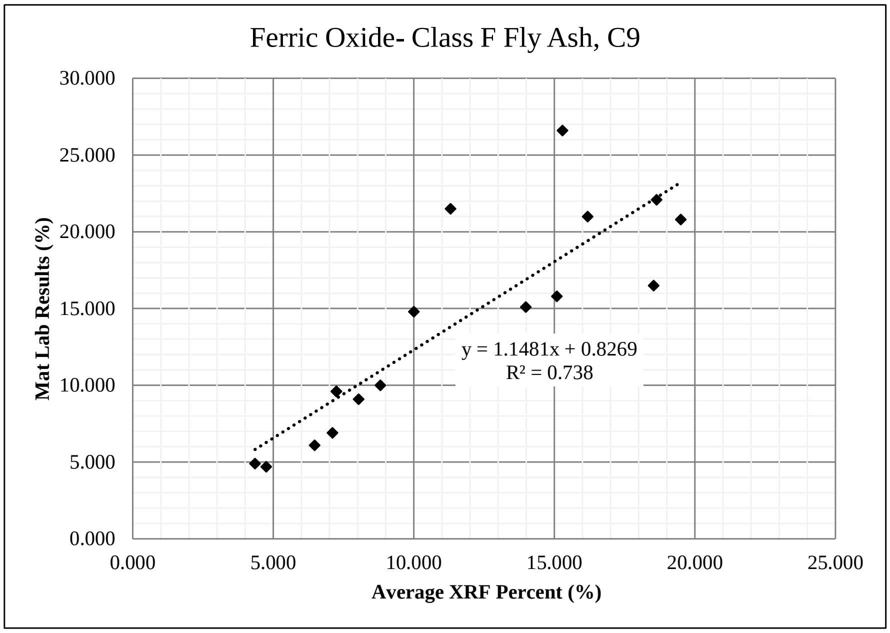
The testing results and statistical analysis of Class F fly ash are shown in Figure 6 and Table 6. The results show that the detected content of ferric oxide from the portable XRF was close to the one from the DOTD materials laboratory, but with a lower standard deviation. However, the portable XRF underestimated silicon dioxide and aluminum oxide to a higher degree.

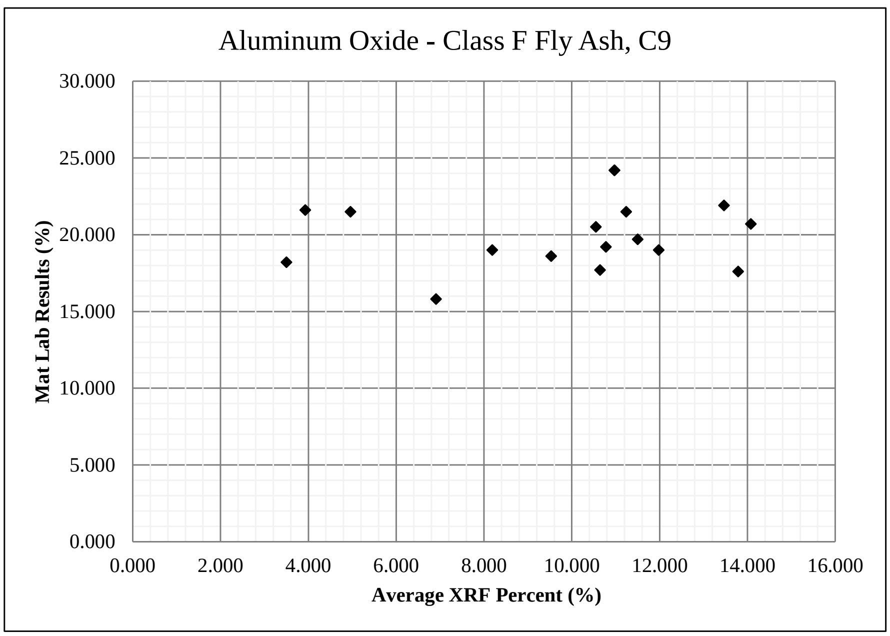
Table 6. Statistical Analysis of Class F Fly Ash Testing Results

	Portable XRF (%)		DOTD Materials Laboratory (%)	
	Mean	Standard Deviation	Mean	Standard Deviation
Silicon Dioxide	23.94	8.64	45.51	4.47
Ferric Oxide	11.32	4.96	13.83	6.63
Aluminum Oxide	9.82	3.17	20.05	2.21

Figure 6. Testing Results of Class F Fly Ash from Portable XRF and DOTD Laboratory



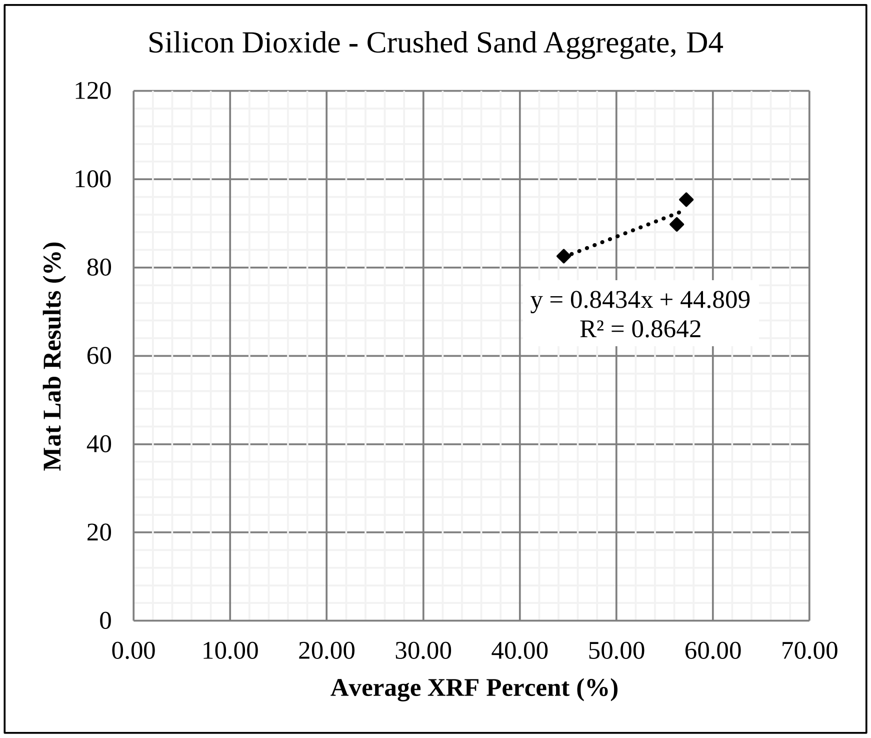


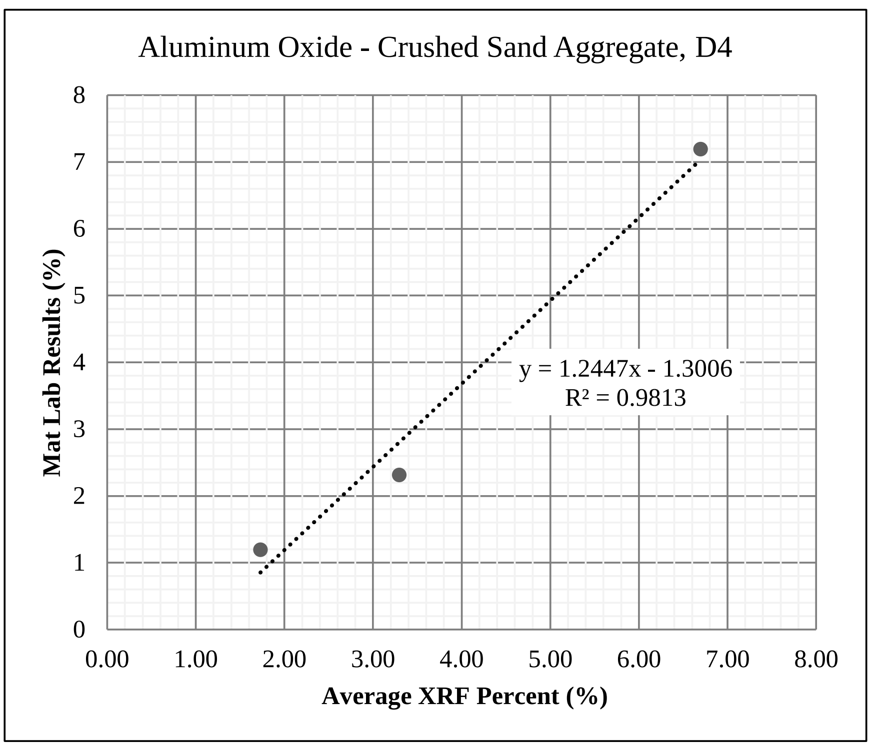


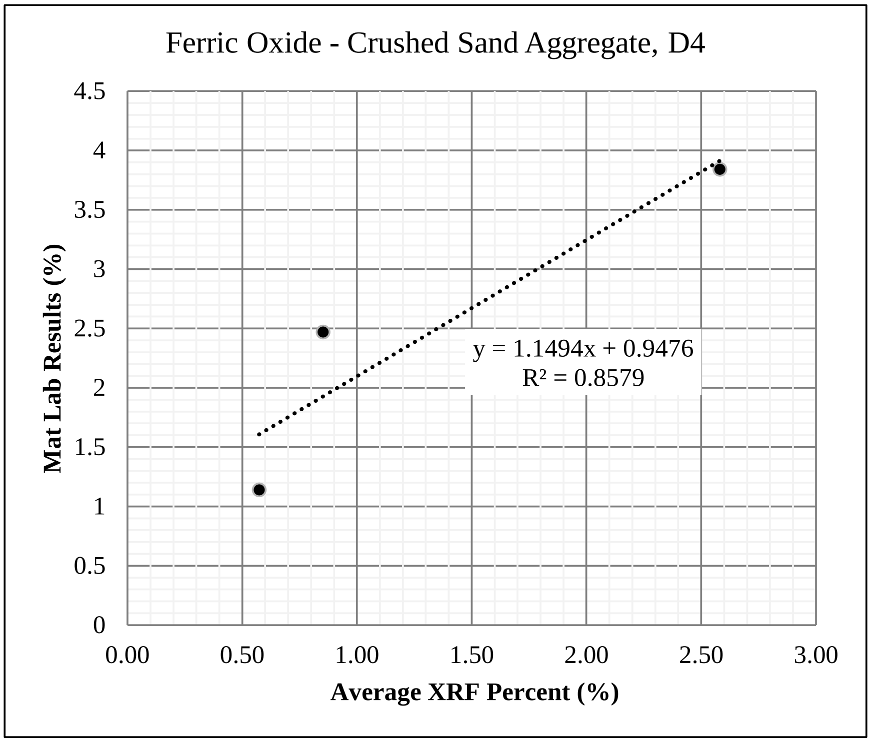
Aggregate – Crushed Sand (D4)

Three crushed sand aggregate samples were tested with the portable XRF in this study. Figure 7 shows the comparison between the portable XRF testing results and the DOTD materials laboratory testing results. It can be observed that the portable XRF generally underestimated the contents, except for aluminum oxide in two samples (3.3% vs 2.31%, and 1.73% vs. 1.19%).

