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USE OF SHOTCRETE MADE WITH MINE WASTE TO REDUCE COSTS AND ENVIRONMENTAL IMPACTS OF WASTE DISPOSAL

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by
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Abstract

Mine waste rock is often recycled for paste and cement backfill in underground cut and fill mining operations. Aggregate in concrete and road surfacing material is another use if the mine waste does not contain deleterious materials that can degrade surface and ground water quality where it is used. Shotcrete usage in mining has been primarily limited to packaged dry mixes from offsite manufacturers. Substituting a manufacturer's pre-mixed shotcrete with crushed and sized mine waste rock can reduce both the shotcrete cost and the environmental impact of waste disposal operations by reducing the required volume capacity and footprint size required for a disposal facility for the waste material.

Keywords: shotcrete, mine waste, cost, ground support, tunnel support

Acknowledgements

Thanks go out to the mine industry, Andy Anderson and Jeremy Salle with DOWL for their help and use of the Butte office’s facilities, Joe Debar with SK Geotechnical for advice and material testing, Brett Bermingham and Jason Brewer with BASF Corporation for donating the admixtures, Chris Ross with Montana Tech for his help with the project.

Table of Contents

List of Tables

List of Figures

1. Introduction

Shotcrete is used by the mining industry for ground support. Though mainly used in underground applications, some use of shotcrete is seen in surface operations for highwall stability control. Majority of mines use dry mix shotcrete that is shipped to the site in a cubic yard bag from a third-party producer. The mine must wait for the product to arrive onsite thus adding down time if inventory is not on hand and shotcrete is required.

In addition to costs related to premanufactured shotcrete, there exists a double edge sword in relation to environmental impacts. Waste rock is an byproduct of mining operations and disposed onsite which may create toxic loads on the environment through the introduction of nitrates and other destructive compounds to the ecosystem. Also, third party bagged shotcrete producer’s quarry/mine site will have environmental impacts unique to their site.

Currently, many underground mines have paste and cement rock fill (CRF) programs that transport mine waste and properly disposes it back into the mine. These programs reduce environmental impacts by reducing waste disposal facility’s footprint which, in turn, reduces any potential toxic load on the environment.

By using crushed mine waste rock as aggregate in a wet mix shotcrete produced onsite, a mining company will be able to reduce costs related to shotcreting and reduce the footprint of the waste disposal facility. Thus, creating a cost-efficient system that couples shotcreting and reduction of the waste disposal of facility footprint.

2. Background

Use of mine waste as aggregate in shotcrete has had limited study to date. In China, two studies where performed to determine if mine tailings and coal gangue could be used as a substitute to aggregate from a sand and gravel mine.

In one study, coal gangue was used as a substitute for coarse aggregate in shotcrete. The mix design for the shotcrete also combined sand that was extracted from a river and crushed coal gangue as the fine aggregate. Compressive strength testing during the study was only performed at 7-day strengths which had a range between 9.589 to 10.797 megapascals (MPa) (1,391 to 1,566 pounds per square inch (psi)) (Xiao, Meng, Ju, Feng, & He, Ze-Quan, 2020).

In 2004, Zou and Sahito experimented with the use of tailings as aggregate in shotcrete mix designs. Tailings with different water content were mixed in different batches and strength specimens where casted. Unfortunately, the maximum 28-day compressive strength achieved was just under 12 MPa (1,740 psi). This strength, they recognized, does not meet typical requirements of United States and Canada mines (Zou & Sahito, 2004) which is typically 6,000 psi at 28-days.

From past studies, use of mine waste has failed to meet the high strength requirements for ground support in underground mining.

3. Shotcrete Mix Design

3.1. Material Testing

Using crushed mine waste as aggregate in shotcrete would require material testing to determine the characteristic index properties of the waste. Because of the inconsistent nature of mine waste, the existence of deleterious materials is a concern. These deleterious materials, such as sulfides, can chemically react with the cement causing reduction of the overall strength of the shotcrete. The 6-year-old mine waste material used in this project is from an anonymous mining operation in North America. The mine waste has been historically used for construction purposes such as structural fill for support of buildings and bridges. Listed below are the ASTM International (ASTM) tests performed on the waste used in this project, and test results are presented in Appendix A.

- C29 Test Method for Bulk Density and Voids in Aggregate
- C40 Test Method for Organic Impurities in Fine Aggregates for Concrete
- C88 Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate
- C117 Test Method for Materials Finer than 75µm (No. 200) Sieve in Mineral Aggregates by Washing
- C127 Test Method for Relative Density (Specific Gravity) and Absorption of Coarse Aggregate
- C128 Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate
- C136 Test Method for Sieve Analysis of Fine Coarse Aggregates

- C535 Test Method for Resistance to Degradation of Large-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine
- D4318-17 Standard Test Methods For Liquid Limit, Plastic Limit, and Plasticity Index of Soils

For developing the mix design, ASTM C33 Standard Specification for Concrete Aggregates and ASTM C1436 Standard Specifications for Shotcrete were used as guidelines to determine if the waste rock was a competent material to be used in the shotcrete. Since the mix design will be used for ground support, American Concrete Institute’s ACI 506.5R-10 Table 4.1, recommends that the aggregate conform to Grading No. 2. See Table I for the grading specifications.

Table I: Grading No.2 from ASTM C1436

Sieve Size	Percent Passing by Mass
12.50 mm (1/2 in)	100
9.50 mm (3/8 in)	90-100
4.75 mm (No. 4)	70-85
2.36 mm (No. 8)	50-70
1.18 mm (No. 16)	35-55
600 µm (No. 30)	20-35
300 µm (No. 50)	8-20
150 µm (No. 100)	2-10

The material used in this project failed to meet the aggregate gradation specifications for three screen sizes: 3/8 inch, No. 4, and No. 100. However, the material has a past record of being used with cementitious material when used in accordance with ASTM C33 Section 6.3 (2018) and ASTM C1480 Section 4.1.3 (2007) cement rock fill applications, at the mine that provided the waste samples used in this study (DeBar, 2020).

3.2. Mix Design Process

Once all of the specifications for the shotcrete mix design were determined, the absolute volume method was used to develop the mix (Kosmatka et al, 1988). Two different water cement ratios (W/C), 0.400 and 0.425, mixes were developed to achieve a specified compressive strength (f_c) of 6,000 pounds per square inch (psi) and a required compressive strength (f_{cr}) of 7,200 psi at 28 days. The completed mix designs for the W/C's are presented in Appendix B.

3.2.1. Admixtures

Admixtures were planned for the two mix designs in order to improve performance of the shotcrete. All the additives: MasterSet DELVO (DELVO), MasterAir AE200, Glenium 3030 (3030), manufactured by BASF Corporation's Master Builders Solutions were selected because of the company's proven track record and the author's past experiences with these chemicals.

Typically, the batch plant and site of placement are separated and the length of time to travel underground to the placement site can vary significantly and be as long as an hour. Since cement begins its hardening process once water is introduced, the shotcrete's workability time begins upon commencement of the chemical reaction. To extend the workability, DELVO, a Type B and D (ASTM C494 classification of admixtures) retarder and water reducer, is used to generate a chemical reaction to prolong the set time of the cement. DELVO dosage was set at 4 fluid ounces per 100 weight of cement (fl oz/cwt) in accordance with recommendations set by the manufacturer (Master Builders Solutions, 2018). For longer set times the admixture dosage will have to be tested with a large (5 cubic yard or larger) mix to determine the required concentration.

Air entrainment is generated by the addition of MasterAir AE 200 to increase pumpability of the mix. Advantages in pumping gained from the addition of an air entrainment admixture results from the reduction of required water and fines in the mix (Chitla, Zollinger, & Macha, 1991). For trial batching, Master Builders Solutions' data sheet (2018) recommends that the dosage of the admixture should be between 0.125 to 1.5 fl oz/cwt. Both mix designs in the two laboratory batch tests had the micro air at 0.75 fl oz/cwt as a starting point but final selection of the dosage will be required after field testing at the mine site.

A high range water reducer (superplastizer), Glenium 3030, was chosen at a 4.5 fl oz/cwt in accordance to the manufacturer's recommendations for a mid-range water reducer (Master Builders Solutions, 2018). However additional dosage of approximately 14.00 to 14.57 fl oz/cwt was used to determine if there would be a negative reaction between the Glenium 3030 and the other admixtures that might cause a reduction in the performance of the shotcrete after a preliminary slump test was performed. Benefits of adding Glenium 3030 to the freshly mixed shotcrete would allow the end user to have a less viscous mix while maintaining design strengths.

3.3. Laboratory Batching

Prior to performing a field test on the mix design, a laboratory batch was mixed for the two W/C's. Results from the testing are summarized in Table II. The two fresh batches of shotcrete were tested for slump prior to dosing with the Glenium 3030.

Table II: Laboratory Batch Test Results

Sieve Size	W/C 0.400	W/C 0.425
Slump (ASTM C143)	3 ½ in	3 ¾ in
Slump – Plasticized (ASTM C143)	8 ½ in	9 ¼ in
Shotcrete Temperature (ASTM C1064)	65ºF	65ºF
Unit Weight (ASTM C138)	155.3 lb/ft^3	143.9 lb/ft^3
Air Content (ASTM C231)	5.0%	9.0%

Six test specimen cylinders were made following ASTM C192 Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory for each W/C and used for compressive strength test samples in accordance with ASTM C39 Test Method for Compressive Strength of Cylindrical Specimens in the Laboratory. Figure 1 compares the compressive strength vs. cure time for both W/C's. It is noted that the 28-day breaks were stopped at 7,560 psi due to maximum loading constraints of the break machine, while the 103-day breaks were performed on a higher rated concrete cylinder break machine. Both machines were calibrated under ASTM E4, therefore, results are comparable between the two break machines.

