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ADDITIVES FOR STRENGTHENING BACKFILL MATERIALS IN STEEP COAL SEAM MINING

OFR 86-62

Contract J0245006

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FOREWARD

This report was prepared by J. F. T. Agapito & Associates, Inc. under USBM Contract No. J0245006. The contract was initiated under the Bureau of Mines program. It was administered under the technical direction of the Spokane Mining Research Center, with Ms. Barbee Scheibner acting as the Technical Project Officer. Mr. Larry Rock was the contract administrator for the Bureau of Mines. This report is a summary of the work recently completed as a part of the contract for the period of August, 1984 to June, 1985. This report was submitted by the authors in September, 1985.

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1.0 INTRODUCTION

1.1 PROJECT SCOPE

This report presents the results of a laboratory study conducted by J. F. T. Agapito & Associates, Inc. under United States Bureau of Mines Contract No. J0245006 entitled "Additives for Strengthening Backfill Waste Materials in Steep Coal Seam Mining."

Steeply dipping coal seams in King County, Washington are currently mined from the surface, leaving a significant portion of the total resource unrecovered. Underground mining using conventional techniques similar to shrinkage stoping has been attempted in the past, but found to be uneconomical. Interest in exploiting these steeply dipping seams remains high because the close proximity to the Seattle urban area eliminates expensive rail shipment. Mining costs could, therefore, be higher than in flat lying seams, and possibly be cost competitive with coal produced in Wyoming, Utah or Colorado.

The United States Bureau of Mines (USBM) is investigating the use of underhand cut and fill mining techniques for steeply dipping coal seams at the Palmer Coke and Coal Company's Black Diamond, Washington operations. The work reported here is an evaluation of the use of regionally available pozzolanic materials to strengthen the backfill materials. Sources of the pozzolans were identified by the USBM. The objective of the project was to develop a backfill mixture using aggregate materials from the mine site with the following design specifications:

- o long-term, unconfined compressive strength of backfill - 200 psi;
- o viscosity of backfill mixture - 60 marsh seconds;

- o minimize bleeding or segregation of cement from backfill mixture;
- o setting time - 24 hours;
- o solids to water ratio as high as possible; and
- o pozzolan to cement or kiln dust ratio as high as possible.

1.2 PROJECT TASKS

In order to meet the objectives, the project was divided into seven tasks:

- o Task 1 - Obtain and ship bulk samples of fill material, including a coal mine waste, an alluvial sand and a decomposed sandstone from the specified mine site to the laboratory facility.
- o Task 2 - Obtain samples of regionally available sources of pozzolanic material, including a Class F pozzolan, a Class C pozzolan, a ground smelter slag, and a cement plant kiln dust.
- o Task 3 - Conduct preliminary laboratory and field testing to characterize the physical and mineralogical properties of backfill aggregate materials.
- o Task 4 - Conduct preliminary tests of backfill mixtures to measure rheological properties and assess the reactivity of various pozzolanic materials with cement or kiln dust mixtures by measuring the unconfined compressive strength.
- o Task 5 - Perform a statistical experiment to establish the variance in strength in replicated tests of backfill mixtures.

- o Task 6 - Design an optimum mixture to achieve the USBM design specifications using the results of Tasks 4 and 5, and measure the triaxial and uniaxial compressive strength after 28, 60 and 90 days of curing.
- o Task 7 - Prepare a final report outlining the experimental work performed and discussing the results of the testing program.

1.3 REPORT CONTENT

This report is divided into seven sections. Section 1.0 contains the introduction, program objectives and tasks. Section 2.0 is an executive summary with the conclusions and recommendations resulting from this investigation. Section 3.0 describes the test materials and their properties. Sample preparation and laboratory testing procedures are discussed in Section 4.0, and results of the preliminary testing are presented in Section 5.0. Section 6.0 contains the results of the replicated test matrix. Properties of the optimum backfill mixture are discussed in Section 7.0.

Test data are presented in Appendices A through D.

1.4 ACKNOWLEDGEMENTS

Technical conduct of this project was by J. F. T. Agapito & Associates, Inc., with Mr. J. R. Aggson responsible for overall management of the effort. Mr. C. E. Brechtel acted as project technical advisor, and D. A. Thies was the project engineer

responsible for conduct of the the testing program. Laboratory support was provided by Western Colorado Testing, Inc.

The authors would like to thank Ms. Barbee Scheibner, Technical Project Officer, U. S. Bureau of Mines, for collaboration on technical aspects of the project, and Mr. William Kombal of the Palmer Coke and Coal Company for cooperation during the procurement of the aggregate materials. We would also like to thank Pozzolanic International for supplying the Class F and Class C pozzolans, and specifically, Mr. Dennis Augustine for supplying technical details on the pozzolans.

2.0 EXECUTIVE SUMMARY

2.1 SUMMARY

The general objective of this project was the investigation of the use of pozzolanic materials in hydraulic backfill with specific application to the mining of steeply pitching coal seams at the Palmer Coke and Coal Company's (PCCC) operations in Black Diamond, Washington. Three potential backfill aggregates were identified by the USBM and PCCC at the Black Diamond property:

- o an alluvial sand;
- o a decomposed sandstone; and
- o coal wash plant waste.

The backfill mixture was to include the minimum possible Portland cement and regionally available pozzolan additives. Local sources of pozzolans were identified by the USBM and included:

- o a Class F fly ash;
- o a Class C fly ash;
- o a cement plant kiln dust; and
- o a smelter slag.

Bulk samples of the backfill aggregates, pozzolans and Portland cement were collected and shipped to the laboratory testing facility in Grand Junction, Colorado.

The characterization of material properties included measurement of in-situ density and moisture content, particle size gradations and chemical constituents. The backfill aggregates were unsuitable for direct use in a hydraulically transported backfill because they contained some large particles. The aggregates were screened to separate all -8 mesh (less than 0.094 in. diameter) particles for

use in the backfill. The +8 mesh (greater than 0.094 in. diameter) fraction of the coal wash plant waste was rewashed to separate the remaining coal materials (specific gravity less than 2.1) from the coal measure rock (specific gravity greater than 2.1). Approximately 68 percent of the +8 mesh fraction contained enough coal material to have a specific gravity less than 2.1. The remaining 32 percent was crushed and rescreened, and the -8 mesh material blended with the original -8 mesh fraction.

Reactivity of the different pozzolans with different aggregates was investigated by compressive strength tests after 28, 60 and 90 days of curing. Data scatter in these tests was large, but the test results were sufficient to establish general trends of behavior. The Class C pozzolan, Class F pozzolan and kiln dust all exhibited higher strength than the ground smelter slag in similar proportions. The Class C fly ash produced the highest strength backfill, but had a very fast setting time. The Class F fly ash and kiln dust had the next highest strength, with smelter slag the lowest strength. All pozzolans improved the backfill pumpability with increasing pozzolan content. Increasing pozzolan content resulted in reduced viscosity, reduced bleeding of cement/pozzolan, reduced separation of fluids-solids and increased the consistency of the mixture.