Figure 7. Testing Results of Crushed Sand Aggregate from Portable XRF and DOTD Laboratory



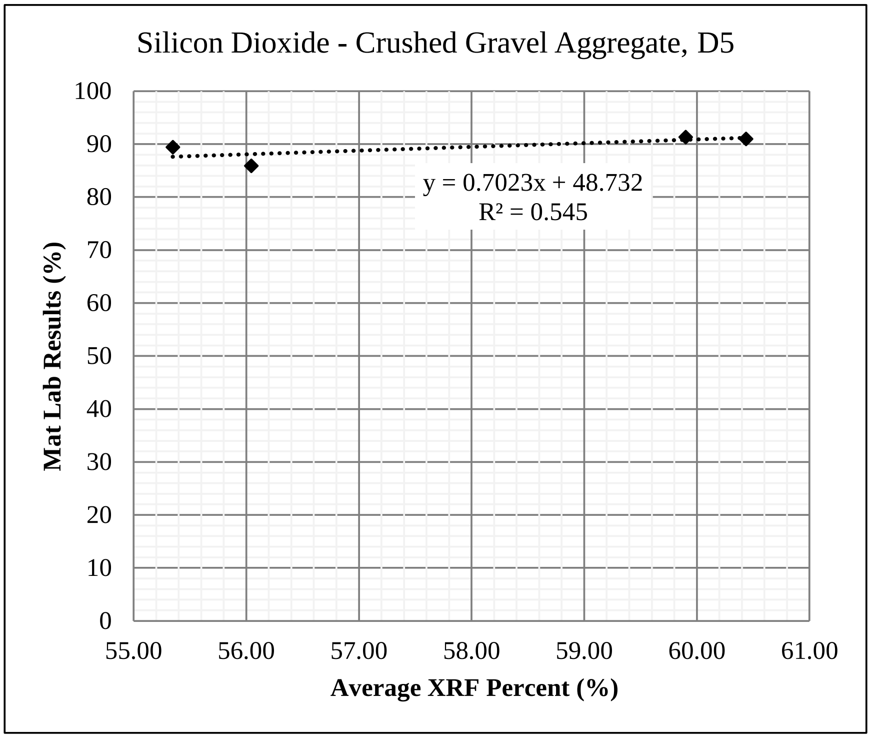


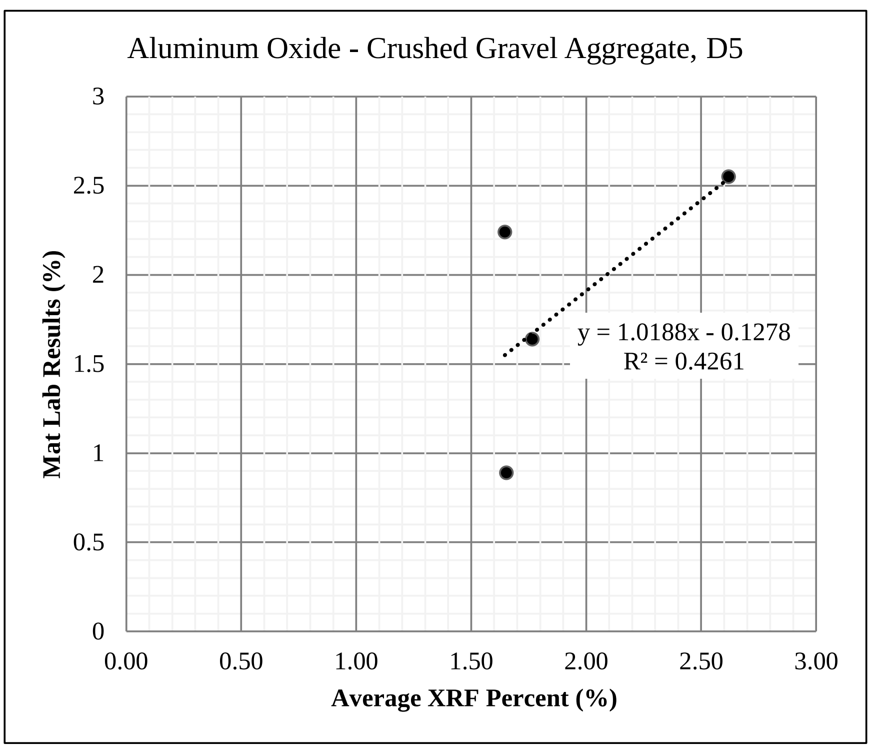


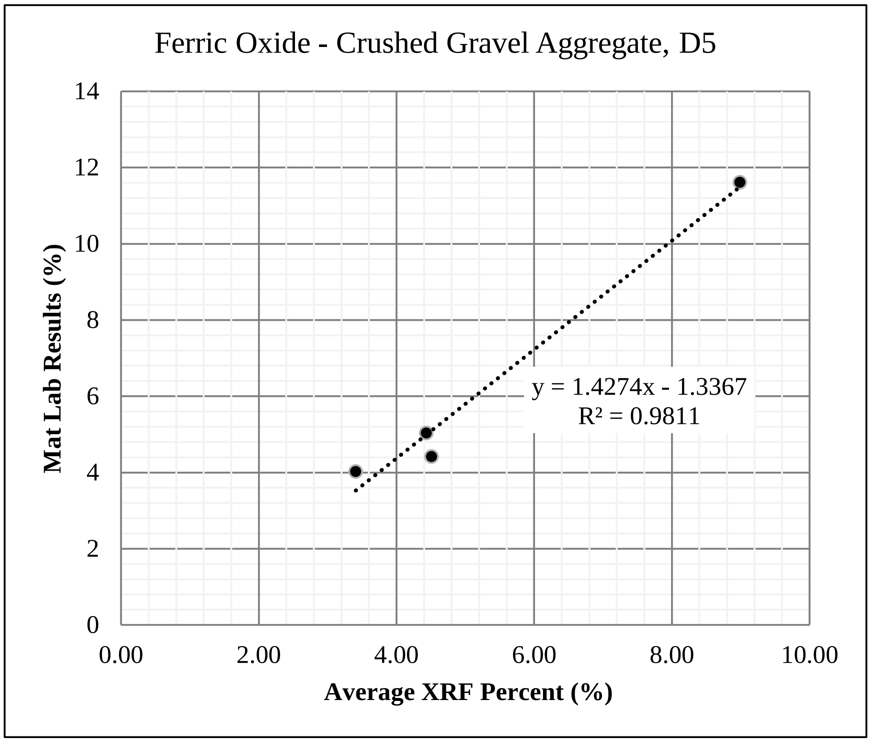
Aggregate – Crushed Gravel (D5)

Four crushed gravel aggregate samples were tested with the portable XRF in this study. Figure 8 shows the correlation between the portable XRF testing results and the DOTD materials laboratory testing results. Similar to the results of crushed sand aggregate, the portable XRF underestimated the contents of silicon oxide and ferric oxide.

Figure 8. Testing Results of Crushed Gravel Aggregate from Portable XRF and DOTD Laboratory