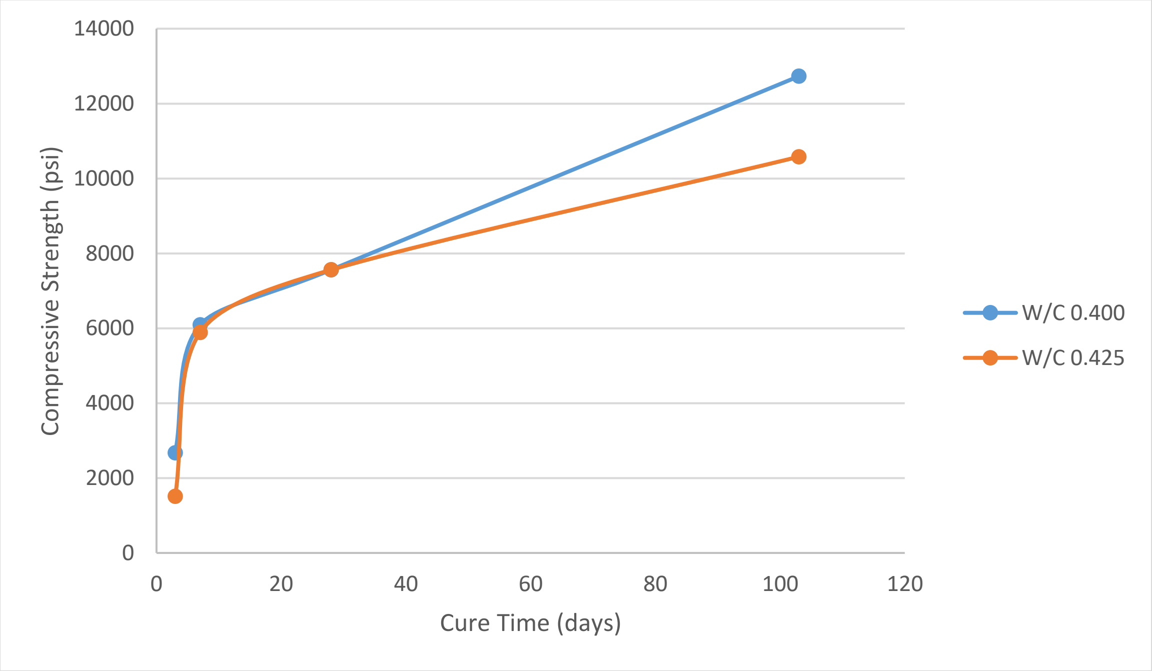

Figure 1: Compressive Strength vs. Cure Time for Laboratory Batch Cylinders

3.4. Field Batching

Following the laboratory batch mix, a field test batch mix was planned at the mine participating in this project to fine tune the mixture proportions and judge the performance of the shotcrete onsite. Due to the mine no longer having any material crushed and the tight deadline that the project was on, site testing was not available.

With no onsite testing available, field testing was planned at Montana Tech's Underground Mine Education Center (UMEC) which is located at the Orphan Boy Mine. Overhead and vertical test panels (Figure 2) were created to test shotcrete unconfined compressive strength in accordance with ASTM C1140 (ASTM 2011). The shotcrete pump available did not have all the required attachments so it was decided that a MAI International 400NT Injection Pump would be used to verify that the shotcrete could be pumped. The injection pump would not turn over to start and the remaining aggregate was wasted.

Though the shotcrete was not able to be field tested, it is of the author's opinion from years of field experience developing shotcrete mix designs that the designed mix should work. Therefore, as usual with a mix design, it falls upon the end user to verify that the shotcrete mix works with their equipment. Once a field batch can be produced, minor adjustments to proportioning of materials and admixtures should be conducted to dial in the mix to the end user's requirements.

Figure 2: Shotcrete Test Panels

4. Environmental Impacts and Cost Savings

4.1. Waste Storage Facility

With using mine waste as aggregate for the manufacture of shotcrete, the waste storage facility can be reduced in size or the life of the permitted waste storage facility can be extended. At the mine site for this evaluation, the waste storage facility has a total design capacity of 27.1 million tons with 11.6 million tons remaining as of August 31, 2020. Based on the projected 10-year planned waste generation at the site, the yearly average is 1.43 million tons.

Reduction of the waste storage facility capacity for the mine via the use of environmental shotcrete is 0.5 percent (%), or an increase of one month of usage. Looking at the last three years of shotcrete use, Table III, the running average is 4,727 cubic yards (CY) per year.

Table III: Bag Shotcrete Usage in Cubic Yards

2017	2018	2019
3,052	4,242	6,888

Using the average shotcrete usage and the proctor results in Appendix A [146.3 pounds per cubic feet (pcf)] from the aggregate used for the shotcrete, the tonnage reduced from the waste storage facility per year can be calculated as follows. Assuming that the material is compacted to the 90% requirement set forth in the geotechnical report for the facility, the mine waste would have an in-place density of 131.7 pcf. Between the two mix designs, 20.7 to 21 cubic feet (CF) per CY of waste rock will be saved from the facility with a yearly total of 6,443 to 6,537 tons. If the use of waste rock for shotcrete started at the beginning of the waste storage facility, 122,000 to 124,000 tons (0.5% of the total tonnage) would go back underground. This calculation assumes that the mine uses the yearly average waste production stated to conclude a life of waste dump (LOWD) of 19 years. Also, from the extended LOWD can be calculated using the total shotcrete aggregate tonnage and the yearly waste average resulting in an addition of one month.

4.2. Cost Estimates

By eliminating the need to ship prepackaged shotcrete to the mine, the use of mine waste shotcrete saves the mine approximately $123 to $135 per cubic yard. From the data provided by the mine, each bag costs $230 including shipping (average cost of all the shotcrete bags purchased). This equates to a savings of approximately $95 to $100 per cubic yard and $448,000 to $472,000 per year (using the average shotcrete usage). Looking at the total life of the waste dump, the cost savings would be $11.7 to $12.2 million.

Crushing and screening costs where obtained using one of InfoMine's handbooks (2019). Two single toggle jaw crushers (10 x 16 in and 12 x 36 in, minimum and maximum production rates respectively) where selected to provide a range of costs of producing a ¾-inch material. Screening of the material down to minus ½-inch was estimated using a horizontal vibrating screen (screening data is the average of the ¾ and ¼-inch screens). For An estimated breakdown of the cost estimates for producing shotcrete on site, see Appendix C. Water costs where obtained from the Butte-Silver Bow Public Works Metered Water Rates (2020). Current cement costs plus shipping for the mine's paste plant were used in the estimate. BASF Corporation provided cost estimates of bulk totes (275 gallons) for each of the admixtures used in the mix designs (Bermingham, 2020). Use of labor to batch the shotcrete in the cost estimate was not included due to the assumptions that the mine already has a batch plant operator and that the operator would be used elsewhere when not batching concrete or shotcrete.

5. Other Mine Implementation Process

For another mine to take advantage of using their waste rock, the following is a recommended guideline. The biggest issue when trying to use waste rock is potential degradation of the overall product due to chemical reactions between the waste rock and the cement. Before any mix design can be completed, at a minimum, the following ASTM tests should be performed:

- C586 Test Method for Potential Alkali Reactivity of Carbonate Rocks as Concrete Aggregates; and,
- C1260 Potential Alkali Reactivity of Aggregates (Mortar-Bar Method).

If the waste rock could possibly be detrimental to shotcrete, it is recommended that more testing be performed to determine if the rock can meet specifications. The consultation of a construction materials engineer would be required at this point in order to determine the best plan to follow.

After deeming that the waste rock is not deleterious to the overall performance of the mix design, a small stockpile is crushed for the mix design phase of the project. During crushing, samples of the material are obtained, and gradations run to dial in the crusher output to the targeted gradation. Sampling of the stockpile should be in accordance with ASTM D3665 (ASTM 2017).

Upon collecting stockpile samples, the ASTM tests mentioned in Section 3 need to be performed. If, at any time during the testing of the aggregate, the material does not meet a specification, it should be evaluated to determine if using out of specification material will be a hindrance. A failure of specification, such as gradation, does not necessarily mean a failure of the material as mentioned in ASTM C33 that if the supplier can demonstrate that the material has an “acceptable performance record in similar concrete” (ASTM 2018) then the material meets specifications.

Design of the shotcrete mixture occurs after all of the material testing has been completed and has met specifications. Consultation of a construction materials engineering firm or the hiring of a construction materials engineer for the mine site is recommended. Shotcrete, like concrete, has several variables to its design and mixing and can be easily compromised if the operator does not understand the design limitations. Using a known method for developing mix designs such as volumetric proportioning, the mixing proportions for the shotcrete can be developed.

A small preliminary test batch of the shotcrete mix design should first be performed at a laboratory to determine if the design works. This allows for further modification of the mixture proportions, if needed, and compressive strength testing to be performed.