The alluvial sand produced the strongest backfill, followed by the decomposed sandstone and then the coal wash plant waste. Mixtures of 50 percent coal wash plant waste with either alluvial sand or decomposed sandstone had strengths similar to the wash plant waste alone.

A replicated testing matrix was developed for the pozzolan materials and alluvial sand to measure the correlation of pozzolan content with compressive strength and to estimate the reproducibility of the strength data. These tests indicated that changes of Portland cement content had a much larger effect on compressive strength than changes in pozzolan content. The majority of data variance was correlated with changes in active constituents (cement/pozzolan/water). Random error was a small component of the data variance.

An optimum backfill mixture was designed based upon the results of the preliminary testing, materials characterization and materials availability. A mixture of 84 percent alluvial sand: 10 percent Class F pozzolan: 6 percent cement was tested at 20, 23 and 26 percent water/80, 77, 74 percent solids. Uniaxial compressive strength and triaxial compressive strength was measured at 28, 60 and 90 days. The uniaxial compressive strength was less than the design strength of 200 psi. This was unexpected since previous tests of an identical mixture had reached the design strength. Linear least-square fits of triaxial compressive strength versus confining pressure predicted that the mixtures containing 23 and 20 percent water would reach the design strength after 90 days of cure. Viscosity of the optimum mixture with 23 percent water was 53 marsh seconds or very close to the design specification.

2.2 CONCLUSIONS

Primary conclusions developed from the work conducted in this project include:

- o The addition of pozzolans to backfill mixtures produced increases in long-term compressive strength and in mixture pumpability.
- o Increasing Portland cement content produced between a 2 to 5 times greater increase in compressive strength per unit increase in cement content than the addition of pozzolans.
- o Alluvial sand produced the highest strength backfill.
- o Alluvial sand is the optimum backfill aggregate material at the Black Diamond site. The total resource is much greater than either decomposed sandstone or coal wash plant waste. The alluvial sand requires minimal materials handling, with as much as 81 percent of the material going directly into the backfill after the initial screening.
- o Use of the decomposed sandstone would require both crushing and screening for use as a backfill aggregate.
- o Coal wash plant waste produced much weaker backfill than either the alluvial sand or decomposed sandstone. Blends of 50 percent coal wash plant waste with either alluvial sand or decomposed sandstone had strengths similar to the coal waste alone.
- o Based upon size gradation and coal separation analysis, only approximately 56 percent of the coal wash plant waste would be used as backfill. This would require rewashing to recover the coal, crushing, and screening the material.
- o Test results indicated that Class F - Product II and Class F - Plant Run pozzolans produced similar strengths when mixed with alluvial sand and six percent cement.

- o A mixture of 84 percent alluvial sand: 10 percent Class F pozzolan: 6 percent Portland cement at 23 percent water was identified as the optimum backfill mixture.
- o Viscosity of the optimum mixture at 23 percent water/77 percent solids was 53 Marsh seconds.
- o Uniaxial compressive strength of the optimum mixture was variable. Preliminary testing of the optimum mixture indicated that the 90 day strength would exceed 200 psi. A second set of tests at different water contents indicated that the strength at 23 percent water and 26 percent water would be less than 200 psi after 90 days of cure.
- o Linear least square curve fits of triaxial compressive strength at 50, 100 and 200 psi confining pressure predict uniaxial compressive strengths will exceed 200 psi after 90 days of cure for 20 and 23 percent water.

2.3 RECOMMENDATIONS

Additional testing of the optimum mixture is recommended as part of the final design of the backfill system. The disparity in uniaxial compressive strength of the final mixture cannot be explained, but might be due to different sample sizes or to irregularities in the sample preparation or curing procedures that went undetected. These tests could be done as part of the design of the pumping system when full size tests of the pumpability of the mixture will be required. A small increase in cement content will be the most cost efficient way of increasing the strength.

The coal wash plant waste was eliminated from the optimum backfill mix because of its limited quantity and the large handling

requirements. When used in large proportions, it reduced the backfill strength. Testing mixtures with smaller proportions of coal wash plant waste (10 - 20 percent of backfill aggregate weight) is recommended if mining operations proceed and if reprocessing of the waste is considered economically viable. Disposal of the coal waste in backfill may be an attractive alternative to surface disposal; however, its use may require increasing cement/pozzolan content to preserve the backfill strength.

3.0 MATERIAL CHARACTERIZATION

The backfill materials were composed of bulk material available at or near the Black Diamond Mine. The aggregate candidates consisted of mine wash plant waste, alluvial sands and decomposed sandstone. Cementing agents and additives include commercial portland cement, kiln dust, Class C pozzolan, Class F pozzolan and smelter slag.

3.1 AGGREGATE MATERIALS

Figure 3.1 shows the location of the Black Diamond Mine. J. F. T. Agapito & Associates, Inc. personnel procured and shipped materials to the Grand Junction, Colorado testing facility. Palmer Coking Coal Company personnel identified the material on-site. The aggregate characteristics are described as follows:

- o Mine Wash Plant Waste

Location: Several old wash plant waste piles exist in the neighborhood of the Black Diamond Mine. Some of the piles have burned and are being worked to yield red cinders for use in landscaping. The pile which was sampled for backfill testing is located directly north of the Palmer Coking Coal Company office.

Quantities: The sampled pile contains approximately one-half million cubic yards of material.

Description: The wash plant waste consists of coal, sandstone, and shale. Coal generally occurs as laminae in the shale, which has deteriorated to friable lumps and silty clay. A lower proportion of the waste is sandstone

