APPENDIX K-5: Cemented Tailings Paste Characterization and Laboratory Test Results

K5-A. Tailings Characterization and Laboratory Test Results

K5-B. Binder Characterization and Laboratory Test Results

K5-C. Paste Characterization, Mixing Procedures, and Laboratory Test Results

K5-D. Photograph Log Trial Batches 2% Binder: Cylinder and Cone Slump Tests

K5-E. Photograph Log Trial Batches 4% Binder: Cylinder and Cone Slump Tests

APPENDIX K5

Cemented Tailings Paste Characterization and

Laboratory Test Results

Black Butte Copper Mine Operating Permit Application

June 22, 2016

This section describes the suitability of the Black Butte Copper tailings, and identifies the local cementitious binders available in Montana and incorporated into the cement paste (CP) mix designs tested to date by Amec Foster Wheeler and others in 2015 for use in cemented paste for surface deposition (into the CTF) and for cemented paste backfill (CPB) (into the underground workings).

The following sections will:

- Present the physical, chemical, and strength characteristics of the BBC tailings.
- Define the physical targets of the paste mix designs for surface deposition and for cemented paste backfill.
- Define the different binder types.
- List the standardized testing methods for the binders, tailings water, and paste,
- Identify the local sources of the different available, sustainable, and cost effective binders.
- Reports the laboratory test results for the binders, tailings water, and two paste mix designs (one containing 2% binder and another containing 4% binder) that are fully presented in Appendix K5 of the MOP Application.
- Include pictures of the cylinder and cone slump tests for the 2% and 4% binder pastes

K5-A. Tailings Characterization and Laboratory Test Results

Black Butte Copper (BBC) tailings samples were prepared by International Metallurgical and Environmental Inc. and shipped to the Amec Foster Wheeler (Amec) laboratory in Hamilton, Ontario for characterization and analysis in order to help in the paste mix designs for surface deposition and back-filling underground workings. The tailings samples originated from one source (related to the BBC Project) and were sent to Amec in two separate batches (shipments).

The first shipment consisted of three buckets containing filter cake packaged in plastic bags and labeled as "LCT tailings" containing ~36 kg of dry tailings (Amec sample number S153-15 A-C) and were received on May 28th, 2015. The second shipment consisted of two buckets containing filter cake packaged in bags labeled as "LCT tailings" containing 43.0 pounds (19.5 kg) of dry tailings (Amec sample number S173-15 A-C) and were received on June 17th, 2015. Process water was decanted from each tailings sample of the as-received filter cake materials and saved.

Tailings samples from each batch were oven dried at 105°C (221°F). The tailings material from the first shipment (S153-15) was used for a full tailings characterization. For the material in the second shipment only basic characterization was conducted in order to verify the consistency of the tailings.

The tailings may be characterized using physical and chemical methods as defined in Table 1 below. Amec Wheeler Foster Laboratory in Hamilton, Ontario, Canada conducted the index and hydraulic conductivity testing. SGS Canada Inc. in Lakefield, Ontario (Canada) conducted the acid-base accounting ABA analyses. MAXXAM Analytics in Hamilton, Ontario (Canada) conducted the water analysis. Other tailings test results from BBC different tailings samples have been previously reported by Knight Piesold (2016) in Appendix K.

Table 1. Physical, Chemical, and Mineralogical Methods for Tailings Materials Characterization

Characterization Type	Method	Method Description
Physical	ASTM D422	Standard Test Method for Particle Size Analysis of Soils (using a hydrometer)
	ASTM D854	Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer
	Laser Particle Size Distribution using a Particle Size Analyzer	Malvern Mastersizer 2000 – MIIA 14730: a representative sample was suspended in 20mL of highly purified and deionized (Milli-Q) water manufactured by Millipore Corp. The suspension was immersed in a low-power (47 kHz) ultrasonic bath for 1 minute to aid in disrupting any loosely bound agglomerates, prior to transfer to the measurement cell for analysis and analyzed in Milli-Q water. One measurement performed on the sample.
Chemical	Elemental Analysis	Various
	Acid-Base Accounting (ABA)	SGS Canada Inc.: ABA Modified Sobek
Mineralogical	X-Ray Diffraction (XRD)	XRD of powdered samples

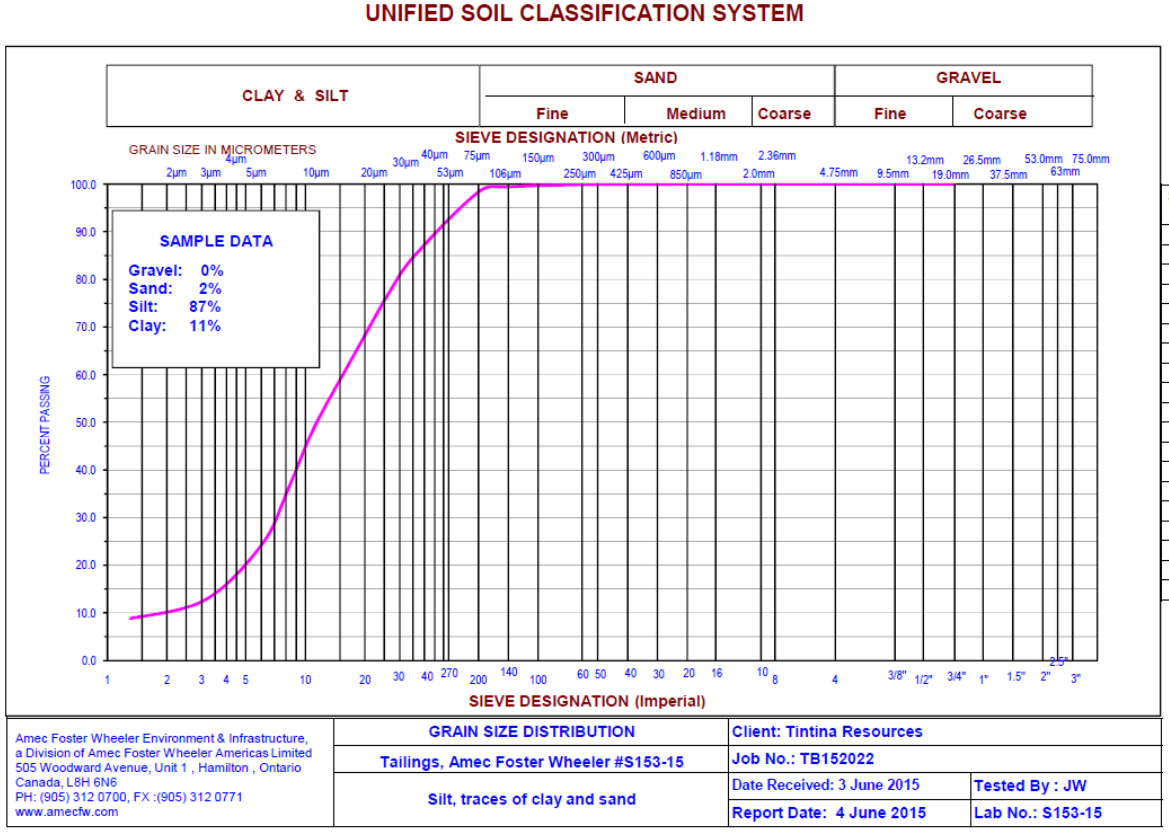
Table 2. Summary of physical test results of tailings.

Tailings sample		**LCT Tailings**	
Sample ID Number		S153-15	S173-15
Test Method	Results		
Hydrometer (ASTM D422)	100% passing	0.85 mm	0.25 mm
	80% passing	~25 μm	~30 μm
	<75 μm	98.3%	99.1%
	<20 μm	~75%	~68%
Laser particle size distribution	P10 (d(0.1))	1.9 μm	1.6 μm
	P50 (d(0.5))	14.4 μm	12.3 μm
	P80 (d(0.8))	40.6 μm	34.2 μm
	<75 μm	94.2%	96.5%
	<20 μm	58.9%	63.6%
Specific gravity (SG) ASTM D854		3.542	3.857

Note: Data from Amec Foster Wheeler in Hamilton, Ontario, Canada

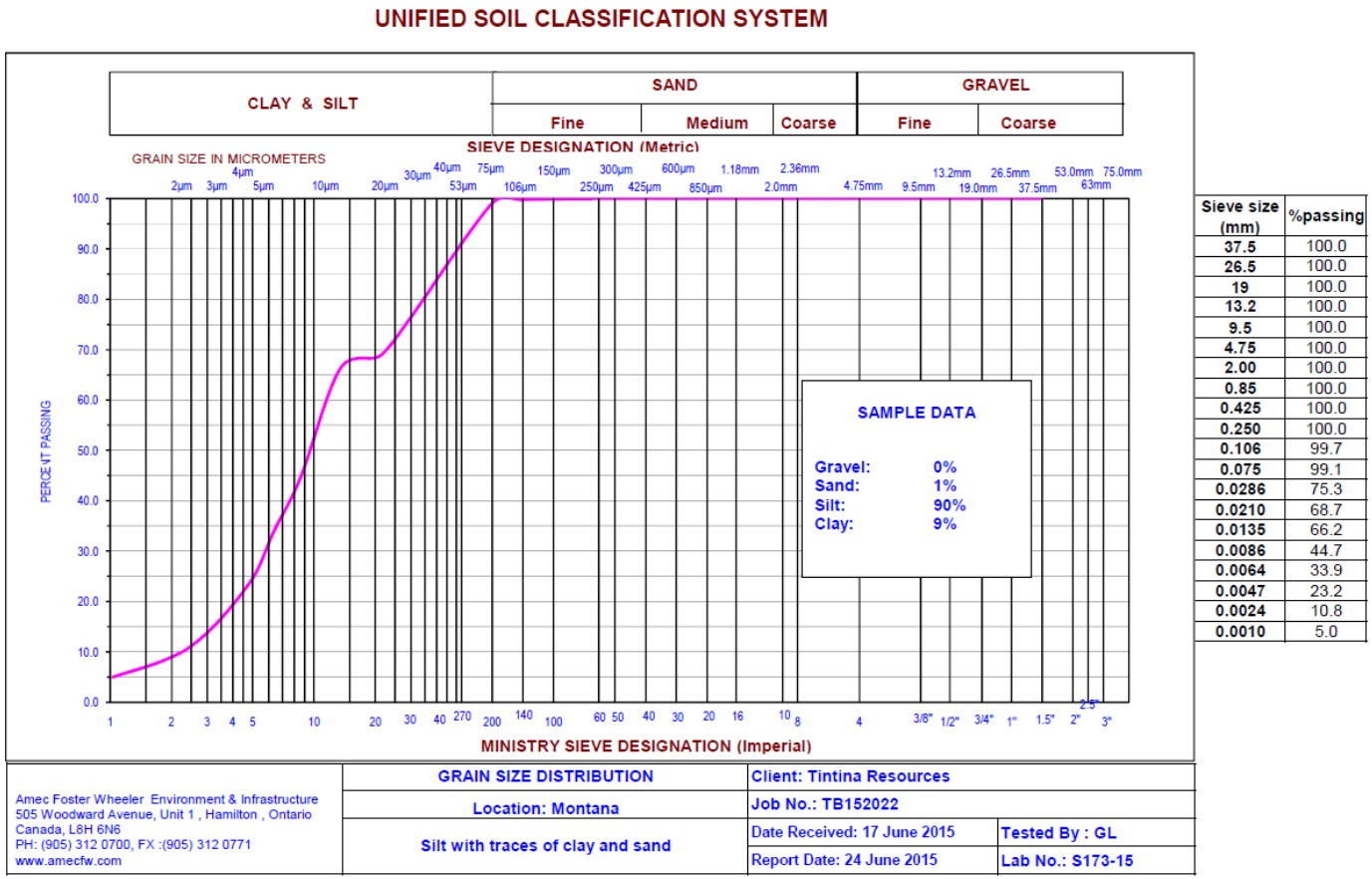
Figures 1 through 2 below show hydrometer particle-size analyses for the tailings samples.