Once all the adjustments and strength data has been collected from the laboratory test batch, the mix should be tested by the end user to determine if the shotcrete mix design will work with their equipment. During this field testing, shotcrete test panels should be made to test the strength of the sprayed mix which is the true strength that the material can obtain. Any final adjustments to the mix design can be made with the admixtures after completion of the test batch. If the field batch is able to meet the design specifications and any end user requirements, then a wet-mix shotcrete program should be developed and implemented by the end user.

Based on a bench mark of three underground mines in the western United States from 2019, the approximate average shotcrete usage was 13,237 yards. Cost and waste rock savings at these mines could be approximately 3 times as much as the case study mine.

6. Summary and Conclusions

6.1. Summary

The author collected crushed ¾-inch minus mine waste obtained from and underground mine in North America where material testing was performed to determine engineering properties. From these tests, it was determined that the gradation of the material did not meet specifications set by the American Concrete Institute's recommended gradation on a few screens but did meet all other testing requirements of ASTM. From experience of the author, it was determined that the mine waste material should be able to work as an aggregate in shotcrete.

Once the engineering properties of the mine waste aggregate were determined, two mix designs where developed by use of absolute volume method (Kosmatka et al, 1988) targeting a W/C of 0.400 and 0.425. The two laboratory trial batches were conducted and tested to verify the two designs. Strength specimens were cast, and 28-day compressive strength test results exceeded the design strengths.

From the test batches at the laboratory, onsite testing was planned, but the desired crushed material was no longer available. Testing of the mix to verify that it could be hydraulically pumped was attempted at the UMEC, but the hydraulic grout pump would not turnover due to insufficient power. Further testing of the shotcrete was not performed due to time constraints of the project.

An evaluation of the waste tonnage savings and cost estimates was performed. With a current LOWD of 19 years, the LOWD could be extended by one month due to savings of 122,000 to 124,000 tons (0.5% of the total tonnage) of waste rock going back underground. Reducing the burden of purchasing bagged shotcrete, resulted in a savings of $448,000 to $472,000 per year of shotcrete produced.

6.2. Conclusions

Overall, the use of mine waste as aggregate in shotcrete appears to be successful from a laboratory environment. Further testing of the mix would be required on site to fine tune the mix to the end user's equipment and requirements. Unfortunately, substituting mine waste for aggregate did not reduce the waste storage facility requirements at this mine site substantially, but it could reduce the time and money by one day to grade, top soil, and seed that material.

While reduction of the waste storage facility only amounted to 0.5% of the total tonnage, the production of shotcrete onsite versus having bag product delivered has an estimated savings of $448,100 to $471,800 per year. This savings increases if the amount of shotcrete increases. Based on a benchmark of three underground mines in the western Untied from 2019, the approximate average shotcrete usage was 13,237 yards. Cost and waste rock savings at these mines could be approximately 3 times as much as the case study mine.

7. Recommendations for Future Work

Since the total tonnage of the waste storage facility at the particular mine site was only reduced by 0.5%, it would be beneficial to determine what the reduction of the nitrate load would be by having the nitrate bearing fines in the shotcrete instead of the impoundment. An environmental sampling program would need to be developed to sample the areas of the storage facility to establish a baseline for the current nitrate load for the study. Further testing would be required on the nitrate in the crushed aggregate to better understand its reactions with cement and the overall percentage of nitrate. Future work be to obtain additional crushed mine waste and test it on the panels.

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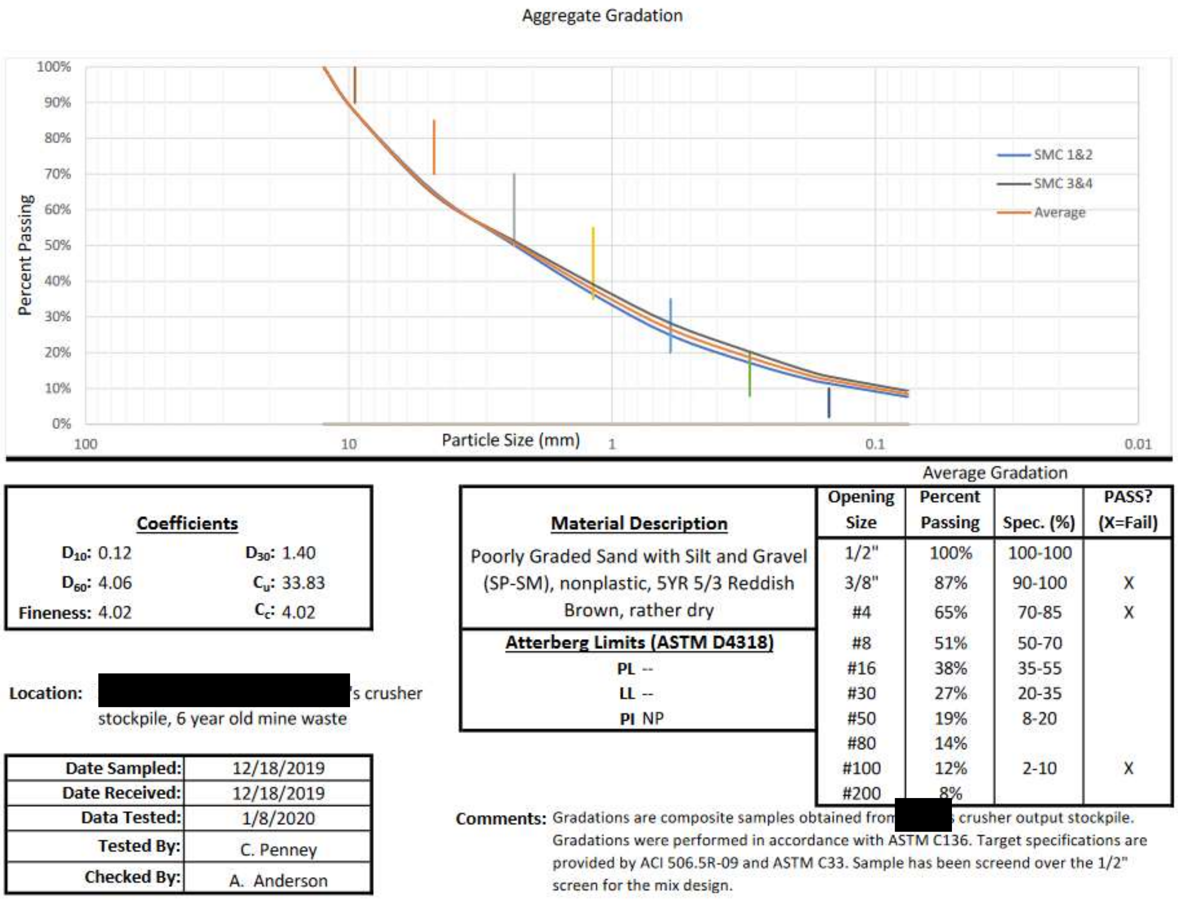
9. Appendix A: Material Testing Results



Coefficients

D_{10}:	0.12	**D_{30}:**	1.40
D_{60}:	4.06	**C_u:**	33.83
Fineness:	4.02	**C_c:**	4.02

Material Description

Poorly Graded Sand with Silt and Gravel (SP-SM), nonplastic, 5YR 5/3 Reddish Brown, rather dry

Atterberg Limits (ASTM D4318)

PL --
LL --
PI NP

Average Gradation

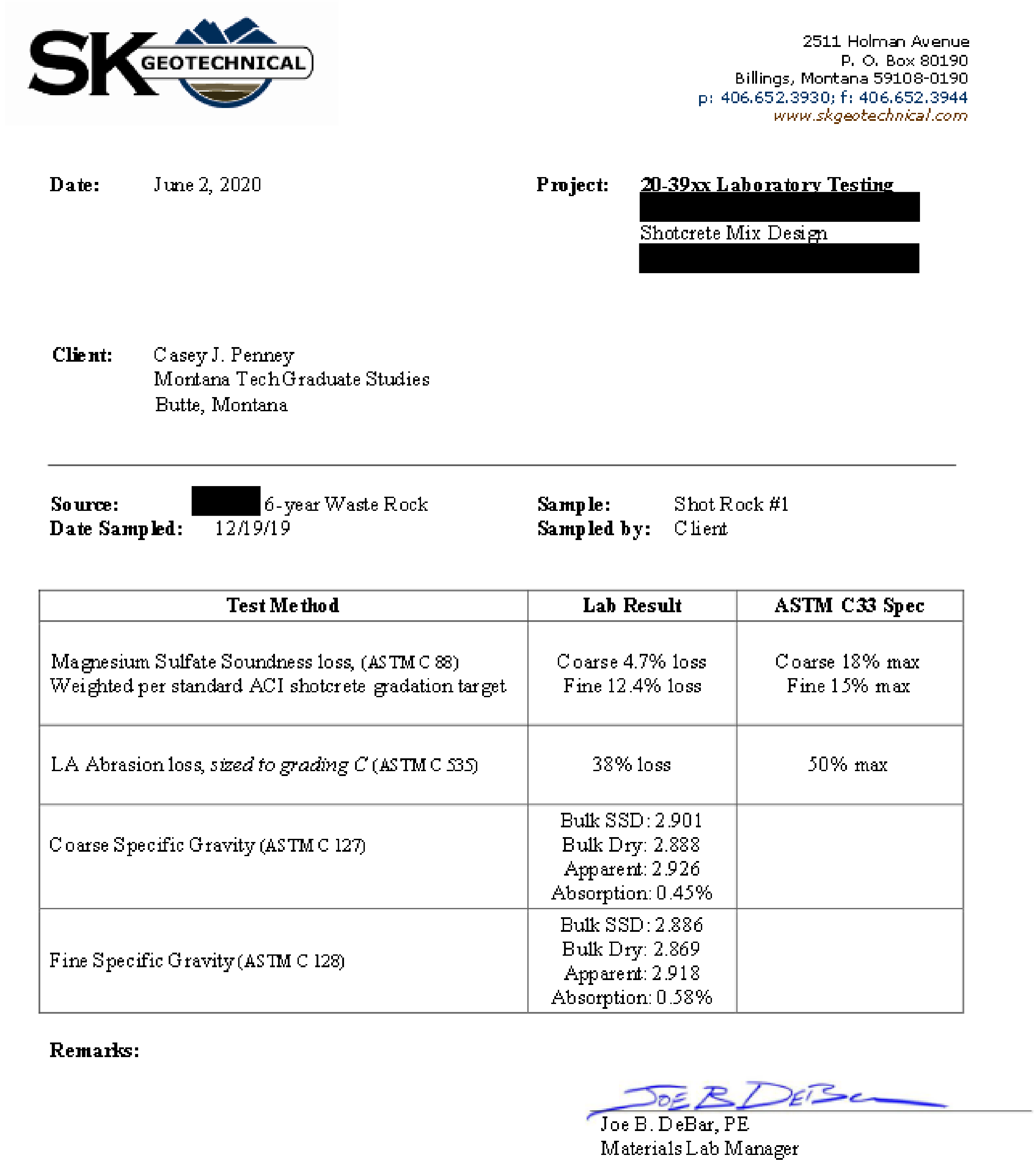
Opening Size	Percent Passing	Spec. (%)	PASS? (X=Fail)
1/2"	100%	100-100	
3/8"	87%	90-100	X
#4	65%	70-85	X
#8	51%	50-70	
#16	38%	35-55	
#30	27%	20-35	
#50	19%	8-20	
#80	14%		
#100	12%	2-10	X
#200	8%		