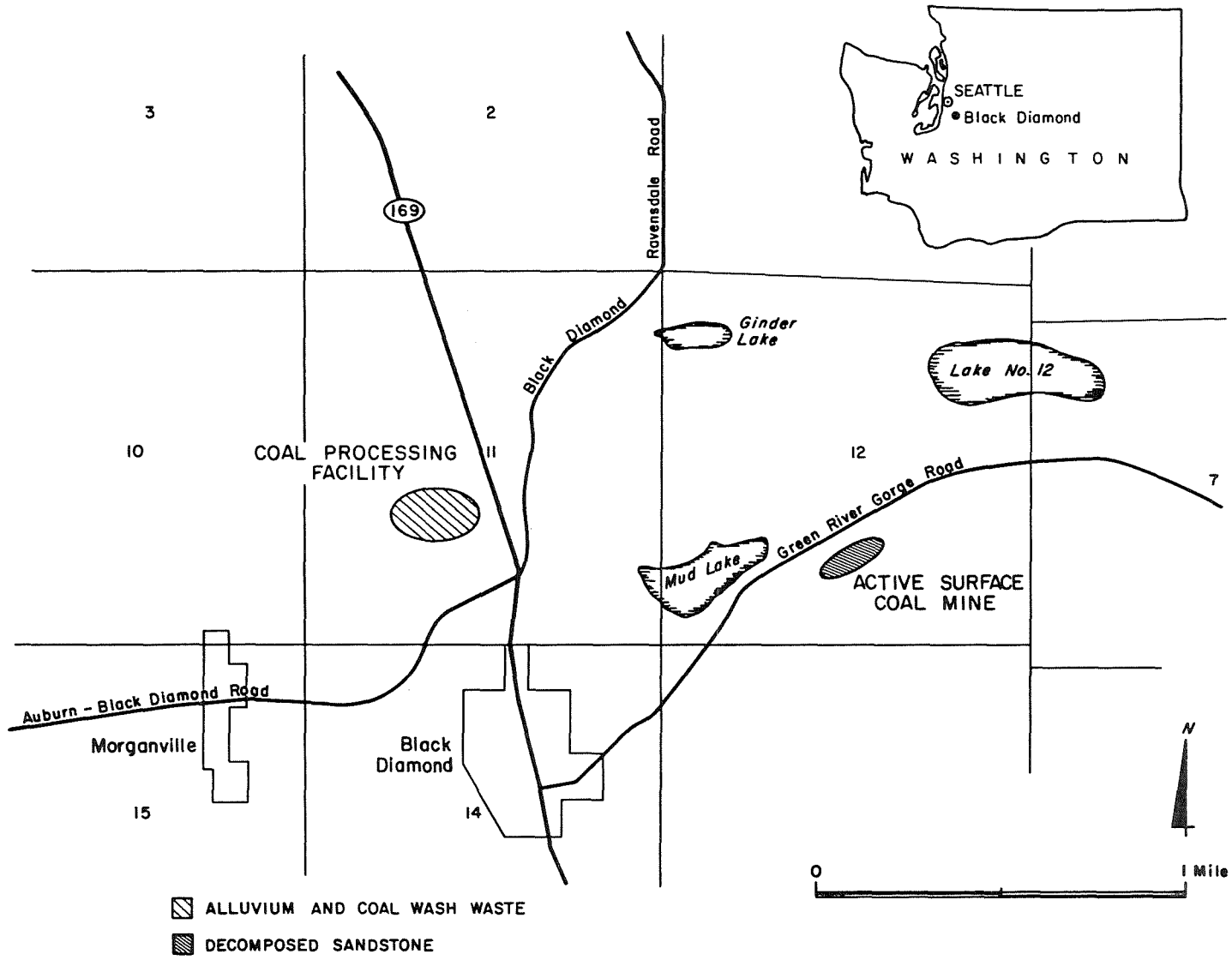


FIGURE 3.1 - Map showing the location of the Black Diamond coal mine.

because it is more easily separated from coal during processing.

o Alluvial Sand

Location: Deposits of alluvial sand blanket the surface of much of the Black Diamond area.

Quantities: Palmer Coke and Coal Company holds mineral and surface rights to at least 2500 acres, which probably are capped by alluvial sand. This could yield as much as 100 million cubic yards of material.

Description: The alluvial sand deposits are Pleistocene glacial outwash sands and gravels composed of approximately 60 percent Cascade volcanics (rhyolites, porphyry), 25 percent argillite (hard metasediments), 10 percent granite, and 5 percent quartz and other materials. All the component materials are hard and strong, with the granites perhaps being weakest of all. The proportions of sand and gravel are extremely variable, ranging from a mostly sandy section to a bouldery intermediate section and a basal sandy section.

o Decomposed Sandstone

Location: Decomposed sandstone is available as waste rock from scattered, open pit coal mining operations. The sandstone might also be quarried from the pit walls.

Quantities: Not surveyed, but estimated as "probably sufficient."

Description: The decomposed sandstone is an Eocene kurtosis sandstone containing coal measures. It decomposes to a clayey, quartz sand with size gradation depending upon

the degree of breakdown to constituent grains of fine to medium sand. Clay altered feldspar contributes many fines in the aggregate.

3.1.1 In-situ characterization

In-situ moisture and density measurements were made at the sample collection points for each of the three aggregate materials. The field measurements were performed by Pacific Testing Laboratories¹, Seattle, Washington. Table 3.1 lists the results of the field measurements.

3.1.2 Particle size distribution

Size gradation analyses were performed on the aggregates, as received from the Black Diamond Mine site. The entire contents of a 55 gal drum were dumped and riffle split, and gradations were performed in accordance to ASTM specifications. Table 3.2 summarizes the size gradations and Figure 3.2 shows a comparison of the particle size distribution for the three aggregates.

3.2 CEMENT AND POZZOLANS

Regionally available cementing agents and additives were identified by the USBM. A type I-II Portland cement, obtained from the Ideal¹ Cement plant in Seattle, Washington, was the primary cementing agent. Commercially available additive materials included Class F and Class C pozzolans from coal fired power plants in Centralia, Washington and Boardman, Oregon, respectively. These products are distributed by Pozzolanic International¹. Kiln dust

¹ Reference to specific brands, equipment or trade names in this report is made to facilitate understanding, and does not imply endorsement by the USBM.

TABLE 3.1 - In-place density test results

Identification	Location	Moisture content (%)	In-place density (pcf)	Dry density (pcf)
Coal mine wash plant waste	East side of pile	20.5	75.0	62.2
Coal mine wash plant waste	West side of pile, north end, 10 ft from bottom of slope	14.2	91.7	80.3
Coal mine wash plant waste	West side of pile, south end 10 ft from bottom	12.9	87.0	77.0
Alluvial sand	Pit No. 1, west on road	8.0	92.0	85.2
Alluvial sand	Pit No. 2, in floor of upper bench	3.3	93.9	139.3
Alluvial sand	Pit No. 2, lower bench, 10 ft from bottom	4.6	106.9	102.2
Decomposed sandstone	Current surface mine	8.0	124.3	115.1

TABLE 3.2 - Particle size gradations of aggregate materials

	Sieve	Percent finer by weight		
		Decomposed sandstone	Alluvial sand	Coal waste
U.S. Standard Sieve Openings (in.)	4	100.0	100.0	100.0
	3	100.0	100.0	100.0
	2	79.2	94.4	84.3
	1-1/2	73.3	92.2	79.2
	1-1/4	68.6	91.8	75.5
	1	66.5	90.6	72.1
	3/4	62.8	89.0	64.4
	1/2	56.6	87.0	58.8
	3/8	52.6	85.8	53.5
U.S. Standard Sieve Numbers	4	48.1	83.1	42.9
	8	42.6	80.6	34.6
	10	41.1	79.8	31.7
	16	37.0	76.4	24.5
	30	30.8	66.5	17.4
	50	22.1	35.6	15.7
	100	11.2	12.2	6.5
	200	5.2	5.2	3.7