Figures 3 and 4 below show the laser particle size analyses for the two tailings samples.



Sieve size (mm)	%passing
26.5	100.0
19	100.0
13.2	100.0
9.5	100.0
4.75	100.0
2.00	100.0
0.85	100.0
0.425	99.9
0.250	99.9
0.106	99.4
0.075	98.3
0.0362	85.3
0.0267	77.5
0.0179	64.7
0.0111	49.0
0.0082	36.3
0.0061	24.5
0.0031	12.7
0.0013	8.8

Figure 1 Hydrometer particle size analysis of tailings sample (S153-15)



Sieve size (mm)	%passing
37.5	100.0
26.5	100.0
19	100.0
13.2	100.0
9.5	100.0
4.75	100.0
2.00	100.0
0.85	100.0
0.425	100.0
0.250	100.0
0.106	99.7
0.075	99.1
0.0286	75.3
0.0210	68.7
0.0135	66.2
0.0086	44.7
0.0064	33.9
0.0047	23.2
0.0024	10.8
0.0010	5.0

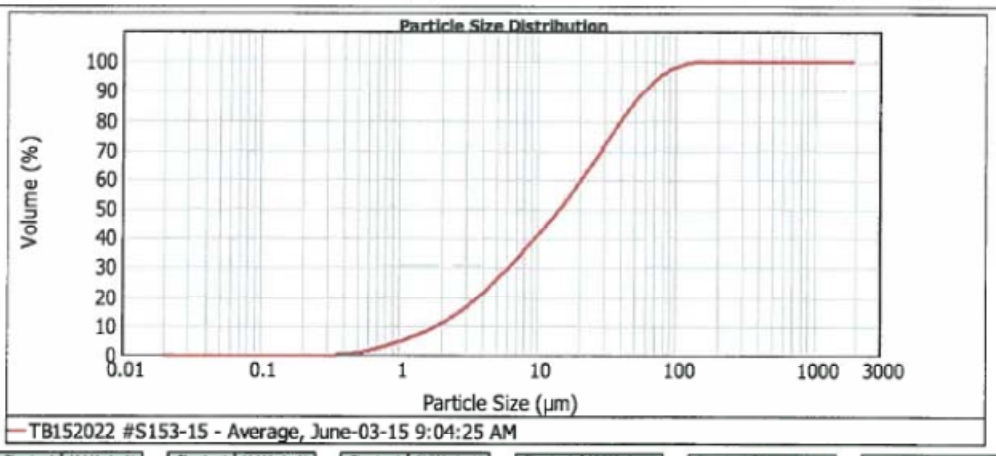
Figure 2 Hydrometer particle size analysis of tailings sample (S173-15)

Sample Name: TB152022 #S153-15 - Average	**SOP Name:** Defaultar	**Measured:** June-03-15 9:04:25 AM
Sample Source & type: CA02117-JUN15	**Measured by:** LR_Malvern1	**Analysed:** June-03-15 9:04:27 AM
Sample bulk lot ref: ar	**Result Source:** Averaged	

Particle Name: Default	**Accessory Name:** Hydro 2000G (A)	**Analysis model:** General purpose	**Sensitivity:** Enhanced
Particle RI: 1.520	**Absorption:** 0.1	**Size range:** 0.020 to 2000.000 um	**Obscuration:** 15.83 %
Dispersant Name: Water	**Dispersant RI:** 1.330	**Weighted Residual:** 0.710 %	**Result Emulation:** Off

Concentration: 0.0128 %Vol	**Span :** 4.014	**Uniformity:** 1.26	**Result units:** Volume
Specific Surface Area: 1.23 m²/g	**Surface Weighted Mean D[3,2]:** 4.886 um	**Vol. Weighted Mean D[4,3]:** 23.916 um	

d(0.1): 1.900 um **d(0.5):** 14.412 um **d(0.8):** 40.600 um

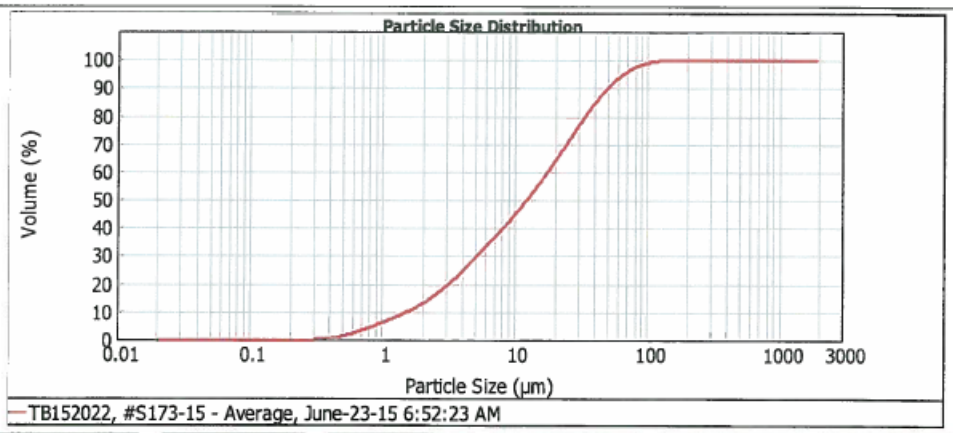


Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.010	0.00	0.105	0.00	1.096	5.18	11.482	44.28	120.226	99.13	1258.925	100.00
0.011	0.00	0.120	0.00	1.259	6.22	13.183	47.71	138.038	99.65	1445.440	100.00
0.013	0.00	0.138	0.00	1.445	7.35	15.136	51.28	158.489	99.90	1659.587	100.00
0.015	0.00	0.158	0.00	1.660	8.61	17.378	55.00	181.970	100.00	1905.461	100.00
0.017	0.00	0.182	0.00	1.905	10.03	19.953	58.86	208.930	100.00	2187.762	100.00
0.020	0.00	0.209	0.00	2.188	11.66	22.909	62.86	239.883	100.00	2511.886	100.00
0.023	0.00	0.240	0.00	2.512	13.50	26.303	66.98	275.423	100.00	2884.032	100.00
0.026	0.00	0.275	0.00	2.884	15.56	30.200	71.16	316.228	100.00	3311.311	100.00
0.030	0.00	0.316	0.00	3.311	17.84	34.674	75.34	363.078	100.00	3801.894	100.00
0.035	0.00	0.363	0.01	3.802	20.31	39.811	79.43	416.869	100.00	4365.158	100.00
0.040	0.00	0.417	0.19	4.365	22.96	45.709	83.34	478.630	100.00	5011.872	100.00
0.046	0.00	0.479	0.54	5.012	25.75	52.481	86.95	549.541	100.00	5754.399	100.00
0.052	0.00	0.550	1.06	5.754	28.64	60.256	90.18	630.957	100.00	6606.934	100.00
0.060	0.00	0.631	1.71	6.607	31.61	69.183	92.95	724.436	100.00	7585.776	100.00
0.069	0.00	0.724	2.47	7.586	34.66	79.433	95.23	831.764	100.00	8709.636	100.00
0.079	0.00	0.832	3.31	8.710	37.77	91.201	96.99	954.993	100.00	10000.000	100.00
0.091	0.00	0.955	4.22	10.000	40.98	104.713	98.28	1096.478	100.00		

Figure 3 Laser particle size analysis of tailings sample (S153-15)