Location: [redacted]'s crusher stockpile, 6 year old mine waste

Date Sampled:	12/18/2019
Date Received:	12/18/2019
Data Tested:	1/8/2020
Tested By:	C. Penney
Checked By:	A. Anderson

Comments: Gradations are composite samples obtained from [redacted] crusher output stockpile. Gradations were performed in accordance with ASTM C136. Target specifications are provided by ACI 506.5R-09 and ASTM C33. Sample has been screend over the 1/2" screen for the mix design.

Figure 3: Mine Waste Gradations



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Date: June 2, 2020

Project: **20-39xx Laboratory Testing**
[redacted]
Shotcrete Mix Design
[redacted]

Client: Casey J. Penney
Montana Tech Graduate Studies
Butte, Montana

Source: [redacted] 6-year Waste Rock
Date Sampled: 12/19/19

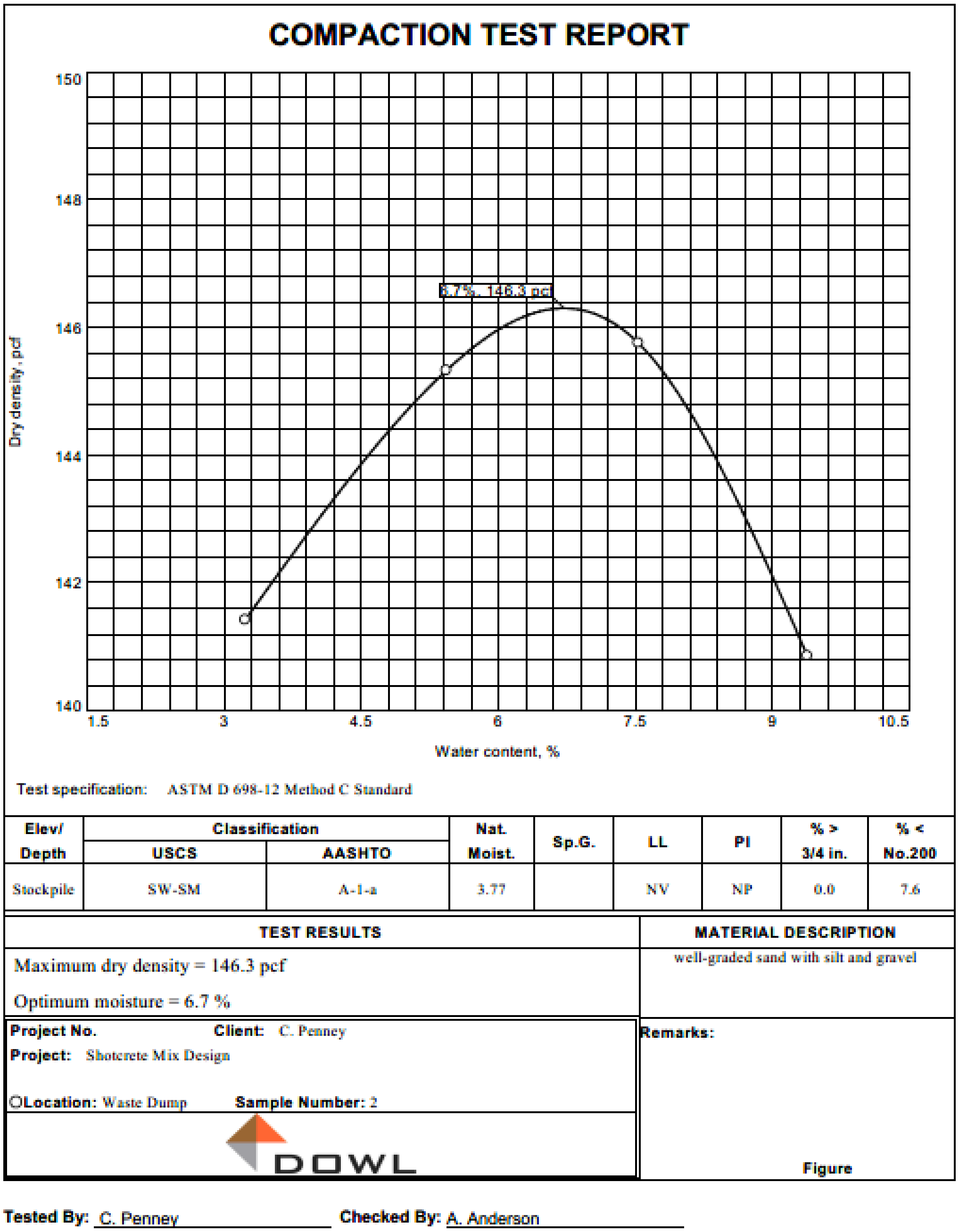
Sample: Shot Rock #1
Sampled by: Client

Test Method	Lab Result	ASTM C33 Spec
Magnesium Sulfate Soundness loss, (ASTM C 88) Weighted per standard ACI shotcrete gradation target	Coarse 4.7% loss Fine 12.4% loss	Coarse 18% max Fine 15% max
LA Abrasion loss, *sized to grading C* (ASTM C 535)	38% loss	50% max
Coarse Specific Gravity (ASTM C 127)	Bulk SSD: 2.901 Bulk Dry: 2.888 Apparent: 2.926 Absorption: 0.45%	
Fine Specific Gravity (ASTM C 128)	Bulk SSD: 2.886 Bulk Dry: 2.869 Apparent: 2.918 Absorption: 0.58%	

Remarks:

Joe B DeBar
Joe B. DeBar, PE
Materials Lab Manager

Figure 4: Mine Waste Index Testing Results



COMPACTION TEST REPORT

Test specification: ASTM D 698-12 Method C Standard

Elev/ Depth	Classification		Nat. Moist.	Sp.G.	LL	PI	% > 3/4 in.	% < No.200
	USCS	AASHTO						
Stockpile	SW-SM	A-1-a	3.77		NV	NP	0.0	7.6