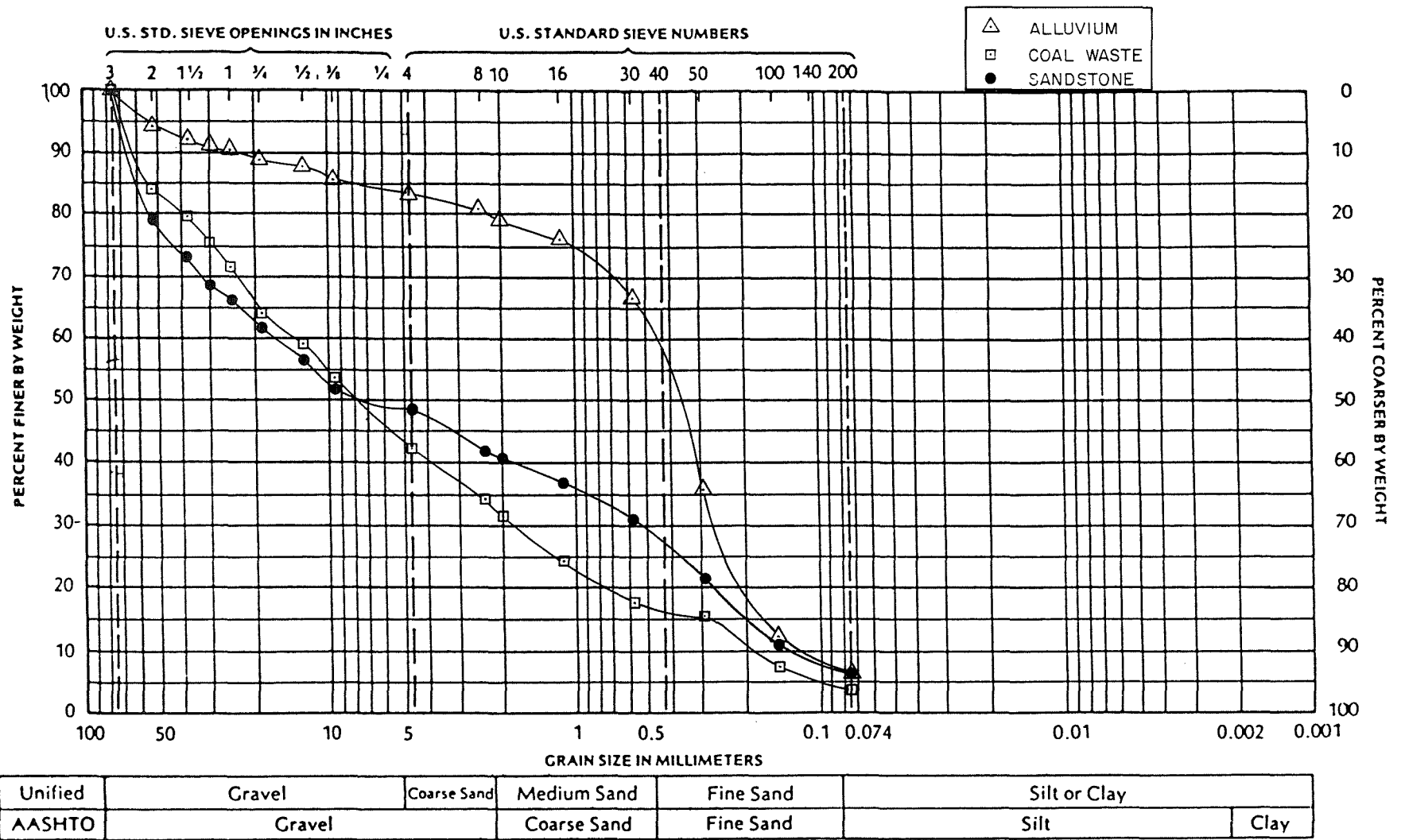


FIGURE 3.2 - Aggregate particle size distribution.

available from the Ideal¹ cement plant and smelter slag from the Bunker Hill Smelter in Kellogg, Idaho were included as test additives.

Results of chemical analyses of the additives are listed in Appendix A. Descriptions of each of the materials are presented in the following:

o Class F Pozzolan

Location: The Class F pozzolan is produced in the Centralia, Washington power plant and distributed by Pozzolanic International¹. Two grades were used in the tests, Plant Run (raw) and Product II (a screened, reject product).

Quantities: 500,000 tons annually.

Description: A fine grained particulate matter resulting from the combustion of pulverized or powdered coal at utility power plants. Fly ash is typically described as "a siliceous or aluminous and siliceous material which is in itself chemically inert, and possesses little or no cementitious value, but when in a finely divided form and the presence of water, will react with calcium hydroxide (lime) at ordinary temperatures to form compounds possessing cementitious properties" (ASTM, 1). Class F fly ash results from the burning of lignite or sub-bituminous coal, and are classified as "low lime" ashes with a CaO content usually less than five percent.

o Class C Pozzolan

Location: The Class C pozzolan is produced by the power plant located in Boardman, Oregon, and is distributed by

Pozzolanic International¹. Annual production from the Boardman plant is listed at 120,000 tons.

Quantity: Pozzolanic International representatives indicated that the Boardman plant is not a reliable source of Class C fly ash because of frequent shutdowns due to low power demand. They suggested the Laramie River Power Station (Wheatland, Wyoming) as an alternative source.

Description: Class C fly ashes are "high lime" ashes (CaO content up to 30 percent) resulting from the burning of lignite or sub-bituminous coal. Most of the CaO in high-lime fly ashes is present in a combined state with silicates and aluminates and is not free to react with other constituents. They develop strength rapidly when mixed with water (ASTM, 1).

o Cement Kiln Dust

Location: The kiln dust was procured from the Ideal Basic Industries¹ plant located in Seattle, Washington.

Quantities: The production of kiln dust during 1983-84 was 40,000 tons, down from 90,000 tons in 1980 because of recycling. Sales to agriculture, for use as lime, amounts to 25,000 tons per year. The balance is dumped in old open-cast pits near Black Diamond, Washington.

Description: Kiln dust is generated during the production of Portland cement, and collected by electrostatic precipitators from kiln stacks in a wet process plant. Its main chemical components are calcium oxides, alkalies, and

sulfates. Free lime is the single most important mineralogical constituent.

o Smelter Slag

Location: Bunker Hill Mine smelter at Smeltonville west of Kellogg, Idaho.

Quantities: Several million cubic yards are available. The slag has some commercial value, and is currently being sold as an additive to balance the iron content of Portland cement and to be spread on roads to melt ice during the winter months.

Description: Sand sized, black, glassy slag, iron rich, not vesicular - no weathering is evident in pile.

o Portland Cement

Location: Ideal Cement Plant, Seattle, Washington.

Quantity: Not known

Description: Portland Cement Type I - II.