Sample Name: TB152022, #S173-15 - Average	**SOP Name:** Defaultar	**Measured:** June-23-15 6:52:23 AM	
Sample Source & type: CA02753-JUN15	**Measured by:** LR_Malvern1	**Analysed:** June-23-15 6:52:25 AM	
Sample bulk lot ref: ar	**Result Source:** Averaged		
Particle Name: Default	**Accessory Name:** Hydro 2000G (A)	**Analysis model:** General purpose	**Sensitivity:** Enhanced
Particle RI: 1.520	**Absorption:** 0.1	**Size range:** 0.020 to 2000.000 um	**Obscuration:** 15.18 %
Dispersant Name: Water	**Dispersant RI:** 1.330	**Weighted Residual:** 0.767 %	**Result Emulation:** Off
Concentration: 0.0109 %Vol	**Span :** 3.951	**Uniformity:** 1.26	**Result units:** Volume
Specific Surface Area: 1.45 m²/g	**Surface Weighted Mean D[3,2]:** 4.135 um	**Vol. Weighted Mean D[4,3]:** 20.368 um	

d(0.1): 1.556 um **d(0.5):** 12.339 um **d(0.8):** 34.161 um



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.010	0.00	0.105	0.00	1.096	6.84	11.482	48.15	120.226	99.56	1258.925	100.00
0.011	0.00	0.120	0.00	1.259	8.02	13.183	51.74	138.038	99.84	1445.440	100.00
0.013	0.00	0.138	0.00	1.445	9.26	15.136	55.50	158.489	99.95	1659.587	100.00
0.015	0.00	0.158	0.00	1.660	10.67	17.378	59.44	181.970	100.00	1905.461	100.00
0.017	0.00	0.182	0.00	1.905	12.23	19.953	63.55	208.930	100.00	2187.762	100.00
0.020	0.00	0.209	0.00	2.188	13.99	22.909	67.78	239.883	100.00	2511.886	100.00
0.023	0.00	0.240	0.00	2.512	15.99	26.303	72.07	275.423	100.00	2884.032	100.00
0.026	0.00	0.275	0.00	2.884	18.21	30.200	76.32	316.228	100.00	3311.311	100.00
0.030	0.00	0.316	0.01	3.311	20.65	34.674	80.43	363.078	100.00	3801.894	100.00
0.035	0.00	0.363	0.12	3.802	23.28	39.811	84.30	416.869	100.00	4365.158	100.00
0.040	0.00	0.417	0.47	4.365	26.07	45.709	87.81	478.630	100.00	5011.872	100.00
0.046	0.00	0.479	1.02	5.012	28.99	52.481	90.89	549.541	100.00	5754.399	100.00
0.052	0.00	0.550	1.74	5.754	32.00	60.256	93.48	630.957	100.00	6606.934	100.00
0.060	0.00	0.631	2.61	6.607	35.08	69.183	95.56	724.436	100.00	7585.776	100.00
0.069	0.00	0.724	3.58	7.586	38.21	79.433	97.16	831.764	100.00	8709.636	100.00
0.079	0.00	0.832	4.62	8.710	41.42	91.201	98.31	954.993	100.00	10000.000	100.00
0.091	0.00	0.955	5.71	10.000	44.72	104.713	99.09	1096.478	100.00		

Figure 4 Laser particle size analysis of tailings sample (S173-15)

Table 3 below shows hydraulic conductivity results from the tailings sample.

Table 3. Hydraulic Conductivity of Tailings.

Sample Tested		**Filtered tailings**
Sample Number		**S**173-15
Test Method	Results	(cm/s)
Hydraulic conductivity (k)	Average inflow (run #1)	4.93×10^{-07}
	Average outflow (run #1)	2.86×10^{-07}
	Average of inflow and outflow (run #1)	3.90×10^{-07}
	Average inflow (run #2)	2.21×10^{-07}
	Average outflow (run #2)	1.87×10^{-07}
	Average of inflow and outflow (run #2)	2.04×10^{-07}
	Overall Average	**2.9×10^{-07}**

Note: Hydraulic conductivity testing conducted by Amec Foster Wheeler in Hamilton, Ontario

The chemistry of the tailings is shown in Table 4 and was conducted by Amec Foster Wheeler. Acid Base accounting results from the tailings are reported in Table 5 and Table 6.

Table 4. Chemical Composition of the Tailings.

Tailings sample	**LCT Tailings**
Sample Number	**S153-15**
Element Oxide (%)	(%)
SiO_2	37.2
Al_2O_3	1.83
Fe_2O_3	27.6
MgO	0.30
CaO	0.39
Na_2O	0.10
K_2O	0.80
TiO_2	0.07
P_2O_5	0.06
MnO	0.03
Cr_2O_3	0.06
V_2O_5	<0.01
C(t)	0.36
LOI*	18.4
S	24.8
SO_3	-
Sum	**86.8**

Notes: (1) Data from Amec Foster Wheeler in Hamilton, Ontario, Canada
(*) Value affected by large percentage of pyrite in sample

Table 5. Acid Base Accounting Results of the Tailings.

Tailings sample	**LCT Tailings**
Sample Number	**S153-15**
Total sulfur (%)	25.5
Sulphide minerals (%)	25.7
Sulphate minerals (%)	<0.01
Acid generating potential (AP, t $CaCO_3$/1000t)	802.00
Neutralization potential (NP, t $CaCO_3$/1000t)	2.00
Net neutralization potential (Net NP, t $CaCO_3$/1000t)	-799.88

Note: Data from SGS Canada Inc. Laboratory in Lakefield, Ontario Canada

Table 6. Acid Base Accounting Analysis Laboratory Certificate for the Tailings Sample.

SGS Canada Inc.
P.O. Box 4300 - 185 Concession St.
Lakefield - Ontario - KOL 2HO
Phone: 705-652-2000 FAX: 705-652-6365

ABA - Modified Sobek

16-June-2015

AMEC Earth & Environmental Limited
Attn : Corina Aldea

505 Woodward Avenue, Unit 1, Hamilton
, L8H 6N6
Phone: (905)312-0700, Fax:(905)312-0771

Date Rec. : 04 June 2015
LR Report: **CA12185-JUN15**
Reference: PO# TB152022*U

Copy: #1

CERTIFICATE OF ANALYSIS
Final Report

Analysis	3: Analysis Approval Date	4: Analysis Approval Time	5: TB152022, #S153-15
Sample Date & Time			NA
Paste pH	11-Jun-15	14:22	3.23
Fizz Rate [---]	11-Jun-15	14:22	1
Sample weight [g]	11-Jun-15	14:22	2.01
	11-Jun-15	14:22	20.00
HCl [Normality]	11-Jun-15	14:22	0.10
NaOH [Normality]	11-Jun-15	14:22	0.10
NaOH to pH=8.3 [mL]	11-Jun-15	14:22	19.20
Final pH	11-Jun-15	14:22	1.17
NP [t CaCO3/1000 t]	11-Jun-15	14:22	2.0
AP [t CaCO3/1000 t]	---	---	802
Net NP [t CaCO3/1000 t]	---	---	-799.88
NP/AP [ratio]	---	---	0.00
Sulphur (total) [%]	12-Jun-15	14:56	25.5
Acid Leachable SO4-S [%]	---	---	<0.01
Sulphide [%]	12-Jun-15	14:56	25.7
Carbon (total) [%]	11-Jun-15	14:22	0.372
Carbonate [%]	11-Jun-15	14:22	0.220

Brian Graham B.Sc.
Project Specialist
Environmental Services, Analytical

OnLine LIMS

K5-B. Binder Characterization and Laboratory Test Results

1.0 INTRODUCTION

This section identifies the local cementitious binders available in Montana, some of which were incorporated into the cement paste (CP) mix designs tested to date for use in cemented paste for surface deposition (into the CTF) and for cemented paste backfill (CPB) (into the underground workings).

The following sections will:

- Define the different binder types,
- List the standardized testing methods for the binders and tailings water, and
- Identify the local sources of the different available, sustainable, and cost effective binders

2.0 BINDER TYPES AVAILABLE FOR CEMENTED TAILINGS PASTE

Binder is defined as any cementing material, either hydrated cement or a product of cement or lime and reactive siliceous materials. The kinds of cement and the curing conditions determine the general type of binder formed. Economic considerations are the primary driving force behind the research and use of supplementary cementitious materials (SCM), such as slag, fly ash and natural pozzolans which can be added to the fill as a partial replacement of Portland Cement (PC). The mixes with SCM have good engineering performance and reduce costs. Among other benefits of using slag, or FA, as partial cement replacement compared to PC is their improved resistance to sulfate attack.

Cement is defined as a powdery substance made with calcined lime and clay. It is mixed with water to form mortar or mixed with sand, gravel, and water to make concrete; a binder, a substance used in construction that sets and hardens and can bind other materials together.

Portland cement (PC) is used as a binder in paste backfill where structural strength is required of the backfill and where resistance to liquefaction is necessary.

Slag is a non-metallic binder product, consisting of silicates and alumino-silicates of calcium, magnesium and other bases, developed in a molten condition simultaneously with iron in a blast furnace; when rapidly cooled it forms a glassy granular material that is ground and used as a supplementary cementaceous material additive to cement; as an additive it provides good engineering performance at reduced costs and has significant improved resistance to sulfate attack over cement.

Slag cement is defined as a hydraulic cement formed when finely ground granulated blast furnace slag is mixed with cement.

Fly ash (FA) is “the finely divided residue that results from the combustion of ground or powdered coal and that is transported by flue gases” as defined by *ASTM C618 “Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete”*. ASTM C618 covers coal FA and raw and calcined natural pozzolan for use in concrete, where cementitious and pozzolanic action is desired.

Pozzolans are a broad class of siliceous or siliceous and aluminous materials which, in themselves, possess little or no cementitious value but which will, in finely divided form and in the presence of water, react chemically with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties.

3.0 TESTING METHODS FOR THE BINDERS AND TAILINGS WATER

The different binders may be characterized using the following testing methods: physical, chemical, mineralogical, and strength tests. Table 3-1 lists the physical testing methods for Portland Cement and Fly Ash. Table 3-2 below lists the standardized chemical, mineralogical, and strength testing methods used to characterize the different binders

Table 3-1. Physical Testing Methods for PC and Fly Ash Binder Materials Characterization

Binder Type(2)	Characterization Type	Method	Method Description
PC	Physical - PC	ASTM C150	Standard Specification for Portland Cement
		ASTM C1038	Standard Test Method for Expansion of Hydraulic Cement Mortar Bars Stored in Water
FA	Physical - FA	ASTM C311	Standard Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use in Portland-Cement Concrete
		ASTM C430	Standard Test Method for Fineness of Hydraulic Cement by the 45-um (No. 325) Sieve
		ASTM C109	Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-inch or [50-mm] Cube Specimens
		ASTM C151	Standard Test Method for Autoclave Expansion of Hydraulic Cement
		ASTM C604	Standard Test Method for True Specific Gravity of refractory Materials by Gas-Comparison Pycnometer
		ASTM C618	Standard Specification for Coal Fly Ash and raw or Calcined Natural Pozzolan for Use in Concrete
		ASTM D4326	Standard Test Method for Major and Minor Elements in Coal and Coke Ash By X-Ray Fluorescence
		AASHTO M295	Standard Test Method for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete

Notes: PC = Portland Cement; FA = fly ash

Table 3-2. Standardized Chemical, Mineralogical, and Strength Testing Methods

Binder Type	Characterization Type	Method	Method Description
FA and Slag	Chemical - PC, FA, and Slag	Major elemental analysis: whole rock analysis using ICP-AES	SiO2, Al203, Fe203, SO3,CaO,MgO, Na2O, K2O, moisture, LOI
Slag	Chemical - Slag	ASTM C989/C989M	Standard Specification for Slag Cement for Use in Concrete and Mortars
PC, FA, and Slag	Mineralogical - PC, FA, and slag from various sources	X-ray diffraction	Various mineral identification
FA and Slag	Cement, Pozzolanic, and Slag Activity Tests – FA and slag from various sources	ASTM C109/C109M	Standard Test Method for Compressive Strength of Hydraulic Cement Mortars
		ASTM C778	Standard Specification for Standard Sand

Notes: PC = Portland cement, FA = fly ash, LOI = Loss on ignition; XRD = X-ray diffraction

Table 3-3 lists the chemical characterization testing methods for the tailings water.