TEST RESULTS

Maximum dry density = 146.3 pcf

Optimum moisture = 6.7 %

MATERIAL DESCRIPTION

well-graded sand with silt and gravel

Project No. **Client:** C. Penney

Project: Shotcrete Mix Design

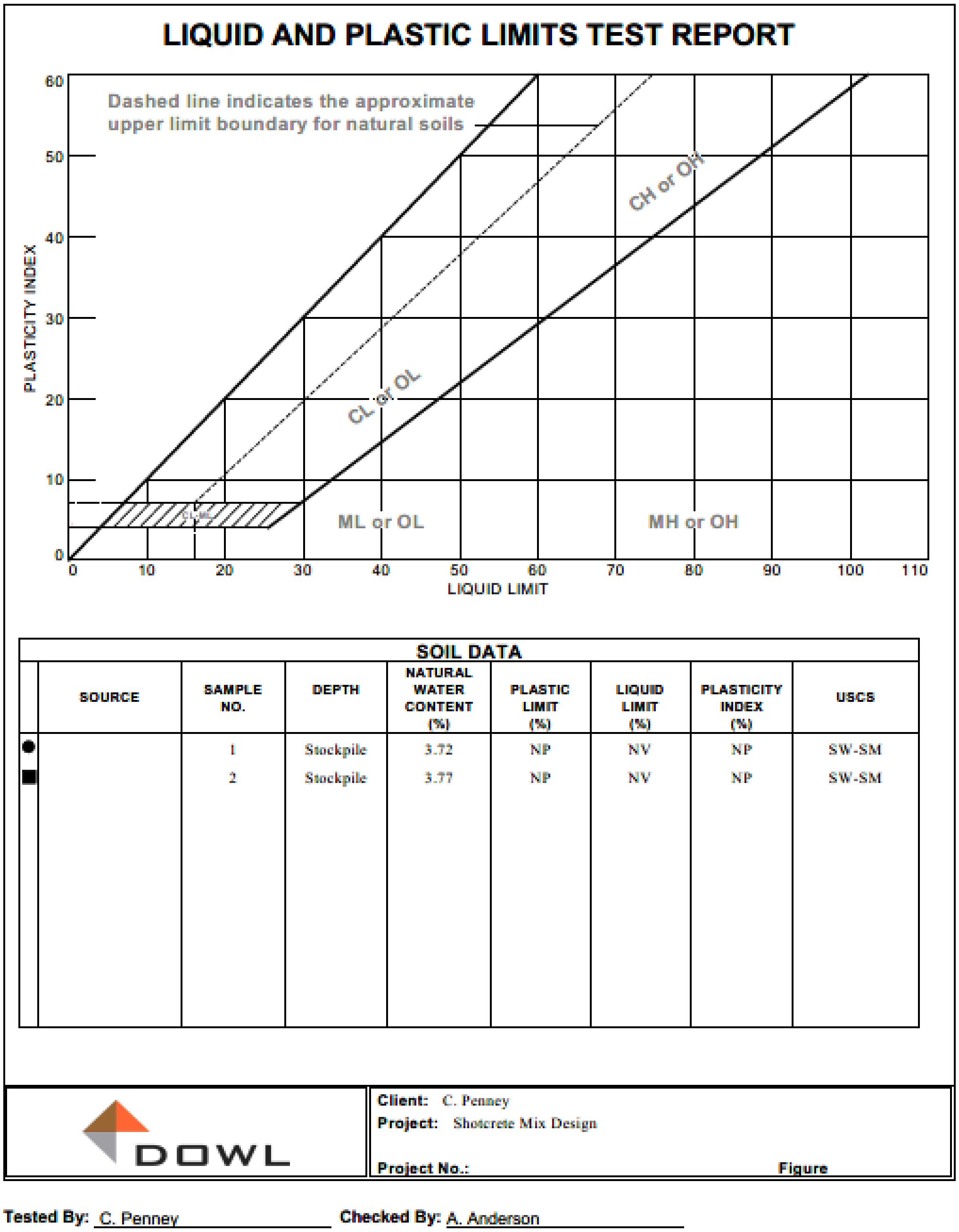
○**Location:** Waste Dump **Sample Number:** 2

Remarks:

Figure

Tested By: C. Penney **Checked By:** A. Anderson

Figure 5: Mine Waste Proctor



LIQUID AND PLASTIC LIMITS TEST REPORT

SOIL DATA

	SOURCE	SAMPLE NO.	DEPTH	NATURAL WATER CONTENT (%)	PLASTIC LIMIT (%)	LIQUID LIMIT (%)	PLASTICITY INDEX (%)	USCS
●		1	Stockpile	3.72	NP	NV	NP	SW-SM
■		2	Stockpile	3.77	NP	NV	NP	SW-SM

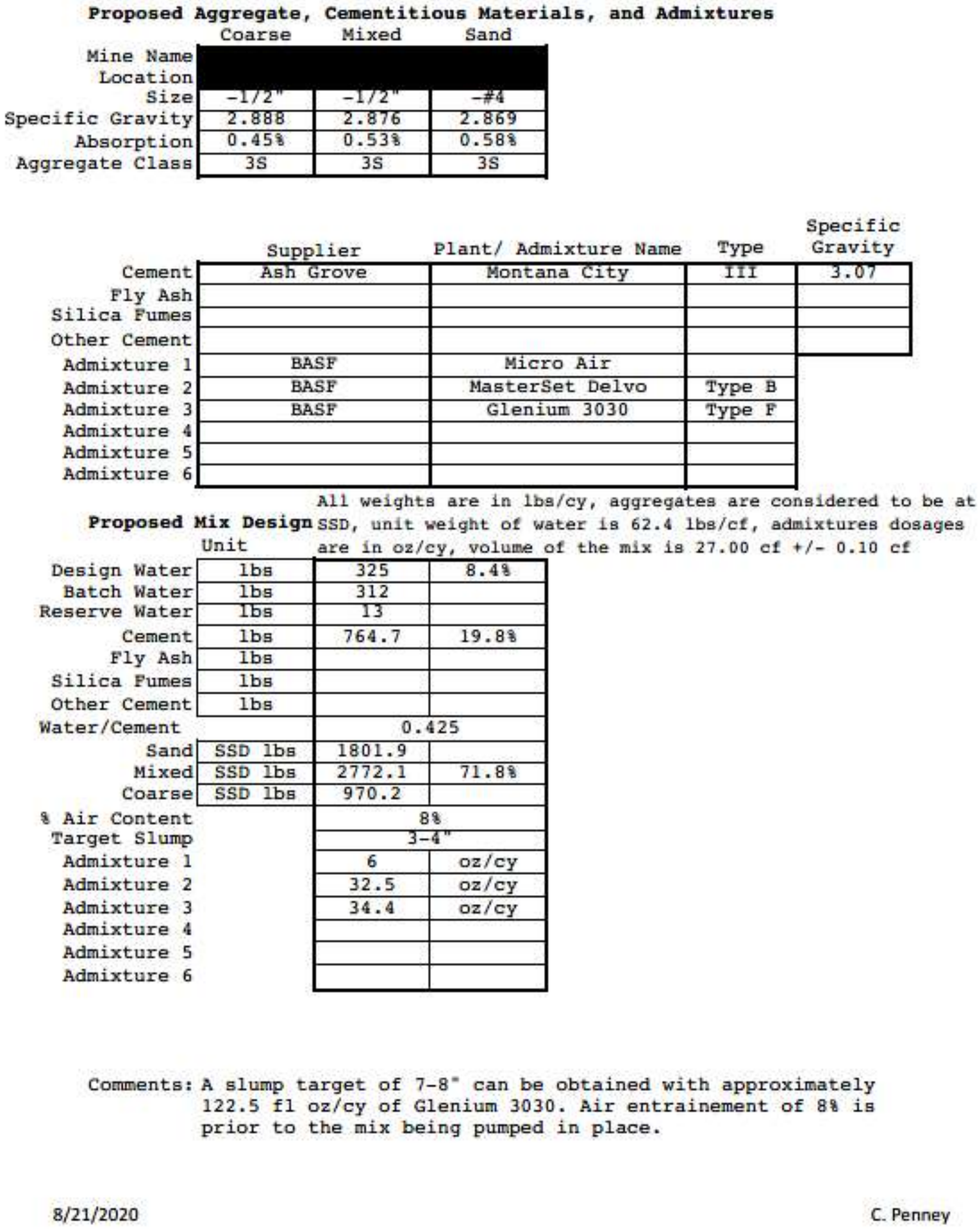
DOWL

Client: C. Penney
Project: Shotcrete Mix Design
Project No.: **Figure**

Tested By: C. Penney **Checked By:** A. Anderson

Figure 6: Mine Waste Atterberg Limits

10. Appendix B: Mix Designs



Proposed Aggregate, Cementitious Materials, and Admixtures

	Coarse	Mixed	Sand
Mine Name	[redacted]	[redacted]	[redacted]
Location	[redacted]	[redacted]	[redacted]
Size	-1/2"	-1/2"	-#4
Specific Gravity	2.888	2.876	2.869
Absorption	0.45%	0.53%	0.58%
Aggregate Class	3S	3S	3S

	Supplier	Plant/ Admixture Name	Type	Specific Gravity
Cement	Ash Grove	Montana City	III	3.07
Fly Ash				
Silica Fumes				
Other Cement				
Admixture 1	BASF	Micro Air		
Admixture 2	BASF	MasterSet Delvo	Type B	
Admixture 3	BASF	Glenium 3030	Type F	
Admixture 4				
Admixture 5				
Admixture 6				

Proposed Mix Design

All weights are in lbs/cy, aggregates are considered to be at SSD, unit weight of water is 62.4 lbs/cf, admixtures dosages are in oz/cy, volume of the mix is 27.00 cf +/- 0.10 cf