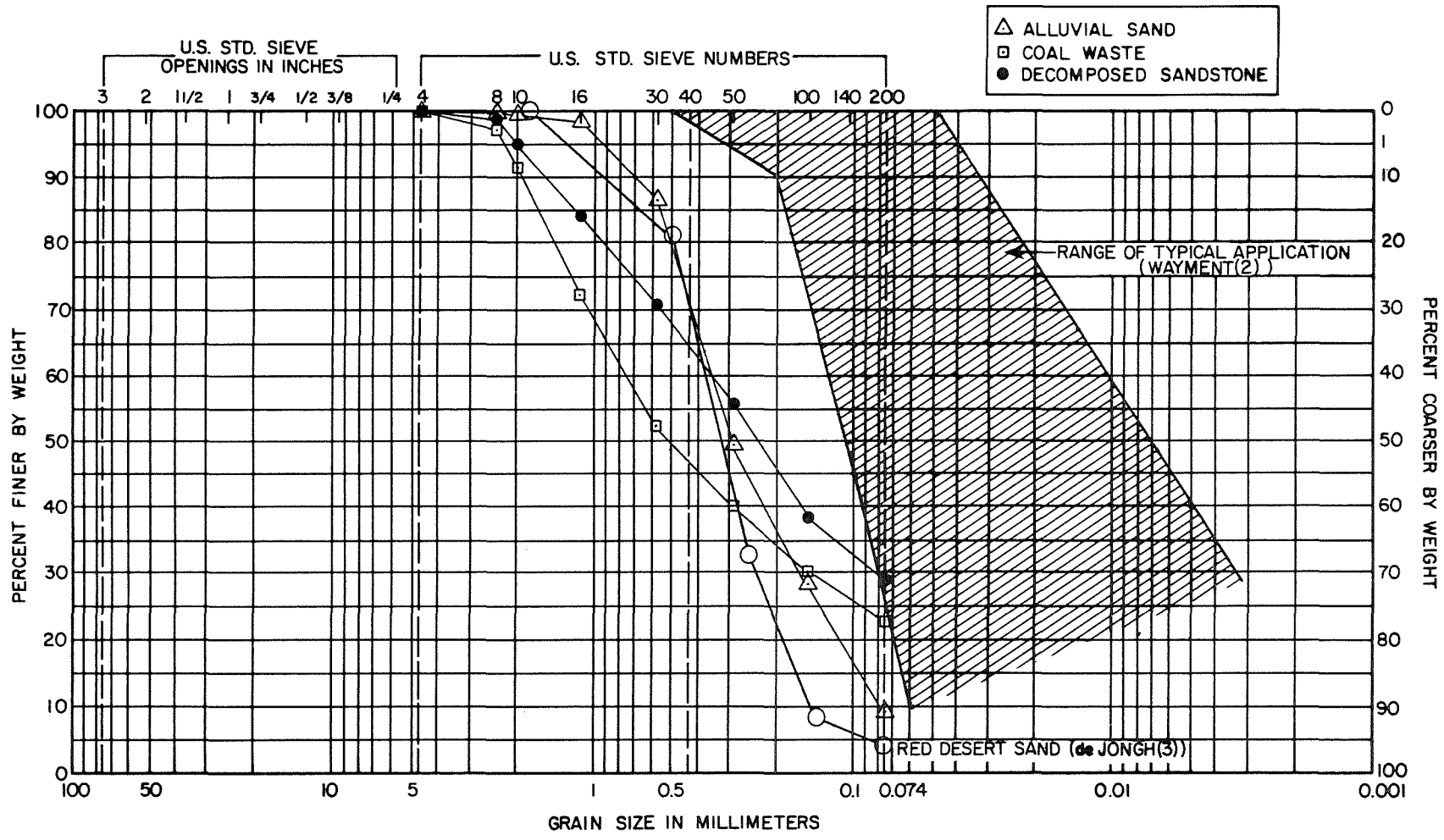
4.0 SAMPLE PREPARATION AND LABORATORY TEST PROCEDURES

Preparation of the backfill materials and mixtures included the evaluation of particle size distribution; screening, crushing and washing; sample mixing and sample forming. Testing included measurements of mixture viscosity, and both uniaxial and triaxial compression.

4.1 SIZE DISTRIBUTION OF BACKFILL AGGREGATE

The size distribution of the aggregate is an important parameter in the design of a backfill mixture for hydraulic placement. Size distribution affects both the hydraulic properties that control pumpability of the mixture and the strength of the mixture. All three aggregate materials contained a coarse portion that would require removal.

A review of published reports on cemented backfill indicated that most hydraulic fills were based upon mill tailings with maximum size particles in the range of 30 to 40 mesh [0.017 in. to 0.023 in. diameter, Wayment (2)]. Since the aggregate in these mixtures would be mined exclusive of the coal mining operation, it would be advantageous to minimize the amount of handling required. It was, therefore, desirable to use the largest particle diameter practical to decrease the proportion of material which must be discarded. De Jongh (3), reported blending desert sand with a maximum particle diameter of 0.08 in. with classified mill tailings to produce a backfill with roughly 7 percent cement. Figure 4.1 shows the particle size distribution of the screened, crushed, and blended aggregates along with particle size distributions reported by Wayment (2) and De Jongh (3).



The three aggregate materials were screened using a #8 sieve (0.094 in. diameter) to separate the coarse fraction (+8) material from the fine fraction (-8) material. Table 4.1 lists the relative quantities of the +8 and -8 fractions.