Table 3-3. Tailings Water(1) Materials Characterization using Chemical Methods

Method	Method Description
Ph	MAXXAM (MT): by AT CAM-SOP00413
Dissolved Sulfate (SO_4)	MAXXAM (MT): by Automated Colourimetry/ Kone - CAM-SOP00464
Dissolved Chloride (Cl)	MAXXAM (MT) by Automated Colourimetry/ Kone - CAM-SOP00463
Metals	MAXXAM (MT): by ICPMS CAM-SOP00447

Notes: (1) Decant Water from the filter cake;

ICPMS = Inductively coupled Plasma Mass Spectroscopy;

MAXXAM is an accredited laboratory

4.0 BINDER SELECTION AND SOURCING FOR USE IN THE BBC PASTE

Selection and sourcing of potential binders for the Black Butte Copper project included the following:

- Identifying commercially suitable binder types for the mine operating permit application.
- Identifying suitable existing binder manufacturers and sources (plants). This activity focused on identifying sustainable and cost effective binder sources for the proposed paste fill plant.
- Review of cementing materials mill test certificates and mineralogy (X-Ray Diffraction analyses) for the following types of local binders: Portland cement, fly ash and slag available in Montana.
- Sourcing of potential binders identified.
- Evaluation of binder candidates identified.

The following binders listed in Table 4-1 are available locally at the cement terminals in Missoula, Montana or Three Forks, Montana and could be used in the Black Butte Copper cemented paste mix designs. Geochemical certificates for each binder type listed in Table 4-1 are included in Section 5.0 below.

Table 4-1. List of Acceptable Locally-Sourced Binders Available for Use in the BBC Paste

Binder Type	Supplier	Type	Binder Source	Cement Plant Source
Portland Cement	Lafarge	Type I/II	Richmond B.C., Canada	Missoula, Montana
	Holcim	Type I/II	Three Forks, Montana	Trident Plant in Three Forks, Montana
	Holcim	Envirocore Hydraulic Cement Type GU	Three Forks, Montana	Trident Plant in Three Forks, Montana
Slag	Lafarge	Grade 100 NewCem	Seattle (via Asia)	Missoula, Montana
Fly Ash	Lafarge	Type F	Centralia, WA Power Plant	Missoula, Montana

Notes: (1) Geochemical certificates for each binder type are included in Section 5.0 below; (2) The Lafarge Portland Cement (Type I/II) and the Lafarge Grade 100 NewCem slag were used as the binders for the BBC paste experimental program

5.0 LAB TEST RESULTS FOR BINDER MATERIALS AND TAILINGS WATER

The Standardized test results for the binders and tailings water are presented below and in Appendix K5. The binder index tests and strength characterization tests were completed by Amec Foster Wheeler in Hamilton, Ontario, Canada and are included below in Tables 5-1, 5-2, and 5-3. Plots showing strength activity index of mortar cubes and compressive strength of mortar cubes using various blend ratios of slag and Portland Cement Type I/II (Slag/PC) from Lafarge are shown in Figures 5.1 and 5.2, respectively.

The binder chemical tests have been conducted by several different accredited laboratories. Water may be characterized using chemical methods as defined below in Table 5-4. Maxxam Analytics Laboratory in Hamilton, Ontario conducted the water chemical analyses.

Table 5-1. Results of Strength Development Testing for Portland Cements

		Compressive strength (MPa)			
Cement type		GU*	Lafarge Type I/II	Holcim Type I/II	Holcim Envirocore
Sample No.		NA	S122-15	S134-15	S135-15
Age (days)	3	13.00	27.82	31.15	19.56
	7	20.00	35.42	43.06	26.42
	28	28.00	45.60	47.41	29.89
7-day/28-day (%)		71.43	77.67	90.83	88.39

Notes: (1) *ASTM C1157 standard requirements for hydraulic cements; (2) Data from Amec Foster Wheeler Laboratory in Hamilton, Ontario, Canada; GU = general use

Table 5-2. Results of Pozzolanic activity testing for Lafarge Fly Ash (Sample # S123-15)

FA/PC blend ratio	Flow	Age	Compressive strength		Density		Strength activity index	Compressive strength 7-day/28-day
(%)	%	days	MPa	psi	kg/m^3	lbs/ft^3	%	%
0/100	108	1	17.4	2524	2168	135.4	-	-
		3	27.8	4034	2157	134.5	-	-
		7	35.4	5136	2132	133.1	-	77.73
		28	45.6	6607	2163	135.0	-	-
20/80	>130	1	13.0	1890	2157	134.6	75	-
		3	25.6	3707	2163	135.0	92	-
		7	33.9	4921	2174	135.7	96	74.99
		28	45.3	6563	2183	136.3	99	-
40/60	>130	1	7.6	1105	2172	135.6	44	-
		3	19.6	2837	2164	135.1	70	-
		7	27.5	3981	2159	134.8	78	66.31
		28	41.4	6004	2217	138.4	91	-
60/40	>130	1	3.4	494	2210	138.0	20	-
		3	10.1	1459	2243	140.0	36	-
		7	16.2	2356	2169	135.4	46	65.58
		28	24.8	3593	2214	138.2	54	-

Note: Data from Amec Foster Wheeler Laboratory in Hamilton, Ontario, Canada

Table 5-3. Results of Slag Activity Testing of Lafarge Slag (Sample S124-15).

Slag/PC blend ratio	Flow	Age	Compressive strength		Density		Strength activity index	Compressive strength 7-day/28-day
	%	days	MPa	psi	kg/m^3	lbs/ft^3	%	%
0/100	111	1	17.4	2,524	2,168	135.4	-	-
		3	27.8	4,034	2,157	134.7	-	-
		7	35.4	5,136	2,132	133.1	-	77.73
		28	45.6	6,607	2,163	135.0	-	-
25/75	76	1	13.8	2,001	2,162	135.0	79	-
		3	25.6	3,707	2,163	135.0	92	-
		7	35.3	5,120	2,174	135.7	100	77.81
		28	45.4	6,580	2,206	137.7	100	-
50/50	87	1	9.0	1,301	2,139	133.6	52	-
		3	19.6	2,837	2,164	135.1	70	-
		7	32.9	4,768	2,166	135.2	93	72.37
		28	45.4	6,588	2,185	136.4	100	-
75/25	93	1	5.2	759	2,142	133.7	30	-
		3	10.1	1,459	2,243	140.0	36	-
		7	16.2	2,536	2,169	135.4	46	45.77
		28	35.5	5,148	2,168	135.3	78	-

Note: Data from Amec Foster Wheeler Laboratory in Hamilton, Ontario, Canada

Figure 5.1. Strength Activity Index of Mortar Cubes Using Various Blend Ratios of Slag and Cement Type I/II (Slag/PC) from Lafarge.

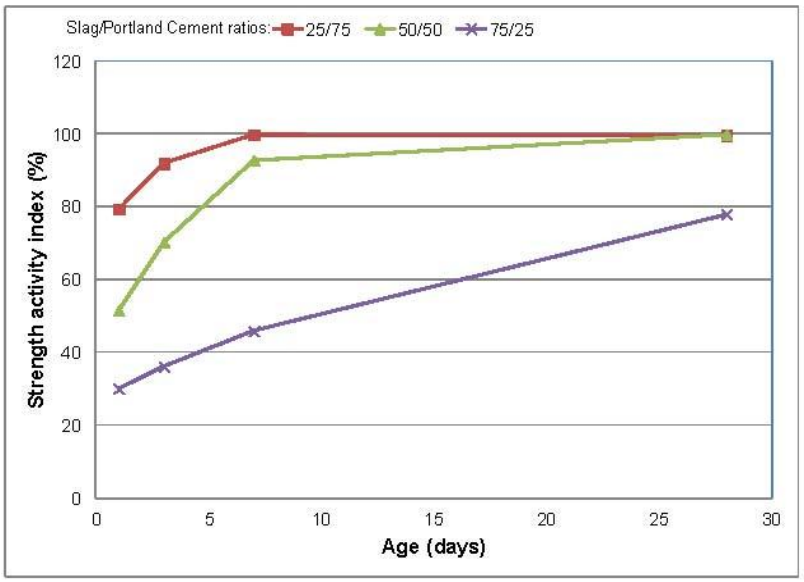


Figure 5.2. Compressive Strength of Mortar Cubes Using Various Blend Ratios of Slag and Cement Type I/II (Slag/PC) from Lafarge.

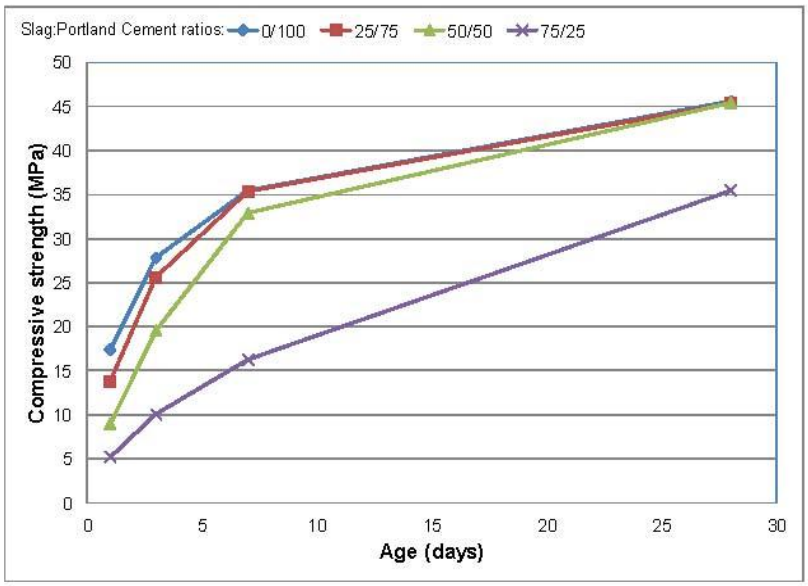


Table 5-4. Chemical Composition of Binders.