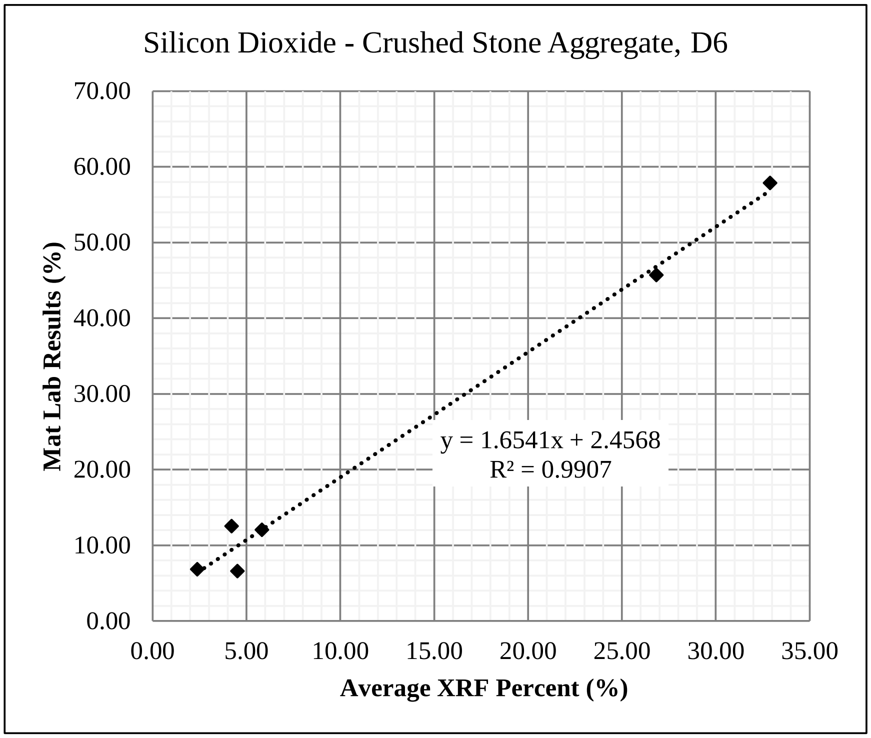


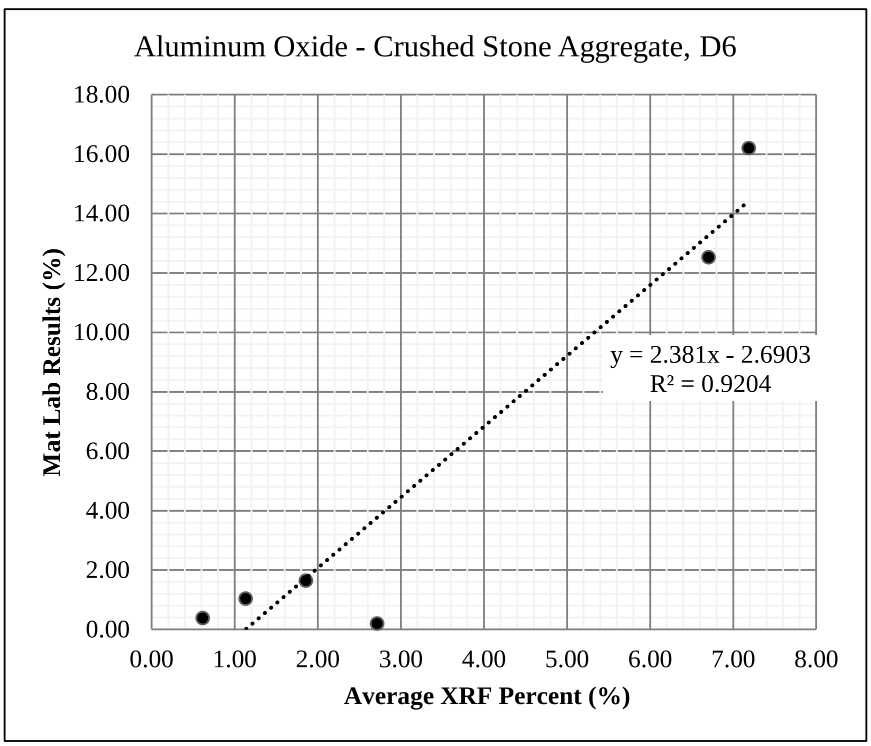


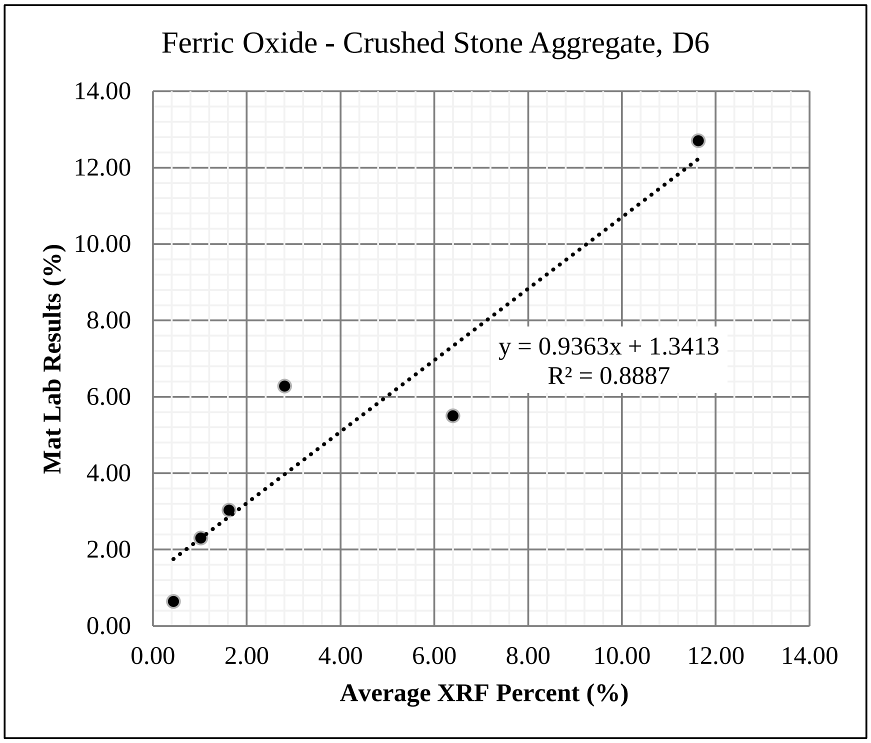
Aggregate – Crushed Stone (D6)

Six crushed stone aggregate samples were tested with the portable XRF device in this study. There was one set of test results showing abnormal readings, and it was excluded for the data analysis. As shown in Figure 9, it is found that a linear relationship with R^2 value of above 0.85 could be established between the portable XRF testing results and the DOTD materials laboratory testing results for silicon oxide, aluminum oxide, ferric oxide, and calcium oxide.

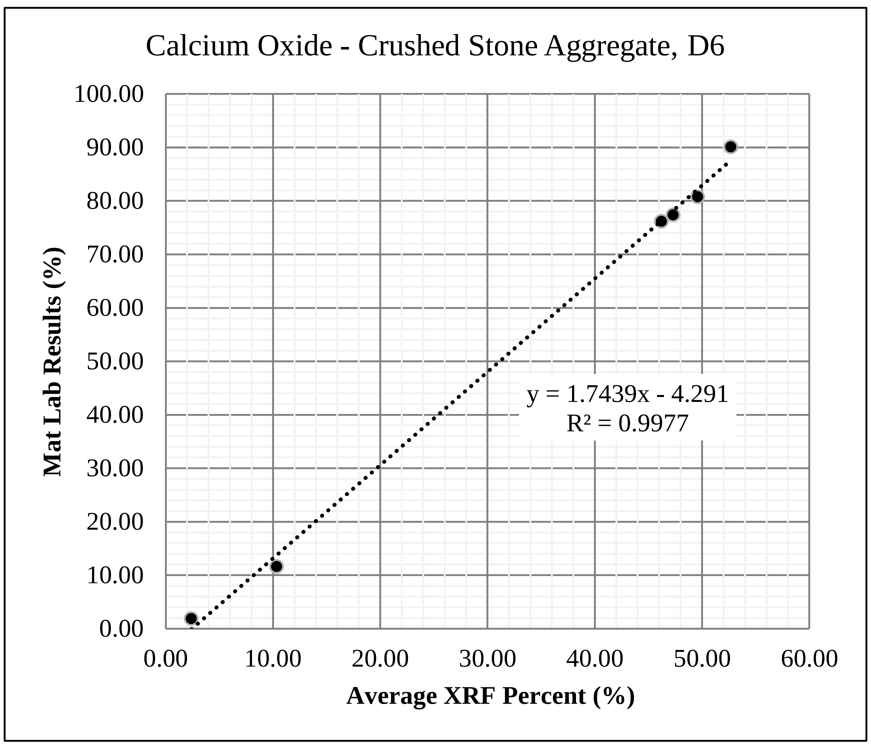
Figure 9. Testing Results of Crushed Stone Aggregate from Portable XRF and DOTD Laboratory







Ferric Oxide - Crushed Stone Aggregate, D6
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
Mat Lab Results (%)
Average XRF Percent (%)
y = 0.9363x + 1.3413
R² = 0.8887



Calcium Oxide - Crushed Stone Aggregate, D6
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
Mat Lab Results (%)
Average XRF Percent (%)
y = 1.7439x - 4.291
R² = 0.9977

Conclusions

By comparing the testing results of portable XRF (Olympus Vanta C series) and DOTD materials laboratory, it is concluded that:

- For A955 grade 60 stainless steel, portable XRF works fairly well for the testing of manganese, copper, nickel, chromium, and molybdenum. The portable XRF device used in this study was able to detect phosphorus, sulfur, and silicon, but cannot produce reliable results for their contents.
- For ASTM F1554 Grade 55 and 105 anchor bolts, the portable XRF device used in this study was not able to detect phosphorus and sulfur that have a content value less than 0.04%. There is a linear relationship between the portable XRF testing results and DOTD materials laboratory testing results for the testing results of element copper.
- For ASTM A194 Grade 2H steel nuts, the portable XRF used in this study was not able to detect phosphorus, and sulfur that have a content value less than 0.5%. For element manganese, there is linear relationship between the portable XRF testing results and DOTD materials laboratory testing results.
- For ASTM F436 type I steel washers, the portable XRF was not able to detect phosphorus and sulfur that have a content value less than 0.03%.
- For portland cement Type I/II, the portable XRF was not able to detect magnesium oxide, which might be due to that magnesium is at the edge of the detection capability of Olympus Vanta C series. Portable XRF works fairly well to detect silicon dioxide, calcium oxide, and ferric oxide though different correlation/calibrations would be needed for all of them. However, the testing results of aluminum oxide from portable XRF are more dispersive, which could be due to the lower atomic weight of aluminum and its low content in the samples.
- For portland cement Type III, a linear relationship with R^2 value of approximately 0.7 could be established between the portable XRF testing results and DOTD materials laboratory testing results for silicon oxide, calcium oxide, and ferric oxide. However, the R^2 value drastically reduced to 0.1206 for aluminum oxide. This confirms that the portable XRF was not able to detect light weight element reliably.
- For Class F fly ash, the detected content of ferric oxide from portable XRF was close to the one from the DOTD materials laboratory, but with a lower standard

deviation. However, the portable XRF underestimated silicon dioxide and aluminum oxide to a higher degree.

- For crushed sand aggregate, the portable XRF generally underestimated the contents, except for aluminum oxide in two samples (3.3% vs 2.31%, and 1.73% vs 1.19%).
- For crushed gravel aggregate, portable XRF underestimated the contents of silicon oxide and ferric oxide.
- For crushed stone aggregate, a linear relationship with R^2 value of above 0.85 could be established between the portable XRF testing results and DOTD materials laboratory testing results for silicon oxide, aluminum oxide, ferric oxide, and calcium oxide.