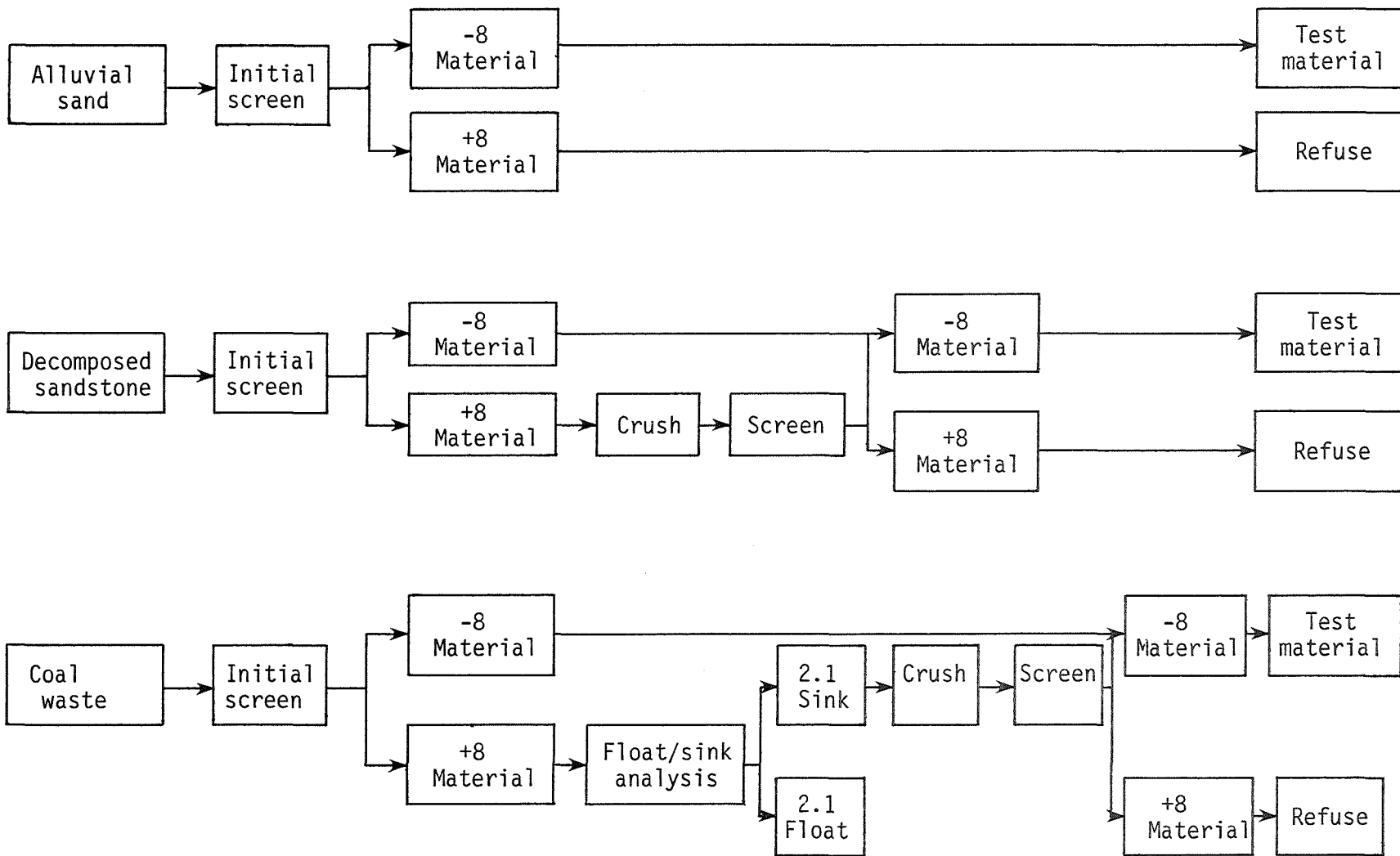
TABLE 4.1 - Aggregate-coarse and fine proportions

Aggregate	-8 Material (%)	+8 Material (%)
Alluvial sand	80.6	19.4
Decomposed sandstone	42.6	57.4
Coal wash waste	34.6	65.4

Table 4.2 is a flow diagram illustrating the various stages used to separate the final aggregates. A single separation was sufficient for the alluvial sand, because 80.6 percent was finer than -8 mesh. Palmer Coke and Coal Company indicated that they would crush the coarse fraction and sell it as gravel. The initial separation of the decomposed sandstone produced 57.4 percent coarse material. This coarse fraction was crushed and then separated again to increase the amount of -8 material. The two -8 portions were then blended.

The coal wash plant waste material contained a significant proportion of coal. Palmer Coke and Coal Company indicated that they would rewash the waste to recover this coal before using it as backfill aggregate. The coal waste was first separated into +8, -8 proportions, and the coarse material was sent to Commercial Testing

TABLE 4.2 - Aggregate screening, crushing and blending flow chart



and Engineering¹ in Golden, Colorado, where a float/sink separation was performed to recover the coal refuse. Materials with a specific gravity greater than 2.1 comprised approximately 32 percent of the +8 fraction and consisted mostly of sandstone and shale particles. This material was crushed and rescreened to separate the -8 fraction. Both the fine fractions were then blended for use as a backfill aggregate.

The materials were then stored in sealed containers to preserve the moisture content.

4.2 SAMPLE PREPARATION

Sample constituents (aggregates, pozzolans, cement and water) were measured to 0.1 gram accuracy before mixing. Each sample was mixed for 5 min. using a 20 quart Hobart¹ industrial mixer.

Samples were formed using a system which simulates underground mining conditions. Porous cement cinder blocks were soaked in water and coated with paper towels to allow removal of any excess water and to prevent the mixture from adhering to the brick. The bricks were arranged to form 2 by 2 by 4 in. samples, as shown in Figure 4.2.

Each mixture was poured into the molds in three separate lifts and rodded to ensure even distribution of material. The mold was then covered to retain moisture, and the samples were left in the mold for 24 hours. The samples were then removed from the mold, stripped of the paper towels, marked and placed in a moist environment to cure. The moisture in the air was maintained in a tank covered with plastic. A humidifier was operated at intervals to ensure a continuous moist curing environment.

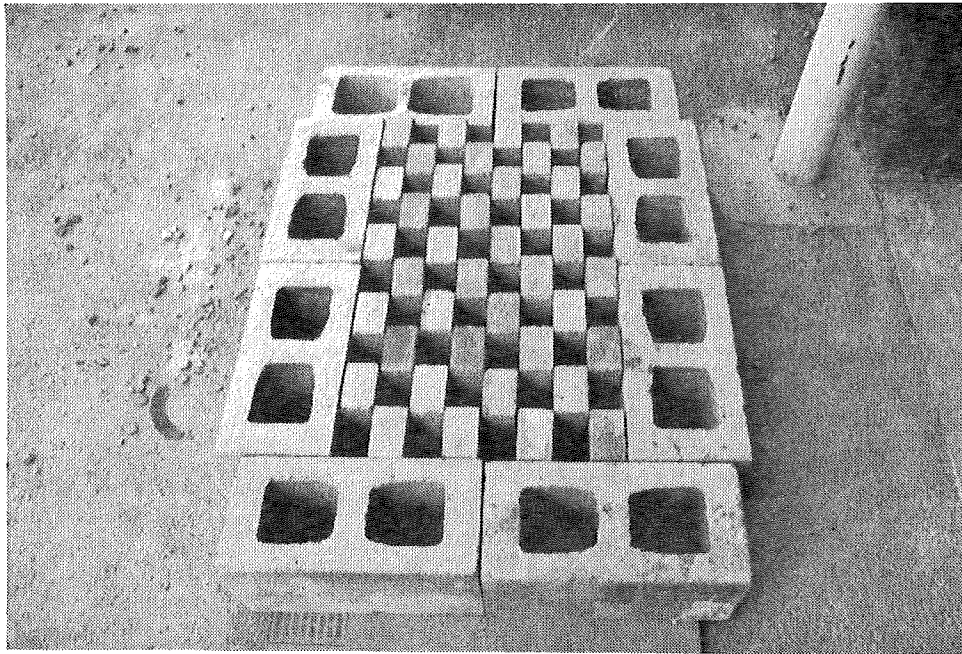


FIGURE 4.2 - Photograph of the sample molds.

Samples were removed from the tank after curing 28, 60 or 90 days. The samples were then weighed and the dimensions measured. The sample ends were capped with a molten sulphur to provide proper alignment in the testing machines.