Binder sample	**Lafarge Portland Cement Type I/II**	**Lafarge Fly Ash Type F**	**Lafarge Slag**	**Holcim Portland Cement Type I/II**	**Holcim Envirocore™**
Sample Number	**S122-15**	**S123-15**	**S124-15**	**S134-15**	**S135-15**
Element Oxide (%)	(%)	(%)	(%)	(%)	(%)
SiO_2	32.0	46.7	20.4	20.2	18.6
Al_2O_3	13.4	18.1	4.83	4.11	4.14
Fe_2O_3	0.99	5.97	3.45	3.29	2.80
MgO	5.08	5.89	0.70	2.37	1.78
CaO	42.3	15.2	63.4	64.6	63.8
Na_2O	0.23	3.11	0.37	0.17	0.12
K_2O	0.41	1.46	0.31	0.49	0.34
TiO_2	0.50	0.95	0.28	0.21	0.22
P_2O_5	0.03	0.41	0.06	0.05	0.05
MnO	0.23	0.10	0.07	0.04	0.04
Cr_2O_3	<0.01	0.02	0.01	0.02	0.02
V_2O_5	<0.01	0.03	0.01	0.01	0.01
C(t)	0.53	0.07	0.58	0.57	1.49
LOI	1.54	0.55	3.13	2.82	6.22
S	1.50	0.35	1.21	1.10	0.91
SO_3	3.75	0.87	3.02	2.76	2.25
Sum	96.7	98.5	97.0	98.4	98.1

Note: Data from Amec Foster Wheeler Laboratory in Hamilton, Ontario, Canada

Tables 5-5 and 5-6 show the geochemistry of the Lafarge Portland Cement (Type I/II) and the Lafarge slag, respectively.

Table 5-5. Geochemistry of the Lafarge Portland Cement (Type I/II).
[Pace Analitical Pages Following including Sample Submission Sheets]

Pace Analytical Services, Inc.
1700 Elm Street - Suite 200
Minneapolis, MN 55414
(612)607-1700

SAMPLE ANALYTE COUNT

Project: Testing
Pace Project No.: 10349606

Lab ID	Sample ID	Method	Analysts	Analytes Reported	Laboratory
10349606003	Lafarge Type 1 Portland Cement (Type I/II)	EPA 6010C	DM	26	PASI-M
		EPA 7471B	LMW	1	PASI-M
		ASTM D2974	JDL	1	PASI-M

Pace Analytical Services, Inc.
1700 Elm Street - Suite 200
Minneapolis, MN 55414
(612)607-1700

ANALYTICAL RESULTS

Project: Testing
Pace Project No.: 10349606

SAMPLE ID: Lafarge Type 1 Lab ID #10349606003

SAMPLE DETAILS: Portland Cement (Type I/II)

Sample: Lafarge Type 1 **Lab ID: 10349606003** Collected: 05/23/16 09:00 Received: 05/24/16 12:45 Matrix: Solid

Results reported on a "dry weight" basis and are adjusted for percent moisture, sample size and any dilutions.

Parameters	Results	Units	PQL	MDL	DF	Prepared	Analyzed	CAS No.	Qual
6010C MET ICP	Analytical Method: EPA 6010C Preparation Method: EPA 3050								
Aluminum	**27600**	mg/kg	41.8	1.4	5	05/26/16 10:45	05/31/16 10:27	7429-90-5	
Antimony	**3.9J**	mg/kg	4.2	0.84	5	05/26/16 10:45	05/31/16 10:27	7440-36-0	D3
Arsenic	**28.1**	mg/kg	4.2	0.84	5	05/26/16 10:45	05/31/16 10:27	7440-38-2	
Barium	**987**	mg/kg	2.1	0.067	5	05/26/16 10:45	05/31/16 10:27	7440-39-3	
Beryllium	**0.13J**	mg/kg	1.0	0.11	5	05/26/16 10:45	05/31/16 10:27	7440-41-7	D3
Boron	**23.4J**	mg/kg	31.4	2.7	5	05/26/16 10:45	05/31/16 10:27	7440-42-8	D3
Cadmium	**0.87**	mg/kg	0.63	0.040	5	05/26/16 10:45	05/31/16 10:27	7440-43-9	

REPORT OF LABORATORY ANALYSIS

Pace Analytical Services, Inc.
1700 Elm Street - Suite 200
Minneapolis, MN 55414
(612)607-1700

ANALYTICAL RESULTS

Project: Testing
Pace Project No.: 10349606

Sample: Lafarge Type 1 **Lab ID: 10349606003** Collected: 05/23/16 09:00 Received: 05/24/16 12:45 Matrix: Solid

Results reported on a "dry weight" basis and are adjusted for percent moisture, sample size and any dilutions.

Parameters	Results	Units	PQL	MDL	DF	Prepared	Analyzed	CAS No.	Qual
6010C MET ICP	Analytical Method: EPA 6010C Preparation Method: EPA 3050								
Calcium	**431000**	mg/kg	105	4.8	5	05/26/16 10:45	05/31/16 10:27	7440-70-2	
Chromium	**59.5**	mg/kg	2.1	0.43	5	05/26/16 10:45	05/31/16 10:27	7440-47-3	
Cobalt	**20.1**	mg/kg	2.1	0.11	5	05/26/16 10:45	05/31/16 10:27	7440-48-4	
Copper	**253**	mg/kg	2.1	0.17	5	05/26/16 10:45	05/31/16 10:27	7440-50-8	
Iron	**21700**	mg/kg	10.5	2.7	5	05/26/16 10:45	05/31/16 10:27	7439-89-6	
Lead	**34.7**	mg/kg	2.1	0.42	5	05/26/16 10:45	05/31/16 10:27	7439-92-1	
Magnesium	**4390**	mg/kg	105	1.1	5	05/26/16 10:45	05/31/16 10:27	7439-95-4	
Manganese	**659**	mg/kg	1.0	0.071	5	05/26/16 10:45	05/31/16 10:27	7439-96-5	
Molybdenum	**7.7**	mg/kg	3.1	0.21	5	05/26/16 10:45	05/31/16 10:27	7439-98-7	
Nickel	**17.9**	mg/kg	4.2	1.1	5	05/26/16 10:45	05/31/16 10:27	7440-02-0	
Potassium	**3490**	mg/kg	523	9.1	5	05/26/16 10:45	05/31/16 10:27	7440-09-7	
Selenium	**4.7**	mg/kg	4.2	1.2	5	05/26/16 10:45	05/31/16 10:27	7782-49-2	B
Silver	**1.6J**	mg/kg	2.1	0.33	5	05/26/16 10:45	05/31/16 10:27	7440-22-4	D3
Sodium	**3220**	mg/kg	209	3.5	5	05/26/16 10:45	05/31/16 10:27	7440-23-5	
Thallium	**2.6J**	mg/kg	4.2	0.71	5	05/26/16 10:45	05/31/16 10:27	7440-28-0	D3
Tin	**39.2**	mg/kg	15.7	0.79	5	05/26/16 10:45	05/31/16 10:27	7440-31-5	
Titanium	**1320**	mg/kg	5.2	0.029	5	05/26/16 10:45	05/31/16 10:27	7440-32-6	
Vanadium	**49.2**	mg/kg	3.1	0.056	5	05/26/16 10:45	05/31/16 10:27	7440-62-2	
Zinc	**1010**	mg/kg	4.2	1.2	5	05/26/16 10:45	05/31/16 10:27	7440-66-6	
7471B Mercury	Analytical Method: EPA 7471B Preparation Method: EPA 7471B								
Mercury	**<0.0043**	mg/kg	0.017	0.0043	1	05/25/16 11:15	05/25/16 21:20	7439-97-6	
Dry Weight	Analytical Method: ASTM D2974								
Percent Moisture	**0.35**	%	0.10	0.10	1		06/02/16 09:56		

REPORT OF LABORATORY ANALYSIS

Pace Analytical Services, Inc.
1700 Elm Street - Suite 200
Minneapolis, MN 55414
(612)607-1700

QUALIFIERS

Project: Testing
Pace Project No.: 10349606

DEFINITIONS

DF - Dilution Factor, if reported, represents the factor applied to the reported data due to dilution of the sample aliquot.

ND - Not Detected at or above adjusted reporting limit.

J - Estimated concentration above the adjusted method detection limit and below the adjusted reporting limit.

MDL - Adjusted Method Detection Limit.

PQL - Practical Quantitation Limit.

RL - Reporting Limit.

S - Surrogate

1,2-Diphenylhydrazine decomposes to and cannot be separated from Azobenzene using Method 8270. The result for each analyte is a combined concentration.

Consistent with EPA guidelines, unrounded data are displayed and have been used to calculate % recovery and RPD values.

LCS(D) - Laboratory Control Sample (Duplicate)

MS(D) - Matrix Spike (Duplicate)

DUP - Sample Duplicate

RPD - Relative Percent Difference

NC - Not Calculable.

SG - Silica Gel - Clean-Up

U - Indicates the compound was analyzed for, but not detected.

N-Nitrosodiphenylamine decomposes and cannot be separated from Diphenylamine using Method 8270. The result reported for each analyte is a combined concentration.

Pace Analytical is TNI accredited. Contact your Pace PM for the current list of accredited analytes.

TNI - The NELAC Institute.

LABORATORIES

PASI-M	Pace Analytical Services - Minneapolis

ANALYTE QUALIFIERS

B	Analyte was detected in the associated method blank.
D3	Sample was diluted due to the presence of high levels of non-target analytes or other matrix interference.
M1	Matrix spike recovery exceeded QC limits. Batch accepted based on laboratory control sample (LCS) recovery.
M6	Matrix spike and Matrix spike duplicate recovery not evaluated against control limits due to sample dilution.
R1	RPD value was outside control limits.