Recommendations

Portable XRF could be used to detect heavy-atomic-weight elements providing the device has been calibrated with the results from benchtop XRF.

Acronyms, Abbreviations, and Symbols

Term	Description
AASHTO	American Association of State Highway and Transportation Officials
FHWA	Federal Highway Administration
DOTD	Louisiana Department of Transportation and Development
LTRC	Louisiana Transportation Research Center
XRF	X-ray Fluorescence

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Appendix – Test Results Data

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
060320	A3	Bar, Stainless Steel Def Grade 60 #4	Carbon	ND	ND	ND	-	0.066
			Manganese	0.990	1.030	1.020	1.01	1.011
			Phosphorus	0.092	0.112	0.116	0.11	0.048
			Sulfur	0.487	0.394	0.604	0.50	0.002
			Silicon	1.061	0.926	1.116	1.03	0.097
			Copper	0.335	0.361	0.341	0.35	0.324
			Nickel	9.870	9.750	9.820	9.81	10.13
			Chromium	17.690	17.620	17.580	17.63	17.01
			Molybdenum	2.053	2.042	2.008	2.03	2.03

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
090239	B2	Anchor Bolt Steel (Grade105)	Phosphorus	ND	ND	ND	-	0.008
			Sulfur	ND	ND	ND	-	0.029
			Copper	0.301	0.297	0.312	0.30	0.276
091346	B2	Anchor Bolt Steel (Grade105)	Phosphorus	ND	ND	ND	-	0.020
			Sulfur	ND	ND	ND	-	0.032
			Copper	0.293	0.317	0.296	0.30	0.279
101824	B2	Anchor Bolt Steel (Grade105)	Phosphorus	ND	ND	ND	-	0.016
			Sulfur	ND	ND	ND	-	0.030
			Copper	0.275	0.276	0.272	0.27	0.262
103957	B2	Anchor Bolt Steel (Grade55)	Phosphorus	ND	ND	ND	-	0.013
			Sulfur	ND	ND	ND	-	0.036
			Copper	0.314	0.323	0.314	0.32	0.290

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
125548	B2	Anchor Bolt Steel (Grade55)	Phosphorus	ND	ND	ND	-	0.011
			Sulfur	ND	ND	ND	-	0.032
			Copper	0.242	0.236	0.231	0.24	0.206
145239	B2	Anchor Bolt Steel (Grade55)	Phosphorus	ND	ND	ND	-	0.009
			Sulfur	ND	ND	ND	-	0.008
			Copper	0.266	0.257	0.258	0.26	0.234
150913 (820052)	B2	Anchor Bolt Steel (Grade105)	Phosphorus	ND	ND	ND	-	0.008
			Sulfur	ND	ND	ND	-	0.024
			Copper	0.237	0.226	0.209	0.22	0.186

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
082158	B3	Nut Hardened Steel, A194, Grade 2H	Carbon	ND	ND	ND	-	0.440
			Manganese	0.792	0.822	0.817	0.81	0.846
			Phosphorus	ND	ND	ND	-	0.018
			Sulfur	ND	ND	ND	-	0.029
083618	B3	Nut Hardened Steel, A194, Grade 2H	Carbon	ND	ND	ND	-	0.400
			Manganese	0.713	0.732	0.696	0.71	0.728
			Phosphorus	ND	ND	ND	-	0.014
			Sulfur	ND	ND	ND	-	0.029
085958	B3	Nut Carbon Steel, A563, Grade DH	Carbon	ND	ND	ND	-	0.413
			Manganese	0.583	0.582	0.600	0.59	0.646
			Phosphorus	ND	ND	ND	-	0.011
			Sulfur	ND	ND	ND	-	0.026

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
102310	B3	Nut Hardened Steel, A194, Grade 2H	Carbon	ND	ND	ND	-	0.443
			Manganese	0.740	0.743	0.777	0.75	0.816
			Phosphorus	ND	ND	ND	-	0.018
			Sulfur	ND	ND	ND	-	0.032
131602	B3	Nut Hardened Steel, A194, Grade 2H	Carbon	ND	ND	ND	-	0.441
			Manganese	0.773	0.757	0.753	0.76	0.814
			Phosphorus	ND	ND	ND	-	0.008
			Sulfur	ND	ND	ND	-	0.031
141517	B3	Nut Hardened Steel, A194, Grade 2H	Carbon	ND	ND	ND	-	0.474
			Manganese	0.768	0.813	0.741	0.77	0.808
			Phosphorus	ND	ND	ND	-	0.013
			Sulfur	ND	ND	ND	-	0.014

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
150641	B3	Nut Hardened Steel, A194, Grade 8	Carbon	ND	ND	ND	-	0.038
			Manganese	1.432	1.391	1.393	1.41	1.444
			Phosphorus	ND	ND	ND	-	0.029
			Sulfur	ND	ND	ND	-	0.024

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
082504	B4	Washer, Hardened Steel F436, Type 1	Phosphorus	ND	ND	ND	-	0.019
			Sulfur	ND	ND	ND	-	0.027
090215	B4	Washer, Hardened Steel F436, Type 1	Phosphorus	ND	ND	ND	-	0.011
			Sulfur	ND	ND	ND	-	0.009
145030	B4	Washer, Hardened Steel F436, Type 1	Phosphorus	ND	ND	ND	-	0.008
			Sulfur	ND	ND	ND	-	0.026

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
073001	C1	Portland Cement Type I	Silicon Dioxide	9.800	9.360	9.930	9.70	19.500
			Calcium Oxide	41.440	37.760	44.280	41.16	62.400
			Magnesium Oxide	ND	ND	ND	-	2.900
			Ferric Oxide	2.857	2.347	2.910	2.70	4.000
			Aluminum Oxide	1.560	1.560	1.670	1.60	4.800
090944	C1	Portland Cement Type II	Silicon Dioxide	10.300	11.660	10.310	10.76	21.500
			Calcium Oxide	44.580	49.500	44.480	46.19	65.700
			Magnesium Oxide	ND	ND	ND	-	3.000
			Ferric Oxide	2.310	2.487	2.392	2.40	3.200
			Aluminum Oxide	1.610	1.920	1.600	1.71	4.900
084922	C1	Portland Cement Type II	Silicon Dioxide	8.890	10.370	9.200	9.49	19.500
			Calcium Oxide	35.940	43.850	39.820	39.87	62.400
			Magnesium Oxide	ND	ND	ND	-	3.300

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
			Ferric Oxide	1.719	2.096	1.954	1.92	3.200
			Aluminum Oxide	1.370	1.790	1.670	1.61	4.400
063009	C1	Portland Cement Type I	Silicon Dioxide	8.870	10.090	9.550	9.50	19.000
			Calcium Oxide	41.110	45.790	41.470	42.79	61.300
			Magnesium Oxide	ND	ND	ND	-	3.900
			Ferric Oxide	2.186	2.392	2.148	2.24	3.300
			Aluminum Oxide	1.630	1.940	1.640	1.74	4.900
081415	C1	Portland Cement Type II	Silicon Dioxide	8.750	10.440	9.550	9.58	19.400
			Calcium Oxide	42.350	48.260	47.480	46.03	64.300
			Magnesium Oxide	ND	ND	ND	-	1.100
			Ferric Oxide	2.320	2.680	2.612	2.54	3.500
			Aluminum Oxide	1.520	1.910	1.700	1.71	4.700
144545	C1		Silicon Dioxide	11.060	11.020	11.480	11.19	19.700

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
		Portland Cement Type II	Calcium Oxide	51.150	54.330	53.350	52.94	63.400
			Magnesium Oxide	ND	ND	ND	-	2.100
			Ferric Oxide	2.800	2.970	2.950	2.91	3.400
			Aluminum Oxide	2.250	2.310	2.270	2.28	5.000
120750	C1	Portland Cement Type II	Silicon Dioxide	9.530	10.890	10.580	10.33	21.600
			Calcium Oxide	38.810	48.000	46.850	44.55	67.000
			Magnesium Oxide	ND	ND	ND	-	1.000
			Ferric Oxide	2.209	2.860	2.750	2.61	3.800
			Aluminum Oxide	1.710	1.710	1.770	1.73	5.000
075216	C1	Portland Cement Type I	Silicon Dioxide	10.020	12.440	14.090	12.18	21.300
			Calcium Oxide	42.510	56.280	60.370	53.05	67.400
			Magnesium Oxide	ND	ND	ND	-	1.000
			Ferric Oxide	2.519	3.160	3.440	3.04	3.700

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
			Aluminum Oxide	1.770	2.170	2.330	2.09	5.100
085927	C1	Portland Cement Type II	Silicon Dioxide	11.270	10.730	9.950	10.65	20.800
			Calcium Oxide	49.090	47.480	43.870	46.81	64.000
			Magnesium Oxide	ND	ND	ND	-	2.500
			Ferric Oxide	2.324	2.274	2.120	2.24	3.200
			Aluminum Oxide	1.970	1.840	1.810	1.87	5.900
092300	C1	Portland Cement Type I	Silicon Dioxide	9.180	8.710	10.390	9.43	19.700
			Calcium Oxide	40.950	36.270	45.580	40.93	62.100
			Magnesium Oxide	ND	ND	ND	-	2.400
			Ferric Oxide	2.330	2.046	2.670	2.35	3.500
			Aluminum Oxide	2.030	1.930	2.310	2.09	5.000
081133	C1		Silicon Dioxide	8.220	9.990	13.110	10.44	19.900
			Calcium Oxide	32.850	41.180	57.860	43.96	62.600

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
		Portland Cement Type II	Magnesium Oxide	ND	ND	ND	-	2.500
			Ferric Oxide	1.674	2.105	3.040	2.27	3.300
			Aluminum Oxide	1.420	1.680	2.060	1.72	4.900
182243	C1	Portland Cement Type II	Silicon Dioxide	8.300	9.580	8.710	8.86	20.600
			Calcium Oxide	39.640	47.010	40.430	42.36	63.300
			Magnesium Oxide	ND	ND	ND	-	1.700
			Ferric Oxide	2.277	2.800	2.450	2.51	3.700
			Aluminum Oxide	1.460	1.360	1.520	1.45	4.600
072351	C1	Portland Cement Type II	Silicon Dioxide	9.130	9.390	8.980	9.17	19.500
			Calcium Oxide	41.140	41.440	42.030	41.54	63.500
			Magnesium Oxide	ND	ND	ND	-	2.600
			Ferric Oxide	2.260	2.293	2.343	2.30	3.500