4.3 MEASUREMENT OF VISCOSITY

Both the Marsh cone viscosity and absolute viscosity were measured for each mixture. The Marsh funnel viscometer was 6.0 in. in diameter at the top and 12.0 in. in overall length. The bottom of the funnel has a smooth orifice 2.0 in. long. The Marsh viscometer measures in units of viscosity of "Marsh seconds." The

funnel used in this program was modified to increase the orifice to approximately 3/8 in. diameter to prevent clogging. This modified funnel was then calibrated against a regular Marsh funnel. The viscosities of water, dish soap, and three different mortar mixes were measured by both the modified and standard Marsh funnels. A regression analysis was performed to derive a linear relationship between the viscosities indicated by the two funnels. Figure 4.3 shows the data scatter and least squares straight line fit of the data. This curve fit was used to convert all Marsh viscosities to the standard time unit.

Another viscosity measurement was performed using a Fann¹ Series 34 viscometer, which indicates viscosity in centipoise or milli-Pascal seconds. This viscometer measured the shear stress transmitted through the fluid between a rotating and stationary cylinder. Viscosity is related to the velocity of rotation, cylinder diameters and magnitude of the shear stress.

4.4 COMPRESSION TESTING TECHNIQUES

Two testing machines were used, depending on the expected strength of the material. A 250,000 lbs capacity machine was used for samples expected to have strengths in excess of 300 psi. Samples with expected strengths less than 300 psi were tested in a 6,000 lb maximum machine.

Load indicating gages were calibrated on January 16, 1985, and were traceable to the National Bureau of Standards.

Triaxial testing was performed using the pressure vessel shown in Figure 4.4. Load was measured outside of the vessel. Confining pressures of 50, 100 and 200 psi were applied and held constant

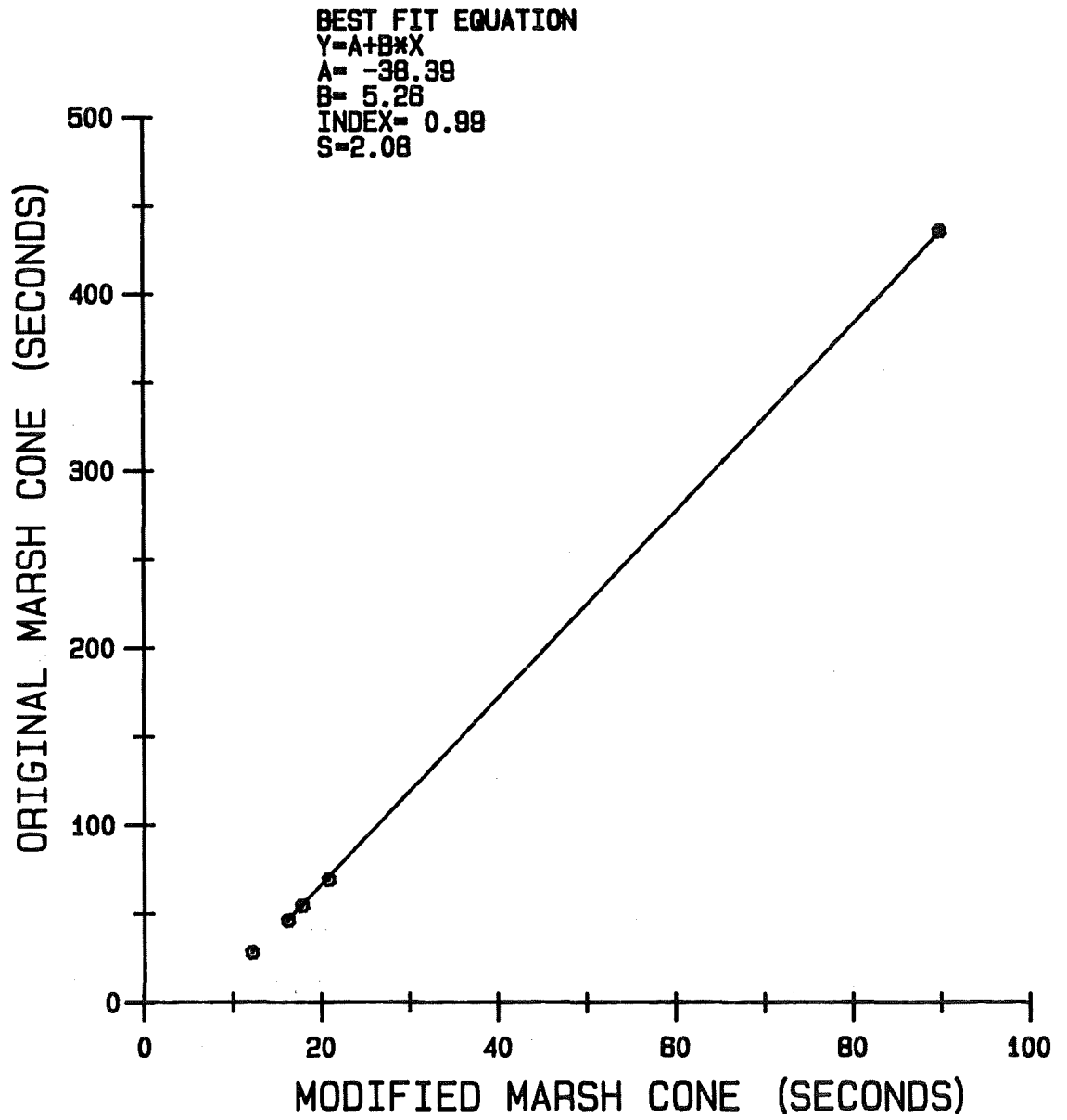


FIGURE 4.3 - Calibration of the modified Marsh viscometer.

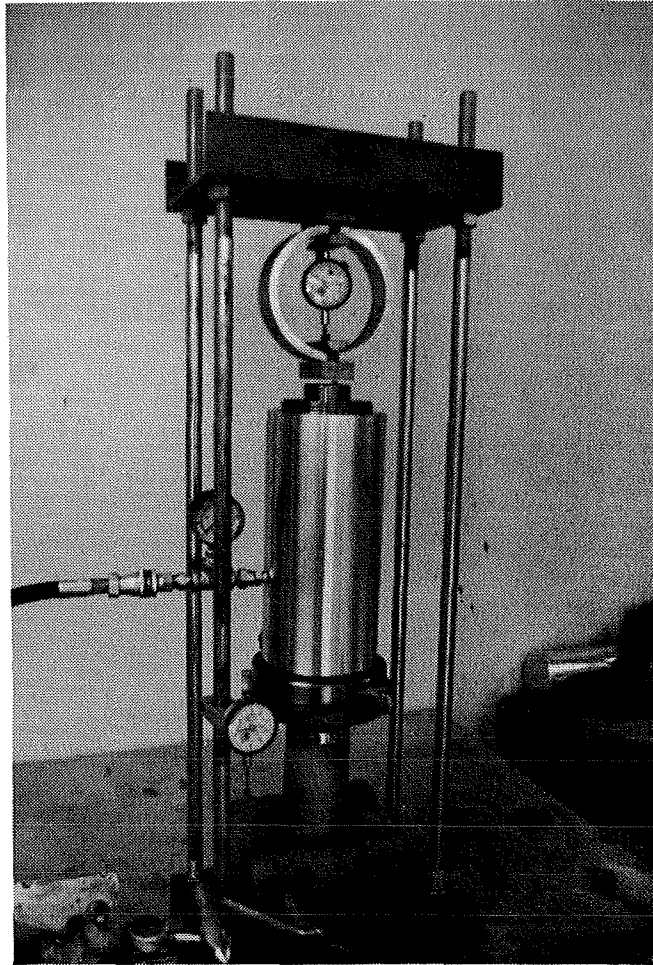


FIGURE 4.4 - Photograph of triaxial testing system.

through the loading cycle. The sample was isolated from the hydraulic fluid by a rubber sleeve. The axial force, corrected for piston friction and confining pressure, was used to calculate axial stress based on the average area of the sample.