Table 5-6. Geochemistry of the Lafarge 100Grade NewCem Slag.
[Pace Analitical Pages Following including Sample Submission Sheets]

Pace Analytical Services, Inc.
1700 Elm Street - Suite 200
Minneapolis, MN 55414
(612)607-1700

June 03, 2016

Rob Shogren
Lafarge
5400 W. Marginal Way
Seattle, WA 98106

RE: Project: Testing
Pace Project No.: 10349606

Dear Rob Shogren:
Enclosed are the analytical results for sample(s) received by the laboratory on May 24, 2016. The results relate only to the samples included in this report. Results reported herein conform to the most current TNI standards and the laboratory's Quality Assurance Manual, where applicable, unless otherwise noted in the body of the report.

If you have any questions concerning this report, please feel free to contact me.

Sincerely,

Jenni Gross

Jennifer Gross
jennifer.gross@pacelabs.com
Project Manager

Enclosures

REPORT OF LABORATORY ANALYSIS

Pace Analytical Services, Inc.
1700 Elm Street - Suite 200
Minneapolis, MN 55414
(612)607-1700

CERTIFICATIONS

Project: Testing
Pace Project No.: 10349606

Minnesota Certification IDs

1700 Elm Street SE Suite 200, Minneapolis, MN 55414
525 N 8th Street, Salina, KS 67401
A2LA Certification #: 2926.01
Alaska Certification #: UST-078
Alaska Certification #MN00064
Alabama Certification #40770
Arizona Certification #: AZ-0014
Arkansas Certification #: 88-0680
California Certification #: 01155CA
Colorado Certification #Pace
Connecticut Certification #: PH-0256
EPA Region 8 Certification #: 8TMS-L
Florida/NELAP Certification #: E87605
Guam Certification #:14-008r
Georgia Certification #: 959
Georgia EPD #: Pace
Idaho Certification #: MN00064
Hawaii Certification #MN00064
Illinois Certification #: 200011
Indiana Certification#C-MN-01
Iowa Certification #: 368
Kansas Certification #: E-10167
Kentucky Dept of Envi. Protection - DW #90062
Kentucky Dept of Envi. Protection - WW #:90062
Louisiana DEQ Certification #: 3086
Louisiana DHH #: LA140001
Maine Certification #: 2013011
Maryland Certification #: 322
Michigan DEPH Certification #: 9909
Minnesota Certification #: 027-053-137
Mississippi Certification #: Pace
Montana Certification #: MT0092
Nevada Certification #: MN_00064
Nebraska Certification #: Pace
New Jersey Certification #: MN-002
New York Certification #: 11647
North Carolina Certification #: 530
North Carolina State Public Health #: 27700
North Dakota Certification #: R-036
Ohio EPA #: 4150
Ohio VAP Certification #: CL101
Oklahoma Certification #: 9507
Oregon Certification #: MN200001
Oregon Certification #: MN300001
Pennsylvania Certification #: 68-00563
Puerto Rico Certification
Saipan (CNMI) #:MP0003
South Carolina #:74003001
Texas Certification #: T104704192
Tennessee Certification #: 02818
Utah Certification #: MN000642013-4
Virginia DGS Certification #: 251
Virginia/VELAP Certification #: Pace
Washington Certification #: C486
West Virginia Certification #: 382
West Virginia DHHR #:9952C
Wisconsin Certification #: 999407970

REPORT OF LABORATORY ANALYSIS

Pace Analytical Services, Inc.
1700 Elm Street - Suite 200
Minneapolis, MN 55414
(612)607-1700

SAMPLE SUMMARY

Project: Testing
Pace Project No.: 10349606

Lab ID	Sample ID	Matrix	Date Collected	Date Received
10349606004	Lafarge New Cem (Grade 100 Slag)	Solid	05/23/16 09:00	05/24/16 12:45

Pace Analytical Services, Inc.
1700 Elm Street - Suite 200
Minneapolis, MN 55414
(612)607-1700

SAMPLE ANALYTE COUNT

Project: Fly Ash Testing
Pace Project No.: 10349606

Lab ID	Sample ID	Method	Analysts	Analytes Reported	Laboratory
10349606004	Lafarge New Cem (Grade 100 Slag)	EPA 6010C	DM	26	PASI-M
		EPA 7471B	LMW	1	PASI-M
		ASTM D2974	JDL	1	PASI-M

Pace Analytical Services, Inc.
1700 Elm Street - Suite 200
Minneapolis, MN 55414
(612)607-1700

ANALYTICAL RESULTS

Project: Testing
Pace Project No.: 10349606

Sample: Lafarge New Cem **Lab ID: 10349606004** Collected: 05/23/16 09:00 Received: 05/24/16 12:45 Matrix: Solid

Results reported on a "dry weight" basis and are adjusted for percent moisture, sample size and any dilutions.

Parameters	Results	Units	PQL	MDL	DF	Prepared	Analyzed	CAS No.	Qual
6010C MET ICP	Analytical Method: EPA 6010C Preparation Method: EPA 3050								
Aluminum	**49300**	mg/kg	42.7	1.4	5	05/26/16 10:45	05/31/16 10:30	7429-90-5	
Antimony	**<0.85**	mg/kg	4.3	0.85	5	05/26/16 10:45	05/31/16 10:30	7440-36-0	D3
Arsenic	**1.5J**	mg/kg	4.3	0.85	5	05/26/16 10:45	05/31/16 10:30	7440-38-2	D3
Barium	**336**	mg/kg	2.1	0.068	5	05/26/16 10:45	05/31/16 10:30	7440-39-3	
Beryllium	**5.0**	mg/kg	1.1	0.12	5	05/26/16 10:45	05/31/16 10:30	7440-41-7	
Boron	**56.0**	mg/kg	32.0	2.8	5	05/26/16 10:45	05/31/16 10:30	7440-42-8	
Cadmium	**0.16J**	mg/kg	0.64	0.041	5	05/26/16 10:45	05/31/16 10:30	7440-43-9	B,D3
Calcium	**183000**	mg/kg	107	4.9	5	05/26/16 10:45	05/31/16 10:30	7440-70-2	
Chromium	**33.0**	mg/kg	2.1	0.44	5	05/26/16 10:45	05/31/16 10:30	7440-47-3	
Cobalt	**0.48J**	mg/kg	2.1	0.11	5	05/26/16 10:45	05/31/16 10:30	7440-48-4	D3
Copper	**5.1**	mg/kg	2.1	0.17	5	05/26/16 10:45	05/31/16 10:30	7440-50-8	

REPORT OF LABORATORY ANALYSIS

Pace Analytical Services, Inc.
1700 Elm Street - Suite 200
Minneapolis, MN 55414
(612)607-1700

ANALYTICAL RESULTS

Project: Testing
Pace Project No.: 10349606

Sample: Lafarge New Cem **Lab ID: 10349606004** Collected: 05/23/16 09:00 Received: 05/24/16 12:45 Matrix: Solid

Results reported on a "dry weight" basis and are adjusted for percent moisture, sample size and any dilutions.

Parameters	Results	Units	PQL	MDL	DF	Prepared	Analyzed	CAS No.	Qual
6010C MET ICP	Analytical Method: EPA 6010C Preparation Method: EPA 3050								
Iron	**2370**	mg/kg	10.7	2.8	5	05/26/16 10:45	05/31/16 10:30	7439-89-6	
Lead	**1.4J**	mg/kg	2.1	0.43	5	05/26/16 10:45	05/31/16 10:30	7439-92-1	D3
Magnesium	**21800**	mg/kg	107	1.1	5	05/26/16 10:45	05/31/16 10:30	7439-95-4	
Manganese	**1150**	mg/kg	1.1	0.073	5	05/26/16 10:45	05/31/16 10:30	7439-96-5	
Molybdenum	**0.38J**	mg/kg	3.2	0.21	5	05/26/16 10:45	05/31/16 10:30	7439-98-7	D3
Nickel	**<1.2**	mg/kg	4.3	1.2	5	05/26/16 10:45	05/31/16 10:30	7440-02-0	D3
Potassium	**2700**	mg/kg	533	9.3	5	05/26/16 10:45	05/31/16 10:30	7440-09-7	
Selenium	**<1.2**	mg/kg	4.3	1.2	5	05/26/16 10:45	05/31/16 10:30	7782-49-2	D3
Silver	**0.39J**	mg/kg	2.1	0.34	5	05/26/16 10:45	05/31/16 10:30	7440-22-4	D3
Sodium	**1170**	mg/kg	213	3.5	5	05/26/16 10:45	05/31/16 10:30	7440-23-5	
Thallium	**2.0J**	mg/kg	4.3	0.73	5	05/26/16 10:45	05/31/16 10:30	7440-28-0	D3
Tin	**1.2J**	mg/kg	16.0	0.81	5	05/26/16 10:45	05/31/16 10:30	7440-31-5	B,D3
Titanium	**1820**	mg/kg	5.3	0.030	5	05/26/16 10:45	05/31/16 10:30	7440-32-6	
Vanadium	**16.1**	mg/kg	3.2	0.057	5	05/26/16 10:45	05/31/16 10:30	7440-62-2	
Zinc	**12.9**	mg/kg	4.3	1.2	5	05/26/16 10:45	05/31/16 10:30	7440-66-6	
7471B Mercury	Analytical Method: EPA 7471B Preparation Method: EPA 7471B								
Mercury	**<0.0045**	mg/kg	0.017	0.0045	1	05/25/16 11:15	05/25/16 21:22	7439-97-6	
Dry Weight	Analytical Method: ASTM D2974								
Percent Moisture	**0.70**	%	0.10	0.10	1		06/02/16 09:56		

REPORT OF LABORATORY ANALYSIS

Pace Analytical Services, Inc.
1700 Elm Street - Suite 200
Minneapolis, MN 55414
(612)607-1700

QUALIFIERS

Project: Testing
Pace Project No.: 10349606

DEFINITIONS

DF - Dilution Factor, if reported, represents the factor applied to the reported data due to dilution of the sample aliquot.

ND - Not Detected at or above adjusted reporting limit.

J - Estimated concentration above the adjusted method detection limit and below the adjusted reporting limit.

MDL - Adjusted Method Detection Limit.

PQL - Practical Quantitation Limit.

RL - Reporting Limit.

S - Surrogate

1,2-Diphenylhydrazine decomposes to and cannot be separated from Azobenzene using Method 8270. The result for each analyte is a combined concentration.