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
			Aluminum Oxide	1.670	1.900	1.550	1.71	4.900
075051	C1	Portland Cement Type I	Silicon Dioxide	10.830	10.550	10.100	10.49	16.900
			Calcium Oxide	47.730	44.890	43.060	45.23	61.500
			Magnesium Oxide	ND	ND	ND	-	0.900
			Ferric Oxide	2.780	2.750	2.563	2.70	3.500
			Aluminum Oxide	1.970	1.920	1.690	1.86	4.000
094644	C1	Portland Cement Type II	Silicon Dioxide	9.720	8.960	9.510	9.40	19.500
			Calcium Oxide	47.820	39.670	46.610	44.70	63.600
			Magnesium Oxide	ND	ND	ND	-	2.000
			Ferric Oxide	2.950	2.226	2.890	2.69	3.700
			Aluminum Oxide	1.790	1.590	1.590	1.66	4.900
082943	C1		Silicon Dioxide	9.640	10.660	9.410	9.90	19.500
			Calcium Oxide	44.960	45.770	45.400	45.38	63.800

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
		Portland Cement Type II	Magnesium Oxide	ND	ND	ND	-	1.600
			Ferric Oxide	2.700	2.660	2.780	2.71	3.800
			Aluminum Oxide	1.630	1.770	1.640	1.68	4.700
153333	C1	Portland Cement Type II	Silicon Dioxide	10.950	10.790	9.730	10.49	20.500
			Calcium Oxide	47.940	44.990	40.670	44.53	63.900
			Magnesium Oxide	ND	ND	ND	-	0.900
			Ferric Oxide	2.618	2.498	2.295	2.47	3.600
			Aluminum Oxide	2.010	1.870	1.560	1.81	4.700
092538	C1	Portland Cement Type II	Silicon Dioxide	10.360	12.120	9.870	10.78	19.800
			Calcium Oxide	49.670	55.820	49.460	51.65	63.900
			Magnesium Oxide	ND	ND	ND	-	1.500
			Ferric Oxide	3.140	3.320	3.030	3.16	3.700

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
			Aluminum Oxide	1.770	2.270	1.690	1.91	5.100
065556	C1	Portland Cement Type I	Silicon Dioxide	10.270	9.550	9.730	9.85	20.900
			Calcium Oxide	42.530	40.220	39.700	40.82	66.600
			Magnesium Oxide	ND	ND	ND	-	1.400
			Ferric Oxide	2.313	2.163	2.137	2.20	3.600
			Aluminum Oxide	1.700	1.540	1.640	1.63	5.000
072943	C1	Portland Cement Type II	Silicon Dioxide	8.670	8.070	11.420	9.39	20.700
			Calcium Oxide	35.210	32.000	49.120	38.78	66.700
			Magnesium Oxide	ND	ND	ND	-	0.800
			Ferric Oxide	1.841	1.709	2.674	2.07	3.500
			Aluminum Oxide	1.660	1.660	2.430	1.92	5.400
081156	C1		Silicon Dioxide	10.940	11.000	13.210	11.72	20.700
			Calcium Oxide	51.880	57.280	57.710	55.62	64.300

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
		Portland Cement Type II	Magnesium Oxide	ND	ND	ND	-	2.100
			Ferric Oxide	2.840	3.020	3.210	3.02	3.000
			Aluminum Oxide	2.240	1.900	2.260	2.13	4.600
173533	C1	Portland Cement Type I	Silicon Dioxide	10.470	8.830	9.320	9.54	19.400
			Calcium Oxide	48.240	37.450	40.680	42.12	62.500
			Magnesium Oxide	ND	ND	ND	-	2.800
			Ferric Oxide	2.720	2.199	2.188	2.37	3.500
			Aluminum Oxide	1.820	1.660	1.720	1.73	4.700
063858	C1	Portland Cement Type II	Silicon Dioxide	9.940	8.980	11.530	10.15	19.200
			Calcium Oxide	48.070	34.670	53.670	45.47	62.700
			Magnesium Oxide	ND	ND	ND	-	3.300
			Ferric Oxide	2.590	1.611	2.700	2.30	3.100

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
			Aluminum Oxide	1.670	1.650	2.210	1.84	4.800
090930	C1	Portland Cement Type I	Silicon Dioxide	10.000	9.710	9.800	9.84	19.600
			Calcium Oxide	42.540	36.660	40.400	39.87	63.600
			Magnesium Oxide	ND	ND	ND	-	1.800
			Ferric Oxide	2.627	2.084	2.342	2.35	3.900
			Aluminum Oxide	1.770	1.810	1.700	1.76	6.400
055308	C1	Portland Cement Type I	Silicon Dioxide	9.670	9.730	9.560	9.65	19.700
			Calcium Oxide	45.450	47.940	43.490	45.63	63.300
			Magnesium Oxide	ND	ND	ND	-	1.900
			Ferric Oxide	2.667	2.970	2.626	2.75	3.800
			Aluminum Oxide	1.600	1.730	1.720	1.68	4.800
081332	C1		Silicon Dioxide	10.420	10.670	9.250	10.11	19.400
			Calcium Oxide	49.770	54.000	44.770	49.51	64.200

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
		Portland Cement Type II	Magnesium Oxide	ND	ND	ND	-	1.100
			Ferric Oxide	2.790	2.910	2.560	2.75	3.500
			Aluminum Oxide	1.590	1.800	1.590	1.66	4.700
063429	C1	Portland Cement Type II	Silicon Dioxide	9.280	9.890	9.590	9.59	19.600
			Calcium Oxide	43.050	47.810	49.840	46.90	64.500
			Magnesium Oxide	ND	ND	ND	-	0.900
			Ferric Oxide	2.388	2.720	2.810	2.64	3.500
			Aluminum Oxide	2.030	1.970	1.730	1.91	5.000
112002	C1	Portland Cement Type II	Silicon Dioxide	11.140	12.030	9.730	10.97	17.200
			Calcium Oxide	53.650	53.910	44.610	50.72	61.000
			Magnesium Oxide	ND	ND	ND	-	2.100
			Ferric Oxide	2.980	2.810	2.472	2.75	3.200

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
			Aluminum Oxide	1.920	2.200	1.600	1.91	4.400
054246	C1	Portland Cement Type I	Silicon Dioxide	12.430	10.600	11.410	11.48	20.500
			Calcium Oxide	51.440	44.850	46.600	47.63	63.700
			Magnesium Oxide	ND	ND	ND	-	0.900
			Ferric Oxide	3.110	2.743	2.760	2.87	3.800
			Aluminum Oxide	2.210	1.920	2.110	2.08	4.800
082509	C1	Portland Cement Type I	Silicon Dioxide	7.680	10.220	11.960	9.95	20.500
			Calcium Oxide	30.780	45.370	53.970	43.37	66.600
			Magnesium Oxide	ND	ND	ND	-	2.700
			Ferric Oxide	1.493	2.278	2.710	2.16	3.200
			Aluminum Oxide	1.080	1.620	1.940	1.55	4.800
083834	C1		Silicon Dioxide	9.710	10.220	9.240	9.72	19.300
			Calcium Oxide	46.580	46.690	41.640	44.97	63.500

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
		Portland Cement Type I	Magnesium Oxide	ND	ND	ND	-	2.100
			Ferric Oxide	2.350	2.370	2.126	2.28	3.100
			Aluminum Oxide	1.680	1.930	1.490	1.70	4.600
070008	C1	Portland Cement Type I	Silicon Dioxide	11.150	10.590	9.040	10.26	20.000
			Calcium Oxide	43.740	43.150	35.560	40.82	63.000
			Magnesium Oxide	ND	ND	ND	-	2.400
			Ferric Oxide	2.301	2.194	1.799	2.10	3.100
			Aluminum Oxide	1.870	1.600	1.510	1.66	4.700
091043	C1	Portland Cement Type II	Silicon Dioxide	8.830	12.240	8.900	9.99	15.400
			Calcium Oxide	41.210	51.400	39.180	43.93	58.800
			Magnesium Oxide	ND	2.600	ND	2.60	2.500
			Ferric Oxide	2.183	2.640	2.044	2.29	2.900

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
			Aluminum Oxide	1.240	1.720	1.200	1.39	3.500
080934	C1	Portland Cement Type II	Silicon Dioxide	10.090	11.630	9.660	10.46	19.700
			Calcium Oxide	51.930	56.380	48.420	52.24	64.400
			Magnesium Oxide	ND	ND	ND	-	1.100
			Ferric Oxide	3.120	3.190	2.740	3.02	3.600
			Aluminum Oxide	1.790	1.870	1.630	1.76	4.800
153648	C1	Portland Cement Type II	Silicon Dioxide	9.420	8.760	8.170	8.78	20.300
			Calcium Oxide	48.210	42.750	39.860	43.61	62.400
			Magnesium Oxide	ND	ND	ND	-	0.300
			Ferric Oxide	2.710	2.418	2.275	2.47	3.400
			Aluminum Oxide	1.670	1.350	1.190	1.40	5.000
155015	C1		Silicon Dioxide	10.740	10.150	10.300	10.40	22.100
			Calcium Oxide	48.670	39.490	40.070	42.74	60.800

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
		Portland Cement Type I	Magnesium Oxide	ND	ND	ND	-	1.100
			Ferric Oxide	3.280	2.430	2.463	2.72	3.700
			Aluminum Oxide	1.930	1.850	1.860	1.88	5.600
144504	C1	Portland Cement Type II	Silicon Dioxide	10.930	8.500	8.820	9.42	19.500
			Calcium Oxide	53.810	45.190	43.300	47.43	63.700
			Magnesium Oxide	ND	ND	ND	-	2.200
			Ferric Oxide	3.030	2.454	2.316	2.60	3.300
			Aluminum Oxide	1.800	1.210	1.140	1.38	4.700
065637	C1	Portland Cement Type I	Silicon Dioxide	8.070	12.840	9.710	10.21	19.300
			Calcium Oxide	44.980	59.320	48.950	51.08	63.400
			Magnesium Oxide	ND	ND	ND	-	2.300
			Ferric Oxide	2.280	3.080	2.206	2.52	3.100