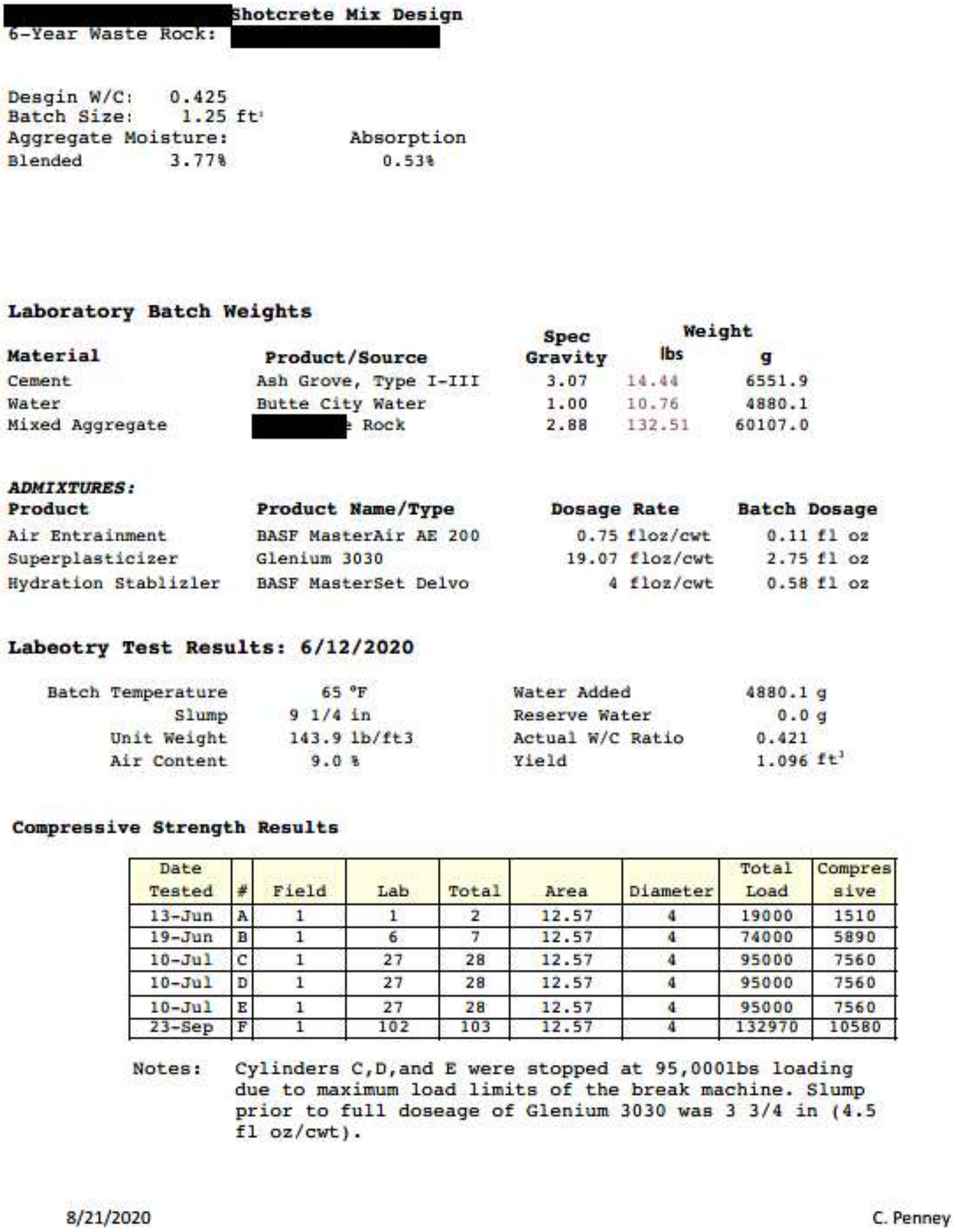
	Unit		
Design Water	lbs	325	8.4%
Batch Water	lbs	312	
Reserve Water	lbs	13	
Cement	lbs	764.7	19.8%
Fly Ash	lbs		
Silica Fumes	lbs		
Other Cement	lbs		
Water/Cement		0.425	
Sand	SSD lbs	1801.9	
Mixed	SSD lbs	2772.1	71.8%
Coarse	SSD lbs	970.2	
% Air Content		8%	
Target Slump		3-4"	
Admixture 1		6	oz/cy
Admixture 2		32.5	oz/cy
Admixture 3		34.4	oz/cy
Admixture 4			
Admixture 5			
Admixture 6			

Comments: A slump target of 7-8" can be obtained with approximately 122.5 fl oz/cy of Glenium 3030. Air entrainement of 8% is prior to the mix being pumped in place.

8/21/2020

C. Penney

Figure 7: 0.425 W/C Mix Design



[redacted] **Shotcrete Mix Design**
6-Year Waste Rock: [redacted]

Desgin W/C: 0.425
Batch Size: 1.25 ft^3
Aggregate Moisture: Absorption
Blended 3.77% 0.53%

Laboratory Batch Weights

Material	Product/Source	Spec Gravity	Weight lbs	Weight g
Cement	Ash Grove, Type I-III	3.07	14.44	6551.9
Water	Butte City Water	1.00	10.76	4880.1
Mixed Aggregate	[redacted] Rock	2.88	132.51	60107.0

ADMIXTURES:

Product	Product Name/Type	Dosage Rate	Batch Dosage
Air Entrainment	BASF MasterAir AE 200	0.75 floz/cwt	0.11 fl oz
Superplasticizer	Glenium 3030	19.07 floz/cwt	2.75 fl oz
Hydration Stablizler	BASF MasterSet Delvo	4 floz/cwt	0.58 fl oz

Labeotry Test Results: 6/12/2020

Batch Temperature	65 °F	Water Added	4880.1 g
Slump	9 1/4 in	Reserve Water	0.0 g
Unit Weight	143.9 lb/ft3	Actual W/C Ratio	0.421
Air Content	9.0 %	Yield	1.096 ft^3

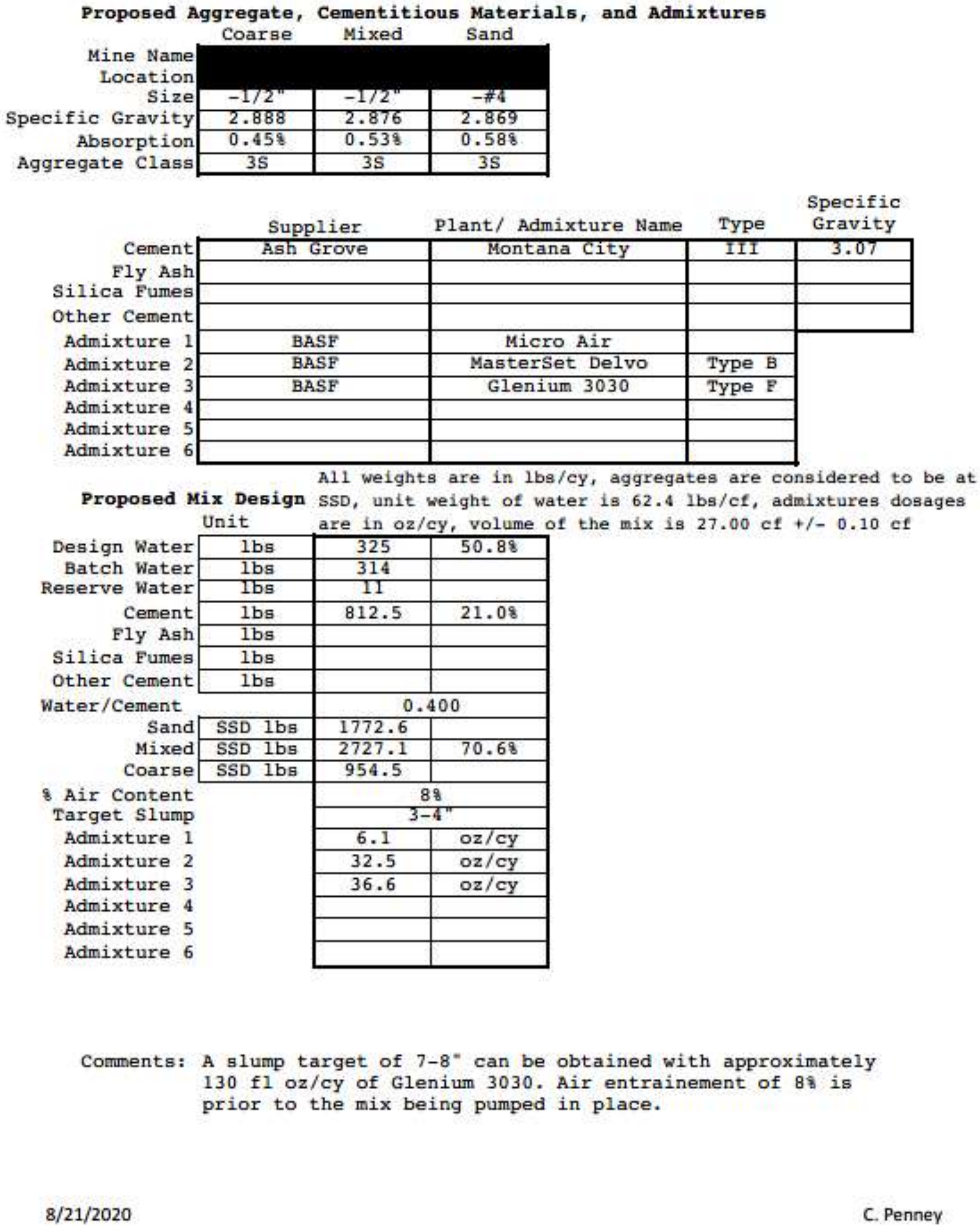
Compressive Strength Results

Date Tested	#	Field	Lab	Total	Area	Diameter	Total Load	Compressive
13-Jun	A	1	1	2	12.57	4	19000	1510
19-Jun	B	1	6	7	12.57	4	74000	5890
10-Jul	C	1	27	28	12.57	4	95000	7560
10-Jul	D	1	27	28	12.57	4	95000	7560
10-Jul	E	1	27	28	12.57	4	95000	7560
23-Sep	F	1	102	103	12.57	4	132970	10580

Notes: Cylinders C,D,and E were stopped at 95,000lbs loading due to maximum load limits of the break machine. Slump prior to full doseage of Glenium 3030 was 3 3/4 in (4.5 fl oz/cwt).