Consistent with EPA guidelines, unrounded data are displayed and have been used to calculate % recovery and RPD values.

LCS(D) - Laboratory Control Sample (Duplicate)

MS(D) - Matrix Spike (Duplicate)

DUP - Sample Duplicate

RPD - Relative Percent Difference

NC - Not Calculable.

SG - Silica Gel - Clean-Up

U - Indicates the compound was analyzed for, but not detected.

N-Nitrosodiphenylamine decomposes and cannot be separated from Diphenylamine using Method 8270. The result reported for each analyte is a combined concentration.

Pace Analytical is TNI accredited. Contact your Pace PM for the current list of accredited analytes.

TNI - The NELAC Institute.

LABORATORIES

PASI-M	Pace Analytical Services - Minneapolis

ANALYTE QUALIFIERS

B	Analyte was detected in the associated method blank.
D3	Sample was diluted due to the presence of high levels of non-target analytes or other matrix interference.
M1	Matrix spike recovery exceeded QC limits. Batch accepted based on laboratory control sample (LCS) recovery.
M6	Matrix spike and Matrix spike duplicate recovery not evaluated against control limits due to sample dilution.
R1	RPD value was outside control limits.

The chemistry of the tailings water (decant water from the filter cake) is shown in Table 5-7 below.

Table 5-7. Chemical Composition of the Mine Water.

Parameters	Units	S153-15	RDL
pH	-	6.98	N/A
Dissolved sulphate (SO_4)	mg/L	1200	1
Dissolved chloride (Cl)	mg/L	340	1
Metals			
Total Aluminum (Al)	mg/L	0.020	0.005
Total Arsenic (As)	mg/L	0.240	0.001
Total Calcium (Ca)	mg/L	570	0.2
Total Copper (Cu)	mg/L	0.520	0.001
Total Iron (Fe)	mg/L	<0.1	0.1
Total Lead (Pb)	mg/L	<0.0005	0.0005
Total Magnesium (Mg)	mg/L	12	0.05
Total Nickel (Ni)	mg/L	0.057	0.001
Total Potassium (K)	mg/L	27	0.2
Total Silicon (Si)	mg/L	3.30	0.05
Total Sodium (Na)	mg/L	25	0.1

Notes: Sample S153-15 is from water-rich phase generated during filter cake processing by International Metallurgical and Environmental Inc. and analyzed by MAXXAM Analytics International Corp.;
RDL = reporting detection limit
N/A = not applicable

K5-C. Paste Characterization, Mixing Procedures, and Laboratory Test Results

1.0 INTRODUCTION

This section describes the cement paste (CP) mix designs tested to date for use in cemented paste for surface deposition (into the CTF) and for cemented paste backfill (CPB) (into the underground workings).

The following sections will:

- Define the physical targets of the paste mix designs for surface deposition and for cemented paste backfill,
- List the standardized testing methods for the paste, and
- Report the laboratory test results for the binders, tailings water, and two paste mix designs (one containing 2% binder and another containing 4% binder).

The Black Butte Copper Tailings will make up a high proportion of the paste designs and the characteristics and index tests have been previously presented in Appendix K5-A.

2.0 CEMENT PASTE MIX DESIGN PHYSICAL TARGETS

Two CP mix design physical targets were established early to guide the BBC experimental paste program:

- The first cemented paste (CP) mix design is for surface deposition with the following targeted physical paste properties:
    - slump for the paste mixes is 7 to 9 inches (~178 - 229 mm) for paste pumpability.
    - No target for unconfined compressive strength (UCS) is available; however UCS and potential strength reduction over time are important for this application.

- The second cemented paste design is for backfill (CPB) with the following targeted physical paste properties:
    - slump for the paste mixes is 6 to 8 inches (~152 - 203 mm) for paste pumpability, and
    - UCS at 14 days for the Johnny Lee Lower and Upper Copper Zones is 150 kPa (0.21 MPa).

3.0 PASTE MIXING PROCEDURES, TESTING PROTOCOLS, AND TEST METHODS

Filter cake Black Butte Copper tailings samples, and binders sourced from Montana cement plants were shipped to Amec Foster Wheeler in Hamilton, Ontario, Canada in 2015. The filter cake tailings samples were prepared and shipped by International Metallurgical and Environmental Inc. in two shipments (sample ID numbers S153-15 and S173-15).

Index tests were first completed on the tailings paste without binder as discussed in Section 3.1 below. CSP mixes were designed later and are described in Section 3.2 below.

3.1 Paste Index Tests

Due to the limited availability of tailings for the project, index tests were conducted on the tailings paste without binder to gain a preliminary understanding of the material behavior in terms of physical properties and rheology (Table 3-1). Small samples were prepared in a Hobart mixer for the following solids concentrations ranging between 75% and 85% by weight. The solids concentrations used were: 75%, 77.50%, 80%, 82.50%, and 85% by adding solids to the mix.

Cylinder slump measurements were taken for each solids concentration. Cylinder, or Boger slump uses an open-ended cylinder having an aspect ratio of 1:1. The cylinder used is typically 3" (75 mm) diameter by 3" (75 mm) tall. Cylinder slump measurement is used and accepted in the mining industry to predict with reasonably accuracy the yield stress values when compared with the vane rheometer results, as described in Pashias et al. (1996). When the mix became very stiff the solids content was not increased any further and the index testing was stopped.

Table 3-1. Trial Batches Paste No Binder.

No.	Cw	Cylinder slump		Cone slump	
	(%)	mm	inches	mm	inches
1	84.00	10	0.39	85	3.35
2	83.00	15	0.59	170	6.69
3	82.50	20	0.79	210	8.27
4	82.00	24	0.94	230	9.06

3.2 Paste Mix Design

CSP mixes were designed to be workable and to meet the project cone slump requirements. The batches used for fresh and hardened paste mix properties had a total batch mass of approximately 51 pounds (23 kg). The amount of water for each batch was determined based on slump measurements conducted in trial batches. The term "Cw" used in the data tables represents the total solids content of the mix, accounting for all water (both mix water and absorbed water on the aggregate). For example, a mix with 165 pounds (75 kg) of dry aggregate, 11 pounds (5 kg) of dry binder, and 44 pounds (20 kg) of water would have a Cw of 80.0%.

3.3 Paste Mixing Procedures

The mixing procedure for the two paste dosages (2% binder content and 4% binder content) is described below. The sample preparation and curing was done in accordance with ASTM C192 / C192M – Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory. The CSP mixes were batched in a 66 pound (30 kg) capacity rheometer mixer according to a general mixing procedure described below:

- Tailings were placed in the mixer.
- The cementitious materials were added.
- Mixing water (Ontario tap water) was added.
- The ingredients were mixed for 3 to 4 minutes.
- Cylinder slump was measured as described in Section 3.1 above.
- Cone slump was measured following ASTM C143 Standard Test Method for Slump of Hydraulic Cement Concrete.
- The mix was further mixed for 1 minute.
- The mix was tamped into the molds while filling the molds for the density and USC samples.

Twelve 2" x 4" (51 mm x 102 mm) and eight 3" x 6" (76 mm and 152 mm) cylinder specimens were prepared for each mix for density and UCS measurements, as well as specimens for geochemistry and triaxial tests. All of the specimens were cured in the curing room at 20°C (70° F) and 100% relative humidity and demolded prior to the density and UCS tests.

3.4 Paste Test Work Steps

The cemented paste test work was conducted in three sequential steps:

1. Index tests were conducted as detailed in Section 3.1 above.
2. Trial batches were conducted to develop mix designs to meet the target properties, including slump, while maximizing the tailings content for a given binder and binder dosage rate. Upon completion of the trial batches the fill and water content for CSP mixes with different binder dosage rates was defined for the full size batches tested in the test program.
3. CSP test program was conducted assuming the following variables (factors):
    - Slump: mixes with one nominal slump value of 8 inches (203 mm) were designed and evaluated in this program.
    - Binder type: one blend of Portland cement Type I/II and slag from Lafarge based on the certificates presented in Appendix K5.
    - Binder dosage rate: mixes with two binder dosage rates were evaluated in the test program: 2% and 4%.

Table 3-2 lists the paste standardized test methods for the fresh mix properties that have been completed for the two different binder dosages: one with 2% total binder (1% Lafarge Portland Cement Type I/II and 1% Lafarge slag), and the other with 4% total binder (2% Lafarge Portland Cement Type I/II and 2% Lafarge slag). Table 3-3 lists the standardized test methods for the hardened properties for the two different binder dosages noted above.

Table 3-2. List of Paste Tests: Fresh Mix Properties

Mix Property	Method (ASTM or Other)	ASTM Description
Cylinder Slump (or Boger slump)	Defined in Pashias et al. (1996)[(1)]	Used to predict yield stress values (Standard Industry best practice) and is compared to vane rheometer results
Cone Slump	ASTM C143	Standard Test Method for Slump of Hydraulic Cement Concrete
Set Time	ASTM C191	Standard Test Methods Time and Setting of Hydraulic Cement by Vicat Needle
	ASTM C192/C192M	Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory
	ASTM C150/C150M	Standard Specification for Portland Cement
Rheology	Used Haake Viscotester 550 instrument (the configuration used in the testing is the standard used in the Paste backfill Industry)(2)	Data collected includes: (1) calculated yield stress (based on the cylinder slump measurement and accepted as a reasonably accurate yield stress value when compared with the vane rheometer results, (2) rheometer yield stress (determined as the peak shear stress), and (3) the Bingham yield stress (defined as the yield stress above which the material becomes fluid)

Notes: (1) Pashias, N, Boger D.V., Summers, J. and Glenister, D.J., A Fifty cents rheometer for yield stress measurement, Journal of Rheology, vol. 40, issue 6, 1996, pp. 1179-1189.
(2) The Haake Viscotester configuration used an immersion sensor system FL100 (radius 0.43-inches (11 mm) and height of 0.63 inches (16 mm) and/or FL10 (radius 20 mm (0.79 inches (20 mm) and height of 2.36 inches (60 mm) with star shaped rotor was used for rheology property measurements. The rotor size was selected based on sample consistency for maximum machine resolution. The shear rate ranged from 0 s^{-1} to 40 s^{-1} and back to 0 s^{-1}. For each solids concentration information including shear rate, shear stress, and viscocity were recorded using a computer program.