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
			Aluminum Oxide	1.080	2.250	1.470	1.60	4.500
081729	C1	Portland Cement Type I	Silicon Dioxide	9.530	9.920	12.890	10.78	19.400
			Calcium Oxide	48.520	51.750	61.820	54.03	63.900
			Magnesium Oxide	ND	ND	ND	-	1.700
			Ferric Oxide	2.750	3.130	3.570	3.15	3.700
			Aluminum Oxide	1.590	1.420	2.330	1.78	4.900
075515	C1	Portland Cement Type II	Silicon Dioxide	9.540	6.230	10.450	8.74	19.700
			Calcium Oxide	52.750	37.280	55.750	48.59	63.600
			Magnesium Oxide	ND	ND	ND	-	1.100
			Ferric Oxide	3.570	2.560	3.850	3.33	3.800
			Aluminum Oxide	1.540	1.130	1.780	1.48	4.600
083750	C1		Silicon Dioxide	11.150	10.170	11.080	10.80	20.200
			Calcium Oxide	53.540	51.280	52.710	52.51	62.100

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
		Portland Cement Type I	Magnesium Oxide	ND	ND	ND	-	3.400
			Ferric Oxide	2.590	2.262	2.364	2.41	2.800
			Aluminum Oxide	1.890	1.770	1.920	1.86	4.700
082621	C1	Portland Cement Type II	Silicon Dioxide	10.260	10.340	11.010	10.54	20.400
			Calcium Oxide	48.650	52.190	55.680	52.17	63.900
			Magnesium Oxide	ND	ND	ND	-	0.900
			Ferric Oxide	2.480	2.760	2.800	2.68	3.200
			Aluminum Oxide	1.650	1.530	1.630	1.60	4.500
065409	C1	Portland Cement Type II	Silicon Dioxide	14.360	11.000	10.830	12.06	19.300
			Calcium Oxide	62.810	55.400	51.860	56.69	63.100
			Magnesium Oxide	ND	ND	ND	-	1.300
			Ferric Oxide	3.330	2.840	2.980	3.05	3.400

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
			Aluminum Oxide	2.700	1.850	2.090	2.21	4.800
110621	C1	Portland Cement Type I	Silicon Dioxide	11.970	11.230	14.370	12.52	20.200
			Calcium Oxide	56.190	53.180	63.370	57.58	63.600
			Magnesium Oxide	ND	ND	ND	-	0.900
			Ferric Oxide	3.440	3.150	3.570	3.39	3.700
			Aluminum Oxide	2.090	1.800	2.620	2.17	4.700
072048	C1	Portland Cement Type I	Silicon Dioxide	11.750	13.440	11.470	12.22	22.600
			Calcium Oxide	50.200	50.670	47.880	49.58	59.100
			Magnesium Oxide	ND	ND	ND	-	3.800
			Ferric Oxide	2.480	2.452	2.500	2.48	2.800
			Aluminum Oxide	1.830	2.520	1.820	2.06	5.600
105729	C1		Silicon Dioxide	7.940	10.470	9.420	9.28	23.100
			Calcium Oxide	46.190	56.490	51.050	51.24	59.800

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
		Portland Cement Type I	Magnesium Oxide	ND	ND	ND	-	2.000
			Ferric Oxide	2.970	3.120	2.870	2.99	3.200
			Aluminum Oxide	1.360	1.900	1.790	1.68	5.000
132418	C1	Portland Cement Type II	Silicon Dioxide	14.800	11.480	9.700	11.99	20.300
			Calcium Oxide	64.900	56.160	53.080	58.05	63.300
			Magnesium Oxide	ND	ND	ND	-	1.000
			Ferric Oxide	3.580	3.320	3.240	3.38	3.700
			Aluminum Oxide	2.770	2.020	1.210	2.00	4.900
102044	C1	Portland Cement Type I	Silicon Dioxide	10.300	10.060	9.580	9.98	19.500
			Calcium Oxide	52.630	53.670	51.100	52.47	63.400
			Magnesium Oxide	ND	ND	ND	-	1.800
			Ferric Oxide	3.170	3.300	3.090	3.19	3.800

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
			Aluminum Oxide	1.690	1.740	1.490	1.64	4.700
122132	C1	Portland Cement Type I	Silicon Dioxide	9.170	9.780	10.720	9.89	19.600
			Calcium Oxide	41.270	50.940	53.140	48.45	63.100
			Magnesium Oxide	ND	ND	ND	-	2.600
			Ferric Oxide	2.210	2.630	2.610	2.48	3.100
			Aluminum Oxide	1.540	1.550	1.670	1.59	4.700
092058	C1	Portland Cement Type II	Silicon Dioxide	13.470	10.210	10.880	11.52	20.700
			Calcium Oxide	59.290	48.960	53.280	53.84	63.800
			Magnesium Oxide	ND	ND	ND	-	1.000
			Ferric Oxide	3.310	2.890	3.030	3.08	3.700
			Aluminum Oxide	2.400	1.520	1.740	1.89	4.800
150951	C1		Silicon Dioxide	13.000	8.890	10.410	10.77	19.300
			Calcium Oxide	59.410	49.720	52.470	53.87	62.300

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
		Portland Cement Type I	Magnesium Oxide	ND	ND	ND	-	1.300
			Ferric Oxide	3.730	3.490	3.580	3.60	3.800
			Aluminum Oxide	2.950	1.640	2.050	2.21	5.200
124300	C1	Portland Cement Type II	Silicon Dioxide	10.590	8.510	10.490	9.86	19.400
			Calcium Oxide	54.680	48.280	54.790	52.58	63.300
			Magnesium Oxide	ND	ND	ND	-	2.200
			Ferric Oxide	3.330	3.170	2.900	3.13	3.200
			Aluminum Oxide	1.720	1.290	1.730	1.58	4.600
073534	C1	Portland Cement Type I	Silicon Dioxide	10.180	9.610	13.660	11.15	20.200
			Calcium Oxide	54.730	53.100	62.200	56.68	62.900
			Magnesium Oxide	ND	ND	ND	-	1.600
			Ferric Oxide	3.960	3.900	3.950	3.94	3.800

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
			Aluminum Oxide	1.590	1.390	2.530	1.84	5.000
083450	C1	Portland Cement Type II	Silicon Dioxide	12.490	11.460	10.930	11.63	19.500
			Calcium Oxide	59.810	53.530	50.460	54.60	63.300
			Magnesium Oxide	ND	ND	ND	-	2.500
			Ferric Oxide	3.600	3.360	3.150	3.37	3.500
			Aluminum Oxide	2.410	1.950	1.840	2.07	4.600
082527	C1	Portland Cement Type II	Silicon Dioxide	12.510	12.090	15.020	13.21	19.600
			Calcium Oxide	58.620	57.380	63.300	59.77	62.600
			Magnesium Oxide	ND	ND	ND	-	2.600
			Ferric Oxide	3.240	3.250	3.140	3.21	3.200
			Aluminum Oxide	2.200	2.080	2.630	2.30	4.600
091614	C1		Silicon Dioxide	13.730	11.640	10.990	12.12	22.400
			Calcium Oxide	58.660	55.190	51.470	55.11	59.000

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
		Portland Cement Type I	Magnesium Oxide	ND	ND	ND	-	2.200
			Ferric Oxide	3.380	3.330	3.070	3.26	3.500
			Aluminum Oxide	2.630	1.990	1.970	2.20	4.900
093837	C1	Portland Cement Type II	Silicon Dioxide	13.910	8.610	8.610	10.38	20.500
			Calcium Oxide	61.780	40.340	41.310	47.81	63.600
			Magnesium Oxide	ND	ND	ND	-	1.000
			Ferric Oxide	3.670	2.670	2.610	2.98	3.700
			Aluminum Oxide	2.310	1.240	1.180	1.58	4.800
082921	C1	Portland Cement Type II	Silicon Dioxide	11.150	12.710	8.650	10.84	19.200
			Calcium Oxide	56.100	56.020	46.050	52.72	62.600
			Magnesium Oxide	ND	ND	ND	-	3.300
			Ferric Oxide	3.130	3.090	2.670	2.96	3.100

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
			Aluminum Oxide	2.030	2.480	1.310	1.94	4.800
111631	C1	Portland Cement Type II	Silicon Dioxide	12.860	8.790	9.520	10.39	19.700
			Calcium Oxide	56.900	42.840	47.040	48.93	62.500
			Magnesium Oxide	ND	ND	ND	-	2.800
			Ferric Oxide	3.000	2.600	2.338	2.65	3.100
			Aluminum Oxide	2.030	1.180	1.450	1.55	4.600
144329	C1	Portland Cement Type I	Silicon Dioxide	13.370	11.770	10.840	11.99	20.200
			Calcium Oxide	59.860	52.990	53.820	55.56	62.600
			Magnesium Oxide	ND	ND	ND	-	1.800
			Ferric Oxide	3.630	3.850	3.590	3.69	3.800
			Aluminum Oxide	2.330	2.040	1.650	2.01	5.000
084723	C1		Silicon Dioxide	14.770	9.760	8.320	10.95	19.600
			Calcium Oxide	63.830	51.990	43.140	52.99	62.300

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
		Portland Cement Type I	Magnesium Oxide	ND	ND	ND	-	2.500
			Ferric Oxide	3.610	3.240	2.640	3.16	3.500
			Aluminum Oxide	2.870	1.530	1.280	1.89	4.600
083200	C1	Portland Cement Type I	Silicon Dioxide	9.480	10.430	9.700	9.87	19.400
			Calcium Oxide	47.660	51.190	45.910	48.25	63.300
			Magnesium Oxide	ND	ND	ND	-	1.900
			Ferric Oxide	2.550	2.730	2.343	2.54	3.200
			Aluminum Oxide	1.590	1.710	1.620	1.64	4.600
064945	C1	Portland Cement Type II	Silicon Dioxide	12.180	9.110	9.140	10.14	19.800
			Calcium Oxide	60.360	52.490	46.560	53.14	64.000
			Magnesium Oxide	ND	ND	ND	-	1.000
			Ferric Oxide	3.620	3.270	2.900	3.26	3.400