8/21/2020 C. Penney

Figure 8: 0.425 W/C Laboratory Batch Results



Proposed Aggregate, Cementitious Materials, and Admixtures

	Coarse	Mixed	Sand
Mine Name	[redacted]	[redacted]	[redacted]
Location	[redacted]	[redacted]	[redacted]
Size	-1/2"	-1/2"	-#4
Specific Gravity	2.888	2.876	2.869
Absorption	0.45%	0.53%	0.58%
Aggregate Class	3S	3S	3S

	Supplier	Plant/ Admixture Name	Type	Specific Gravity
Cement	Ash Grove	Montana City	III	3.07
Fly Ash				
Silica Fumes				
Other Cement				
Admixture 1	BASF	Micro Air		
Admixture 2	BASF	MasterSet Delvo	Type B	
Admixture 3	BASF	Glenium 3030	Type F	
Admixture 4				
Admixture 5				
Admixture 6				

Proposed Mix Design

All weights are in lbs/cy, aggregates are considered to be at SSD, unit weight of water is 62.4 lbs/cf, admixtures dosages are in oz/cy, volume of the mix is 27.00 cf +/- 0.10 cf

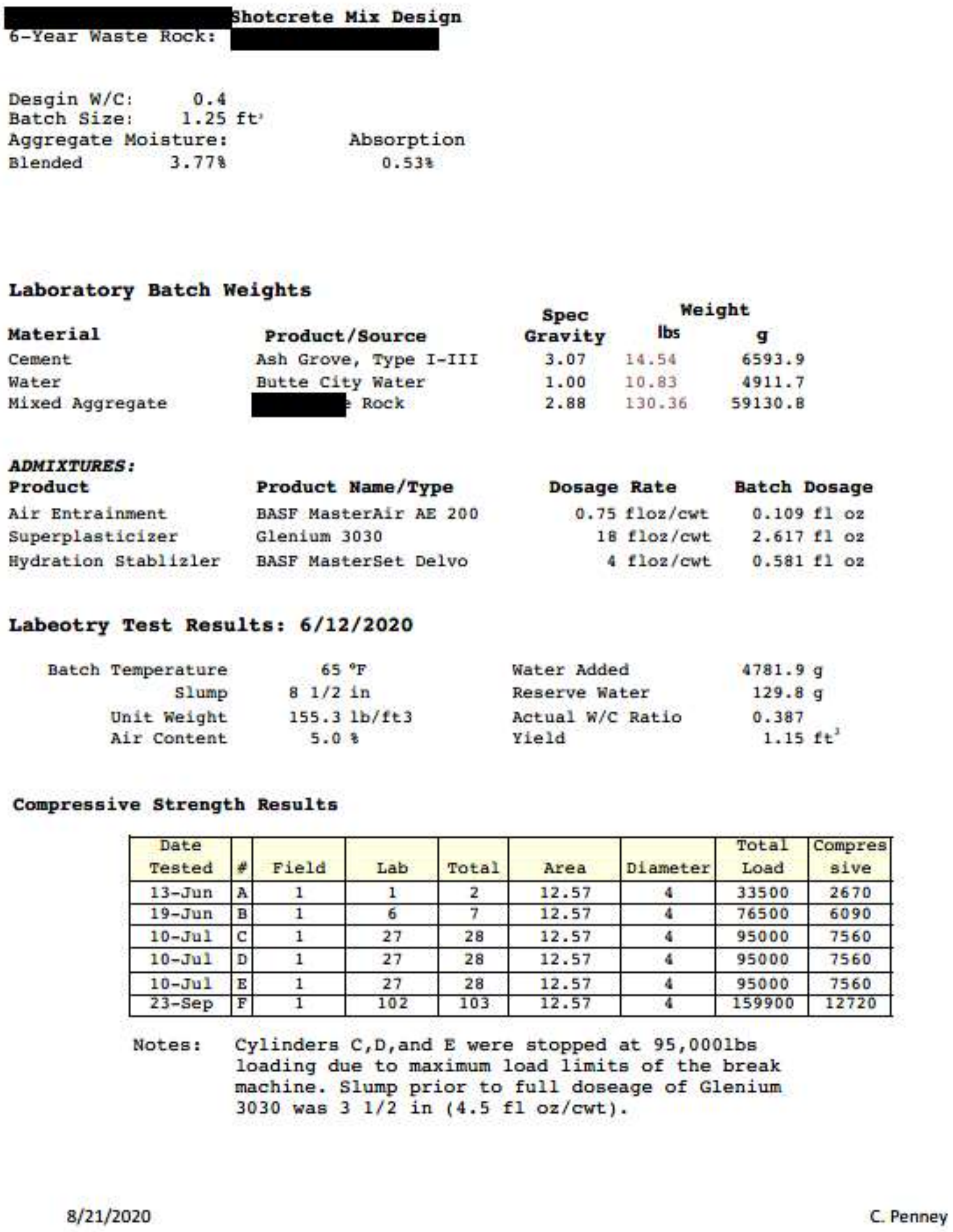
	Unit		
Design Water	lbs	325	50.8%
Batch Water	lbs	314	
Reserve Water	lbs	11	
Cement	lbs	812.5	21.0%
Fly Ash	lbs		
Silica Fumes	lbs		
Other Cement	lbs		
Water/Cement		0.400	
Sand	SSD lbs	1772.6	
Mixed	SSD lbs	2727.1	70.6%
Coarse	SSD lbs	954.5	
% Air Content		8%	
Target Slump		3-4"	
Admixture 1		6.1	oz/cy
Admixture 2		32.5	oz/cy
Admixture 3		36.6	oz/cy
Admixture 4			
Admixture 5			
Admixture 6			

Comments: A slump target of 7-8" can be obtained with approximately 130 fl oz/cy of Glenium 3030. Air entrainement of 8% is prior to the mix being pumped in place.

8/21/2020

C. Penney

Figure 9: 0.400 W/C Mix Design



[redacted]Shotcrete Mix Design
6-Year Waste Rock: [redacted]

Desgin W/C: 0.4
Batch Size: 1.25 ft^3

Aggregate Moisture:		Absorption
Blended	3.77%	0.53%

Laboratory Batch Weights

Material	**Product/Source**	**Spec Gravity**	**Weight** lbs	g
Cement	Ash Grove, Type I-III	3.07	14.54	6593.9
Water	Butte City Water	1.00	10.83	4911.7
Mixed Aggregate	[redacted] Rock	2.88	130.36	59130.8

ADMIXTURES:

Product	**Product Name/Type**	**Dosage Rate**	**Batch Dosage**
Air Entrainment	BASF MasterAir AE 200	0.75 floz/cwt	0.109 fl oz
Superplasticizer	Glenium 3030	18 floz/cwt	2.617 fl oz
Hydration Stablizler	BASF MasterSet Delvo	4 floz/cwt	0.581 fl oz

Labeotry Test Results: 6/12/2020

Batch Temperature	65 °F	Water Added	4781.9 g
Slump	8 1/2 in	Reserve Water	129.8 g
Unit Weight	155.3 lb/ft3	Actual W/C Ratio	0.387
Air Content	5.0 %	Yield	1.15 ft^3