Table 3-3. Paste Tests: Hardened Properties

Mix Property	Method (ASTM or Other)	ASTM Description
Hardened Density	ASTM C642	Standard Test Method for Density , Absorption, and Voids in Hardened Concrete
Unconfined Compressive Strength	ASTM C39/C39M	Standard Test Method for Compressive Strength of Cylinderical Concrete Specimens

3.5 Cemented Tailings Paste Test Results Using 2% and 4% Total Binders

The laboratory test results for the two cemented tailings paste mix designs using 2% and 4% total binder dosage rates are presented in Tables 3-4, 3-5, 3-6, 3-7, 3-8, and 3-9. Each paste sample tested used 50% Lafarge Grade 100 NewCem slag and 50% Lafarge Portland Cement (Type I/II) sourced from the Missoula, Montana cement plant.

Table 3-4. Surface paste Mix Designs

No.	Mix Label	Binder type (%)		Binder dosage rate	Cw	Cylinder slump	
		PC	S	(%)	(%)	(mm)	(inches)
1	LCT-S50-2	50	50	2	79.50	16	0.63
2	LCT-S50-4	50	50	4	79.00	15	0.59

No.	Mix Label	Cone slump		Testing age	Cylinder specimen
		(mm)	(inches)	(days)	
1	LCT-S50-2	210	8.27	7, 14, 28, 56	2”x4”, 3”x6”
2	LCT-S50-4	205	8.07	7, 14, 28, 56	2”x4”, 3”x6”

Table 3-5. Hydraulic Conductivity of Paste With 2% and 4% Total Binders.

Sample Tested		Surface paste 2% binder, 50%S-50% PC	Surface Paste 4% binder, 50%S-50% PC
Sample Number		LCT-550- 2	LCT-550-4
Test Method	Results	(cm/s)	(cm/s)
Hydraulic conductivity (k)	Average inflow (run #1	1.69×10^{-06}	9.50×10^{-09}
	Average outflow (run #1)	1.64×10^{-06}	1.09×10^{-08}
	Average of inflow and outflow (run #1)	1.66×10^{-06}	1.02×10^{-08}
	Average inflow (run #2)	-	-
	Average outflow (run #2)	-	-
	Average of inflow and outflow (run #2)	-	-
	Overall Average	1.6×10^{-06}	1.0×10^{-8}

Table 3-6. Trial Batches Paste 2% Binder.

No.	Cw	Cylinder slump		Cone slump	
	(%)	mm	inches	mm	inches
1	80.00	14	0.55	155	6.1
2	79.50	16	0.63	210	8.3

Table 3-7. Trial Batches Paste 4% Binder.

No.	Cw	Cylinder slump		Cone slump	
	(%)	mm	inches	mm	inches
1	82.00	0	0.00	0	0
2	81.50	6	0.24	65	2.6
3	81.00	10	0.39	80	3.1
4	80.00	10	0.39	115	4.5
5	79.00	15	0.59	205	8.1

Table 3-8. Surface Paste Density Results up to 28 Days Using 2% and 4% Binder Contents and Different Cylinder Sizes

Batch #	Mix label	Binder dosage rate	Cone slump		Density results, 3" x 6" cylinders											
					Age (days)											
					7				14				28			
					Average		St. Dev.		Average		St. Dev.		Average		St. Dev.	
		(%)	(mm)	(inches)	(kg/m^3)	(lb/yd^3)	(kg/m^3)	(lb/yd^3)	(kg/m^3)	(lb/yd^3)	(kg/m^3)	(lb/yd^3)	(kg/m^3)	(lb/yd^3)	(kg/m^3)	(lb/yd^3)
1	LCT-S50-	2	210	8.27	-	-	-	-	-	-	-	-	2260	3810	-	-
2	LCT-S50-	4	205	8.07	2270	3826	-	-	2258	3805	-	-	2294	3867	-	-

Batch #	Mix label	Binder dosage rate	Cone slump		Density results, 2" x 4" cylinders											
					Age (days)											
					7				14				28			
					Average		St. Dev.		Average		St. Dev.		Average		St. Dev.	
		(%)	(mm)	(inches)	(kg/m^3)	(lb/yd^3)	(kg/m^3)	(lb/yd^3)	(kg/m^3)	(lb/yd^3)	(kg/m^3)	(lb/yd^3)	(kg/m^3)	(lb/yd^3)	(kg/m^3)	(lb/yd^3)
1	LCT-S50-	2	210	8.27	-	-	-	-	-	-	-	-	-	-	-	-
2	LCT-S50-	4	205	8.07	2366	3988	14.5	24.4	2365	3987	8.2	13.9	2370	3995	10.9	18.4

Table 3-9. Surface Paste UCS Test Results up to 28 Days Using 2% and 4% Binder Contents and Different Cylinder Sizes

Batch #	Mix label	Binder dosage rate	Cone slump		UCS results, 3" x 6" cylinders											
					Age (days)											
					7				14				28			
					Average		St. Dev.		Average		St. Dev.		Average		St. Dev.	
		(%)	(mm)	(in)	(MPa)	(psi)	(MPa)	(psi)	(MPa)	(psi)	(MPa)	(psi)	(MPa)	(psi)	(MPa)	(psi)
1	LCT-S50-2	2	210	8.27	0.00	0.00	-	-	0.00	0.00	-	-	0.09	12.85	-	-
2	LCT-S50-4	4	205	8.07	0.50	73.15	-	-	0.85	123.08	-	-	1.12	162.20	-	-

Batch #	Mix label	Binder dosage rate	Cone slump		UCS results, 2" x 4" cylinders											
					Age (days)											
					7				14				28			
					Average		St. Dev.		Average		St. Dev.		Average		St. Dev.	
		(%)	(mm)	(in)	(MPa)	(psi)	(MPa)	(psi)	(MPa)	(psi)	(MPa)	(psi)	(MPa)	(psi)	(MPa)	(psi)
1	LCT-S50-2	2	210	8.27		-	-	-		-	-	-		-	-	-
2	LCT-S50-4	4	205	8.07	0.50	71.80	0.012	-	0.94	136.68	0.007	1.01	1.14	164.8	0.12	18.12

4.0 CONCLUSIONS

The results of the cement tailings paste testing include:

- The optimum C_w for the 2% binder mix is 79.5% at a cone slump of 8.3”.
- The optimum C_w for the 4% binder mix is 79% at a cone slump of 8.1”.
- The 2% binder mix does not achieve final set until approximately 28 days age.
- The 4% binder mix achieves final set after approximately 96 hours (4 days).
- All the 28 day UCS test results for the 4% binder mix show a continued increase in strength when compared to 7-day results.
- The 4% binder mix achieves 0.85 MPa at 7 days, 1.12 MPa at 28 days.

K5-D. Photograph Log Trial Batches 2% Binder

PHOTOGRAPHIC RECORD

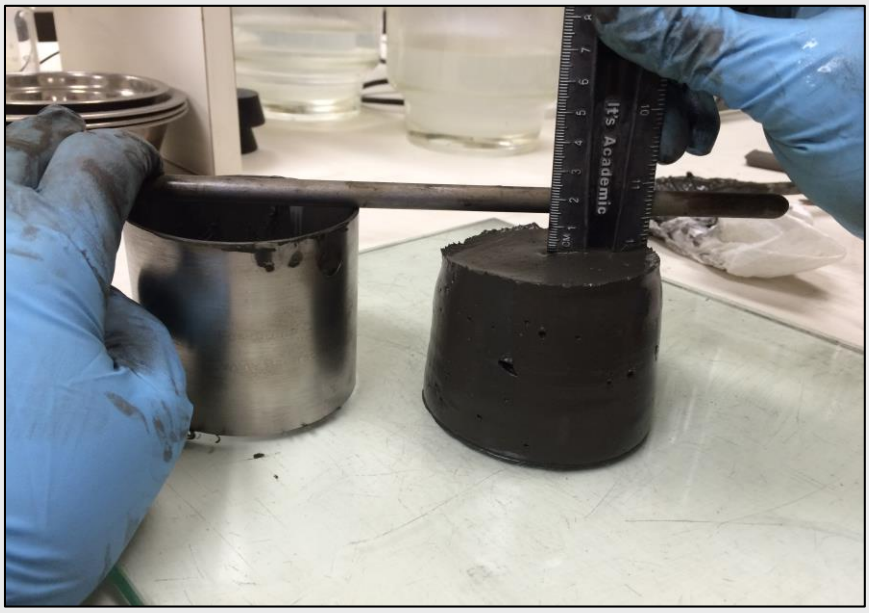
PHOTOGRAPH	1

Description
LST tailings (#S153-15), Cw=80%, 2%, cylinder slump 14mm

PHOTOGRAPH	2

Description
LST tailings (#S153-15), Cw=80%, 2%, cone slump 155mm

PHOTOGRAPHIC RECORD



PHOTOGRAPH	3

Description
LST tailings (#S153-15), Cw=79.5%, 2%, cylinder slump 16mm

PHOTOGRAPH	4

Description
LST tailings (#S153-15), Cw=79.5%, 2%, cone slump 210mm

K5-E. Photograph Log Trial Batches 4% Binder

PHOTOGRAPHIC RECORD

PHOTOGRAPH	1

Description
LST tailings (#S153-15), Cw=81.5%, 4% binder, cylinder slump 6mm

PHOTOGRAPH	2

Description
LST tailings (#S153-15), Cw=81.5%, 4% binder, cone slump 65mm

PHOTOGRAPHIC RECORD

PHOTOGRAPH	3

Description
LST tailings (#S153-15), Cw=81%, 4% binder, cylinder slump 10mm

PHOTOGRAPH	4

Description
LST tailings (#S153-15), Cw=81%, 4% binder, cone slump 80mm

PHOTOGRAPHIC RECORD

PHOTOGRAPH	5

Description
LST tailings (#S153-15), Cw=80%, 4% binder, cylinder slump 10mm

PHOTOGRAPH	6

Description
LST tailings (#S153-15), Cw=80%, 4% binder, cone slump 115mm

PHOTOGRAPHIC RECORD

PHOTOGRAPH	7

Description
LST tailings (#S153-15), Cw=79%, 4% binder, cylinder slump 15mm

PHOTOGRAPH	8

Description
LST tailings (#S153-15), Cw=79%, 4% binder, cone slump 205mm