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
			Aluminum Oxide	2.340	1.660	1.430	1.81	4.800
083747	C1	Portland Cement Type II	Silicon Dioxide	9.490	11.400	9.770	10.22	20.200
			Calcium Oxide	49.120	52.670	50.190	50.66	62.700
			Magnesium Oxide	ND	ND	ND	-	1.900
			Ferric Oxide	3.050	3.260	2.770	3.03	3.100
			Aluminum Oxide	1.160	1.690	1.530	1.46	4.500
085057	C1	Portland Cement Type II	Silicon Dioxide	12.610	14.390	11.320	12.77	19.900
			Calcium Oxide	58.150	57.940	55.720	57.27	63.000
			Magnesium Oxide	ND	ND	ND	-	2.700
			Ferric Oxide	3.120	3.310	2.890	3.11	3.200
			Aluminum Oxide	1.930	2.480	1.910	2.11	4.800
070415	C1		Silicon Dioxide	12.950	10.800	11.700	11.82	18.300
			Calcium Oxide	60.860	55.020	57.420	57.77	61.500

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
		Portland Cement Type I	Magnesium Oxide	ND	ND	ND	-	4.200
			Ferric Oxide	3.170	3.180	3.290	3.21	3.300
			Aluminum Oxide	2.560	2.140	2.450	2.38	5.000
082957	C1	Portland Cement Type II	Silicon Dioxide	13.560	11.230	10.140	11.64	19.500
			Calcium Oxide	63.010	52.790	56.240	57.35	63.700
			Magnesium Oxide	ND	ND	ND	-	1.500
			Ferric Oxide	3.750	3.720	3.580	3.68	3.700
			Aluminum Oxide	2.310	1.910	1.670	1.96	4.800
085533	C1	Portland Cement Type II	Silicon Dioxide	14.890	12.780	12.480	13.38	19.500
			Calcium Oxide	63.370	57.150	57.980	59.50	62.300
			Magnesium Oxide	ND	ND	ND	-	1.900
			Ferric Oxide	3.350	3.430	3.520	3.43	3.400

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
			Aluminum Oxide	2.540	2.350	2.300	2.40	5.000
111921	C1	Portland Cement Type II	Silicon Dioxide	9.450	8.690	8.620	8.92	19.900
			Calcium Oxide	49.970	42.920	39.360	44.08	66.500
			Magnesium Oxide	ND	ND	ND	-	2.400
			Ferric Oxide	2.830	2.314	2.191	2.45	3.300
			Aluminum Oxide	1.720	1.770	1.540	1.68	5.100
062539	C1	Portland Cement Type II	Silicon Dioxide	10.740	8.850	10.380	9.99	20.300
			Calcium Oxide	49.520	36.390	47.950	44.62	63.700
			Magnesium Oxide	ND	ND	ND	-	1.000
			Ferric Oxide	2.880	2.116	2.770	2.59	3.800
			Aluminum Oxide	1.810	1.420	1.740	1.66	4.700
111547	C1		Silicon Dioxide	10.800	10.380	8.900	10.03	17.800
			Calcium Oxide	55.070	52.680	43.470	50.41	64.600

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
		Portland Cement Type II	Magnesium Oxide	ND	ND	ND	-	2.300
			Ferric Oxide	3.040	2.670	2.425	2.71	3.300
			Aluminum Oxide	1.980	1.850	1.490	1.77	4.600
081341	C1	Portland Cement Type I	Silicon Dioxide	9.370	8.450	7.540	8.45	19.400
			Calcium Oxide	43.900	38.340	29.730	37.32	62.800
			Magnesium Oxide	ND	ND	ND	-	2.400
			Ferric Oxide	2.556	2.125	1.596	2.09	3.500
			Aluminum Oxide	1.850	1.610	1.430	1.63	4.700
064400	C1	Portland Cement Type II	Silicon Dioxide	10.580	10.580	9.670	10.28	18.800
			Calcium Oxide	54.260	52.690	50.790	52.58	62.700
			Magnesium Oxide	ND	ND	ND	-	3.200
			Ferric Oxide	2.650	2.550	2.460	2.55	3.100

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
			Aluminum Oxide	1.950	1.970	1.640	1.85	4.700
073332	C1	Portland Cement Type I	Silicon Dioxide	8.910	9.280	10.340	9.51	22.100
			Calcium Oxide	37.670	37.920	46.900	40.83	70.200
			Magnesium Oxide	ND	ND	ND	-	1.200
			Ferric Oxide	1.257	1.273	1.563	1.36	2.200
			Aluminum Oxide	1.820	1.960	2.100	1.96	5.900
081624	C1	Portland Cement Type II	Silicon Dioxide	11.370	15.210	13.870	13.48	20.100
			Calcium Oxide	57.710	64.090	61.760	61.19	63.900
			Magnesium Oxide	ND	ND	ND	-	1.100
			Ferric Oxide	3.490	3.460	3.370	3.44	3.500
			Aluminum Oxide	2.030	2.680	2.370	2.36	4.600
081731	C1		Silicon Dioxide	14.850	11.940	14.360	13.72	19.600
			Calcium Oxide	64.100	56.540	61.140	60.59	62.500

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
		Portland Cement Type I	Magnesium Oxide	2.400	ND	ND	2.40	2.600
			Ferric Oxide	3.510	3.090	3.490	3.36	3.500
			Aluminum Oxide	2.880	2.370	2.680	2.64	4.400
081941	C1	Portland Cement Type II	Silicon Dioxide	12.670	14.480	13.010	13.39	19.500
			Calcium Oxide	58.950	63.110	57.390	59.82	62.900
			Magnesium Oxide	ND	ND	ND	-	2.800
			Ferric Oxide	3.320	3.320	3.000	3.21	3.400
			Aluminum Oxide	2.280	2.750	2.770	2.60	5.200
083445	C1	Portland Cement Type II	Silicon Dioxide	14.180	10.080	13.980	12.75	19.300
			Calcium Oxide	62.700	48.860	60.830	57.46	62.600
			Magnesium Oxide	2.500	ND	ND	2.50	3.100
			Ferric Oxide	3.090	2.810	3.160	3.02	3.200

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
			Aluminum Oxide	2.500	1.760	2.650	2.30	4.800
085647	C1	Portland Cement Type I	Silicon Dioxide	3.000	3.320	3.800	3.37	18.700
			Calcium Oxide	40.610	41.890	43.700	42.07	62.100
			Magnesium Oxide	ND	ND	ND	-	2.000
			Ferric Oxide	2.569	2.552	2.582	2.57	3.200
			Aluminum Oxide	0.280	0.310	0.560	0.38	4.500
090610	C1	Portland Cement Type I	Silicon Dioxide	10.250	9.130	12.790	10.72	18.600
			Calcium Oxide	54.900	47.530	61.080	54.50	62.200
			Magnesium Oxide	ND	ND	ND	-	0.900
			Ferric Oxide	3.930	3.500	3.690	3.71	3.800
			Aluminum Oxide	2.070	2.020	2.830	2.31	4.900
100534	C1		Silicon Dioxide	4.280	4.340	4.460	4.36	19.100
			Calcium Oxide	45.780	45.230	47.030	46.01	62.400

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
		Portland Cement Type I	Magnesium Oxide	ND	ND	ND	-	1.900
			Ferric Oxide	2.798	2.643	2.748	2.73	3.300
			Aluminum Oxide	0.470	0.580	0.640	0.56	4.700
105654	C1	Portland Cement Type I	Silicon Dioxide	11.390	8.370	11.440	10.40	18.500
			Calcium Oxide	57.430	46.300	57.050	53.59	62.600
			Magnesium Oxide	ND	ND	ND	-	0.900
			Ferric Oxide	3.400	2.960	3.240	3.20	3.400
			Aluminum Oxide	2.330	1.740	2.730	2.27	5.100
081240	C1	Portland Cement Type I	Silicon Dioxide	13.810	13.370	11.200	12.79	19.200
			Calcium Oxide	60.100	56.800	53.990	56.96	60.900
			Magnesium Oxide	ND	2.200	ND	2.20	3.300
			Ferric Oxide	3.240	3.180	3.160	3.19	3.200

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
			Aluminum Oxide	2.670	2.520	2.270	2.49	4.700
124250	C1	Portland Cement Type I	Silicon Dioxide	0.389	4.920	4.870	3.39	19.000
			Calcium Oxide	17.365	48.350	44.370	36.70	61.200
			Magnesium Oxide	ND	ND	1.700	1.70	2.600
			Ferric Oxide	2.048	2.810	2.772	2.54	3.400
			Aluminum Oxide	ND	0.930	0.870	0.90	5.100
094949	C1	Portland Cement Type I	Silicon Dioxide	12.570	8.820	11.640	11.01	20.300
			Calcium Oxide	57.390	38.130	55.330	50.28	63.000
			Magnesium Oxide	ND	ND	ND	-	0.900
			Ferric Oxide	3.330	2.162	3.220	2.90	3.200
			Aluminum Oxide	1.990	1.490	1.770	1.75	4.400
101258	C1		Silicon Dioxide	2.500	2.540	2.570	2.54	19.700
			Calcium Oxide	38.520	37.880	38.320	38.24	62.800

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
		Portland Cement Type I	Magnesium Oxide	ND	ND	ND	-	1.000
			Ferric Oxide	2.449	2.453	2.459	2.45	3.200
			Aluminum Oxide	ND	0.230	ND	0.23	4.400
124941	C1	Portland Cement Type I	Silicon Dioxide	2.600	2.870	2.820	2.76	19.700
			Calcium Oxide	37.340	39.980	37.080	38.13	62.100
			Magnesium Oxide	ND	ND	ND	-	2.500
			Ferric Oxide	2.464	2.341	2.280	2.36	3.100
			Aluminum Oxide	ND	ND	ND	-	4.400