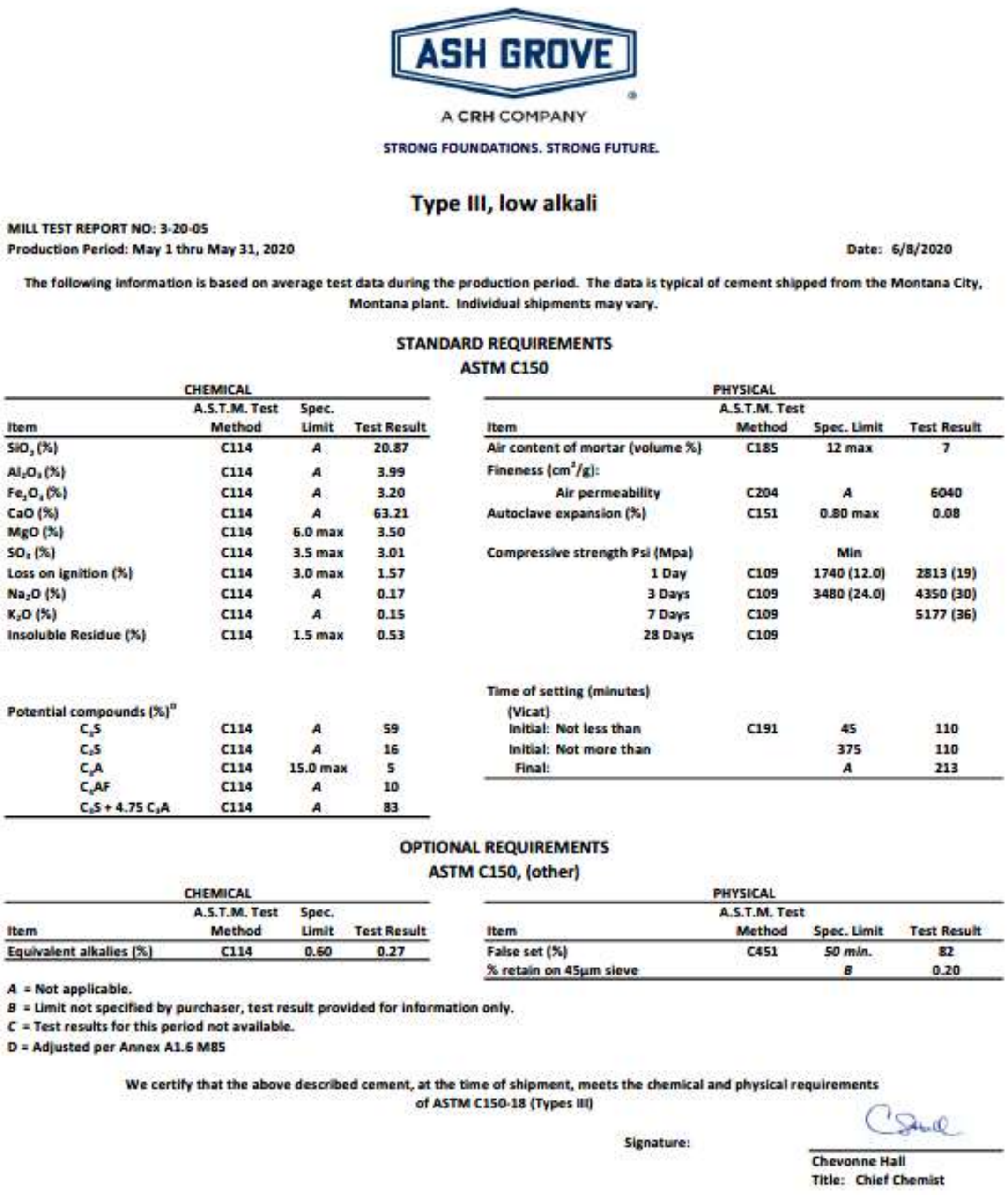
Compressive Strength Results

Date Tested	#	Field	Lab	Total	Area	Diameter	Total Load	Compressive
13-Jun	A	1	1	2	12.57	4	33500	2670
19-Jun	B	1	6	7	12.57	4	76500	6090
10-Jul	C	1	27	28	12.57	4	95000	7560
10-Jul	D	1	27	28	12.57	4	95000	7560
10-Jul	E	1	27	28	12.57	4	95000	7560
23-Sep	F	1	102	103	12.57	4	159900	12720

Notes: Cylinders C,D,and E were stopped at 95,000lbs loading due to maximum load limits of the break machine. Slump prior to full doseage of Glenium 3030 was 3 1/2 in (4.5 fl oz/cwt).

8/21/2020 C. Penney

Figure 10: 0.400 W/C Laboratory Batch Results



ASH GROVE

A CRH COMPANY

STRONG FOUNDATIONS. STRONG FUTURE.

Type III, low alkali

MILL TEST REPORT NO: 3-20-05
Production Period: May 1 thru May 31, 2020

Date: 6/8/2020

The following information is based on average test data during the production period. The data is typical of cement shipped from the Montana City, Montana plant. Individual shipments may vary.

STANDARD REQUIREMENTS
ASTM C150

CHEMICAL

Item	A.S.T.M. Test Method	Spec. Limit	Test Result
SiO_2 (%)	C114	*A*	20.87
Al_2O_3 (%)	C114	*A*	3.99
Fe_2O_3 (%)	C114	*A*	3.20
CaO (%)	C114	*A*	63.21
MgO (%)	C114	6.0 max	3.50
SO_3 (%)	C114	3.5 max	3.01
Loss on ignition (%)	C114	3.0 max	1.57
Na_2O (%)	C114	*A*	0.17
K_2O (%)	C114	*A*	0.15
Insoluble Residue (%)	C114	1.5 max	0.53
Potential compounds (%)^D			
C_3S	C114	*A*	59
C_2S	C114	*A*	16
C_3A	C114	15.0 max	5
C_4AF	C114	*A*	10
$C_3S + 4.75\ C_3A$	C114	*A*	83

PHYSICAL

Item	A.S.T.M. Test Method	Spec. Limit	Test Result
Air content of mortar (volume %)	C185	12 max	7
Fineness (cm^2/g):			
Air permeability	C204	*A*	6040
Autoclave expansion (%)	C151	0.80 max	0.08
Compressive strength Psi (Mpa)		Min	
1 Day	C109	1740 (12.0)	2813 (19)
3 Days	C109	3480 (24.0)	4350 (30)
7 Days	C109		5177 (36)
28 Days	C109		
Time of setting (minutes) (Vicat)			
Initial: Not less than	C191	45	110
Initial: Not more than		375	110
Final:		*A*	213

OPTIONAL REQUIREMENTS
ASTM C150, (other)

CHEMICAL

Item	A.S.T.M. Test Method	Spec. Limit	Test Result
Equivalent alkalies (%)	C114	0.60	0.27

PHYSICAL

Item	A.S.T.M. Test Method	Spec. Limit	Test Result
False set (%)	C451	*50 min.*	82
% retain on 45μm sieve		*B*	0.20

A = Not applicable.
B = Limit not specified by purchaser, test result provided for information only.
C = Test results for this period not available.
D = Adjusted per Annex A1.6 M85

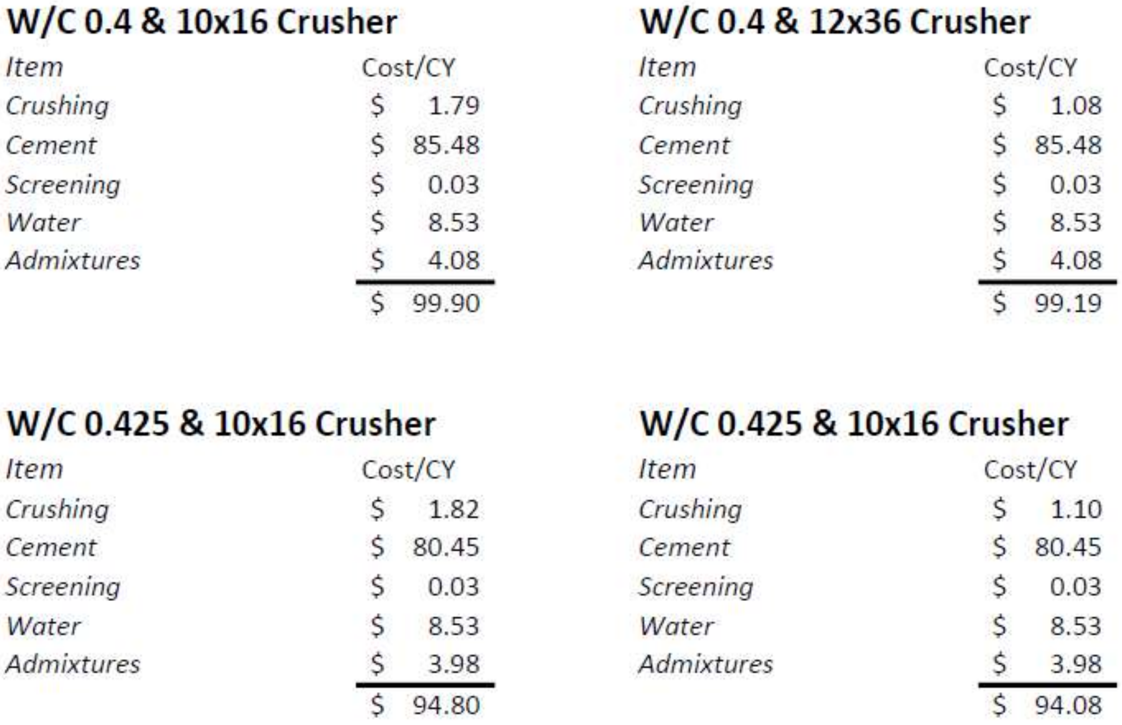
We certify that the above described cement, at the time of shipment, meets the chemical and physical requirements of ASTM C150-18 (Types III)

Signature:

Chevonne Hall
Title: Chief Chemist

Figure 11: Cement Specifications

11. Appendix C: Cost Estimates



W/C 0.4 & 10x16 Crusher

Item	Cost/CY
Crushing	$ 1.79
Cement	$ 85.48
Screening	$ 0.03
Water	$ 8.53
Admixtures	$ 4.08
	$ 99.90

W/C 0.4 & 12x36 Crusher

Item	Cost/CY
Crushing	$ 1.08
Cement	$ 85.48
Screening	$ 0.03
Water	$ 8.53
Admixtures	$ 4.08
	$ 99.19

W/C 0.425 & 10x16 Crusher

Item	Cost/CY
Crushing	$ 1.82
Cement	$ 80.45
Screening	$ 0.03
Water	$ 8.53
Admixtures	$ 3.98
	$ 94.80

W/C 0.425 & 10x16 Crusher

Item	Cost/CY
Crushing	$ 1.10
Cement	$ 80.45
Screening	$ 0.03
Water	$ 8.53
Admixtures	$ 3.98
	$ 94.08

Figure 12: Wet Mix Shotcrete Cost Estimates

SIGNATURE PAGE

This is to certify that the thesis prepared by Casey Penney entitled “Use of Shotcrete Made with Mine Waste to Reduce Costs and Environmental Impacts of Waste Disposal” has been examined and approved for acceptance by the Department of Mining Engineering, Montana Technological University, on this 5th day of November, 2020.

Paul W. Conrad
Paul Conrad, PhD, Professor
Department of Mining Engineering
Chair, Examination Committee

Scott Rosent
Scott Rosenthal, Associate Professor and Department Head
Department of Mining Engineering
Member, Examination Committee

M. Sadeghi
Mohammad Sadeghi, PhD, Assistant Professor
Department of Geological Engineering
Member, Examination Committee