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
064738	C3	Portland Cement Type III	Silicon Dioxide	4.190	4.010	4.590	4.26	20.600
			Calcium Oxide	44.340	43.630	45.500	44.49	62.700
			Magnesium Oxide	ND	ND	ND	-	1.300
			Ferric Oxide	2.621	2.628	2.853	2.70	3.300
			Aluminum Oxide	0.720	0.450	0.750	0.64	4.700
070751	C3	Portland Cement Type III	Silicon Dioxide	11.270	4.010	10.370	8.55	18.600
			Calcium Oxide	60.080	60.450	58.790	59.77	66.350
			Magnesium Oxide	ND	ND	ND	-	1.750
			Ferric Oxide	3.700	3.590	3.710	3.67	3.650
			Aluminum Oxide	2.140	2.240	2.060	2.15	5.150
093411	C3	Portland Cement Type III	Silicon Dioxide	8.460	9.830	10.040	9.44	19.400
			Calcium Oxide	38.220	41.420	41.520	40.39	64.100
			Magnesium Oxide	ND	ND	ND	-	1.400

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
			Ferric Oxide	2.193	2.213	2.363	2.26	3.400
			Aluminum Oxide	1.300	1.710	1.510	1.51	4.100

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
085455	C9	Fly Ash Class F	Silicon Dioxide	7.920	9.740	9.440	9.03	41.500
			Ferric Oxide	6.430	6.470	6.500	6.47	6.100
			Aluminum Oxide	4.260	5.560	5.060	4.96	21.500
151317	C9	Fly Ash Class F	Silicon Dioxide	26.630	21.270	23.710	23.87	47.800
			Ferric Oxide	8.990	7.100	8.000	8.03	9.100
			Aluminum Oxide	7.400	6.000	7.320	6.91	15.800
125510	C9	Fly Ash Class F	Silicon Dioxide	24.980	21.760	24.590	23.78	41.600
			Ferric Oxide	16.960	15.520	16.080	16.19	21.000
			Aluminum Oxide	11.040	10.010	11.280	10.78	19.200
110434	C9	Fly Ash Class F	Silicon Dioxide	18.060	20.670	16.500	18.41	40.400
			Ferric Oxide	9.400	13.120	11.400	11.31	21.500
			Aluminum Oxide	8.040	9.330	7.190	8.19	19.000
110359	C9		Silicon Dioxide	27.030	30.550	41.360	32.98	46.500

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
		Fly Ash Class F	Ferric Oxide	14.160	15.450	15.660	15.09	15.800
			Aluminum Oxide	11.740	13.270	17.230	14.08	20.700
101857	C9	Fly Ash Class F	Silicon Dioxide	7.720	10.060	9.230	9.00	46.800
			Ferric Oxide	18.150	18.640	18.810	18.53	16.500
			Aluminum Oxide	2.640	4.360	3.500	3.50	18.200
095919	C9	Fly Ash Class F	Silicon Dioxide	33.380	38.240	36.790	36.14	50.500
			Ferric Oxide	4.680	4.810	4.740	4.74	4.700
			Aluminum Oxide	12.510	14.670	14.190	13.79	17.600
095508	C9	Fly Ash Class F	Silicon Dioxide	5.590	9.010	7.670	7.42	39.700
			Ferric Oxide	7.030	7.200	7.080	7.10	6.900
			Aluminum Oxide	2.850	5.000	3.940	3.93	21.600
082634	C9	Fly Ash Class F	Silicon Dioxide	32.730	28.650	24.460	28.61	50.400
			Ferric Oxide	4.900	4.390	3.760	4.35	4.900

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
			Aluminum Oxide	12.470	10.230	8.950	10.55	20.500
082334	C9	Fly Ash Class F	Silicon Dioxide	24.600	27.050	25.720	25.79	47.700
			Ferric Oxide	9.700	10.210	10.100	10.00	14.800
			Aluminum Oxide	10.460	12.010	11.250	11.24	21.500
082107	C9	Fly Ash Class F	Silicon Dioxide	33.960	26.550	38.540	33.02	47.400
			Ferric Oxide	13.870	13.630	14.460	13.99	15.100
			Aluminum Oxide	13.830	10.660	15.900	13.46	21.900
075306	C9	Fly Ash Class F	Silicon Dioxide	24.420	25.780	23.040	24.41	49.400
			Ferric Oxide	7.090	7.910	6.730	7.24	9.600
			Aluminum Oxide	10.740	12.090	10.080	10.97	24.200
072113	C9	Fly Ash Class F	Silicon Dioxide	23.510	22.420	36.690	27.54	42.300
			Ferric Oxide	19.130	19.310	20.050	19.50	20.800
			Aluminum Oxide	9.800	9.330	15.380	11.50	19.700

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
072755	C9	Fly Ash Class F	Silicon Dioxide	17.370	19.150	20.910	19.14	38.000
			Ferric Oxide	14.030	14.540	17.300	15.29	26.600
			Aluminum Oxide	8.510	9.780	10.300	9.53	18.600
073353	C9	Fly Ash Class F	Silicon Dioxide	33.510	22.520	28.540	28.19	40.800
			Ferric Oxide	21.160	16.790	17.970	18.64	22.100
			Aluminum Oxide	14.200	9.360	12.380	11.98	19.000
074947	C9	Fly Ash Class F	Silicon Dioxide	44.640	27.690	33.530	35.29	53.500
			Ferric Oxide	9.450	7.350	9.630	8.81	10.000
			Aluminum Oxide	10.230	8.490	13.210	10.64	17.700
075306	C9	Fly Ash Class F	Silicon Dioxide	24.420	25.780	23.040	24.41	49.400
			Ferric Oxide	7.090	7.910	6.730	7.24	9.600
			Aluminum Oxide	10.740	12.090	10.080	10.97	24.200

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
082615	D4	Nat Sand	Silicon Dioxide	58.19	53.23	57.33	56.25	89.8
			Aluminum Oxide	3.56	2.73	3.60	3.30	2.31
			Iron Oxide	0.81	0.89	0.86	0.85	2.47
141604	D4	Nat Sand	Silicon Dioxide	44.95	45.83	42.85	44.54	82.57
			Aluminum Oxide	6.58	7.03	6.48	6.70	7.19
			Iron Oxide	2.65	2.59	2.51	2.58	3.84
145504	D4	Nat Sand	Silicon Dioxide	60.30	58.35	53.08	57.24	95.35
			Aluminum Oxide	1.77	1.72	1.70	1.73	1.19
			Iron Oxide	0.56	0.57	0.60	0.57	1.14

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
082216	D5	Gravel	Silicon Dioxide	60.44	62.02	57.24	59.90	91.32
			Aluminum Oxide	1.65	1.74	1.91	1.77	1.64
			Iron Oxide	3.45	3.33	3.44	3.41	4.03
100320	D5	Gravel	Silicon Dioxide	57.66	58.39	52.08	56.04	85.91
			Aluminum Oxide	1.74	1.37	1.85	1.65	0.89
			Iron Oxide	7.88	9.15	9.94	8.99	11.62
141357	D5	Gravel	Silicon Dioxide	62.67	64.25	54.39	60.44	91.01
			Aluminum Oxide	2.65	2.77	2.44	2.62	2.55
			Iron Oxide	4.56	4.46	4.50	4.51	4.42
145257	D5	Gravel	Silicon Dioxide	60.11	51.55	54.38	55.35	89.43

Sample ID		**Description**	**CHEMICAL COMPONENT**	**XRF1 (%)**	**XRF2 (%)**	**XRF3 (%)**	**Average XRF (%)**	**MAT LAB RESULTS (%)**
			Aluminum Oxide	1.61	1.53	1.80	1.65	2.24
			Iron Oxide	4.39	4.42	4.49	4.43	5.04

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
082329	D6	Limestone	Silicon Dioxide	6.59	5.70	5.21	5.83	12.05
			Aluminum Oxide	2.33	1.87	1.37	1.86	1.64
			Iron Oxide	1.69	1.57	1.62	1.63	3.03
			Calcium Oxide	48.59	45.54	44.52	46.22	76.18
082920	D6	Limestone Oolitic	Silicon Dioxide	4.05	5.06	3.54	4.22	12.54
			Aluminum Oxide	1.16	1.37	0.87	1.13	1.04
			Iron Oxide	0.97	1.13	0.96	1.02	2.30
			Calcium Oxide	50.97	49.22	48.61	49.60	80.76
100811	D6	Limestone	Silicon Dioxide	5.16	2.78	5.61	4.52	6.61
			Aluminum Oxide	0.58	ND	4.85	2.72	0.20
			Iron Oxide	0.35	0.39	0.57	0.44	0.64
			Calcium Oxide	53.70	51.43	52.97	52.70	90.14
125244	D6		Silicon Dioxide	35.74	36.58	26.39	32.90	57.85

Sample ID		Description	CHEMICAL COMPONENT	XRF1 (%)	XRF2 (%)	XRF3 (%)	Average XRF (%)	MAT LAB RESULTS (%)
		Lightweight (Exp Shale)	Aluminum Oxide	7.34	7.33	5.45	6.71	12.53
			Iron Oxide	6.38	6.51	6.31	6.40	5.50
			Calcium Oxide	2.53	2.59	2.07	2.39	1.86
141915	D6	Limestone	Silicon Dioxide	2.42	2.50	2.23	2.38	6.84
			Aluminum Oxide	0.67	0.61	0.56	0.61	0.38
			Iron Oxide	2.79	2.75	2.89	2.81	6.28
			Calcium Oxide	48.13	48.74	45.03	47.30	77.38
145404	D6	Granite	Silicon Dioxide	25.76	28.31	26.45	26.84	45.71
			Aluminum Oxide	6.62	7.69	7.26	7.19	16.20
			Iron Oxide	11.45	11.81	11.63	11.63	12.70
			Calcium Oxide	9.99	10.63	10.41	10.34	11.63