Both uniaxial and triaxial tests utilized a spherical head to ensure even loading of samples.

5.0 PRELIMINARY COMPRESSION TESTING

Preliminary testing of backfill mixtures was conducted to evaluate the reactivity of the various pozzolans and Portland cement when combined with the aggregates. Mixtures of three different aggregate:pozzolan:cement ratios were tested after curing intervals of 28 days, 60 days and 90 days.

5.1 SAMPLE MIXTURES

Preliminary mixtures were designed based upon published reports of the use of pozzolanic materials in mine backfill. Thomas and Cowling (4) reported that strengths of 200 psi were obtained after 28 days of cure using 4 percent cement and the addition of pozzolanic copper reverberatory furnace slag in the 12 to 16 percent range. Similar data reported by McGuire (5) showed strengths between 150 psi and 440 psi while using 12 to 18 percent Falconbridge slag and 6 percent Portland cement.

Water contents must be high to ensure proper hydraulic characteristics. Mine backfills are typically pumped as a slurry with 30 to 40 percent water. Both Thomas and Cowling (4) and McGuire (5) utilized 30 percent water in their tests of pozzolans. Since high water contents reduce the strength of backfill mixtures, it is advantageous to minimize the water content. The addition of pozzolanic materials tends to increase pumpability due to the fine size and round particles.

Water content of each sample mixture was varied in response to the viscosity requirements. Sufficient water to give 23 percent water/77 percent solids by weight was added initially to each mixture. Then a marsh viscosity measurement was made to indicate

if the mixture was near the 60 marsh seconds requirement. If the mixture was not near the required viscosity, water was added in 3.0 in.³ (50 cm³) increments. Table 5.1 lists the preliminary test matrix. Portland cement content was fixed at 6.0 percent, with pozzolan contents ranging between zero and 20 percent. The amount of kiln dust required to replace the Portland cement was estimated to be 7.6 percent based upon its CaO content (see Appendix A). Class C pozzolan was evaluated without the addition of Portland cement.

5.2 PRELIMINARY COMPRESSIVE STRENGTH TESTING

The results of the preliminary compressive strength tests are listed in Tables 5.2 through 5.6. Mixture constituents, water:cement ratios, viscosities and individual sample strengths are presented in Appendix B.

Table 5.2 presents the results for mixtures of Portland cement with pozzolans. In these tests, pozzolan content was 20 to 50 wt. percent of the Portland cement content. The data shows a general trend of reduction in compressive strength with increasing pozzolan content/decreasing Portland cement content. The data shows that the Class F, Class C and kiln dust mixtures give higher strength than the ground smelter slag. The Class C pozzolan gave higher strength at 20 percent, but lower strength at 35 and 50 percent concentration, than the Class F pozzolan.

Table 5.3 lists the results of tests where Class C pozzolan was used as the only cementing agent with the various backfill aggregate materials. The Class C pozzolan content varied from 10,

TABLE 5.1 - Preliminary backfill mixture test matrix

Aggregate	Additive (pozzolan)	Cement/ kiln dust	* Number of samples			Total number of tests
			Ratio 1	Ratio 2	Ratio 3	
			0:80:20	0:65:35	0:50:50	
None	Class F-plant run	Portland Type 1 & 2	4	4	4	12
	Class F-product II		4	4	4	12
	Class C		4	4	4	12
	Kiln dust		4	4	4	12
	Smelter slag		4	4	4	12
			94:0:6	84:10:6	74:20:6	
Alluvial sand	Class F-plant run	Portland Type 1 & 2	4	4	4	12
	Class F-product II		4	4	4	8
	Class C		4	4	4	8
	Kiln dust		4	4	4	8
	Smelter slag		4	4	4	8
Decomposed sandstone	Class F-plant run	Portland Type 1 & 2	4	4	4	12
	Class F-product II		4	4	4	8
	Class C		4	4	4	8
	Kiln dust		4	4	4	8
	Smelter slag		4	4	4	8
Coal wash Plant waste	Class F-plant run	Portland Type 1 & 2	4	4	4	12
	Class F-product II		4	4	4	8
	Class C		4	4	4	8
	Kiln dust		4	4	4	8
	Smelter slag		4	4	4	8
Alluvial sand/ Coal wash Plant waste	Class F-plant run	Portland Type 1 & 2	4	4	4	12
	Class F-product II		4	4	4	8
	Class C		4	4	4	8
	Kiln dust		4	4	4	8
	Smelter slag		4	4	4	8
Decomposed sandstone/ Coal wash Plant waste	Class F-plant run	Portland Type 1 & 2	4	4	4	12
	Class F-product II		4	4	4	8
	Class C		4	4	4	8
	Kiln dust		4	4	4	8
	Smelter slag		4	4	4	8
			92.4:0:7.6	82.4:10:7.6	72.4:20:7.6	
Alluvial sand	Class F-plant run	Kiln dust	4	4	4	12
Decomposed sandstone	Class F-plant run	Kiln dust	4	4	4	12
Coal waste	Class F-plant run	Kiln dust	4	4	4	12
Alluvial sand/ Coal waste	Class F-plant Run	Kiln dust	4	4	4	12
Decomposed sandstone/ Coal waste	Class F-plant run	Kiln dust	4	4	4	12
			90:10:0	80:20:0	70:30:0	
Alluvial sand	Class C		4	4	4	12
Decomposed sandstone	Class C		4	4	4	12
Coal Waste	Class C		4	4	4	12
Alluvial sand/ Coal waste	Class C		4	4	4	12
Decomposed sandstone/ Coal waste	Class C		4	4	4	12

* Four samples were made for each mix - 2 were tested at 28 days, 1 at 60 days and 1 at 90 days.
Ratio is expressed as a percentage of solid constituents:
(Aggregate: Pozzolan (Additive): Cementing Agent)

TABLE 5.2 - Compressive strength of pozzolan - Portland cement mixtures

Pozzolan - cement ratio (weight percent)	20:80			35:65			50:50		
	28	60	90	28	60	90	28	60	90
Curing time (days)									
	<u>Compressive strength (psi)</u>								
Portland cement									
Class F - plant run	7531	7455	7602	5773	7956	8382	4920	4435	5116
Class F - product II	7480	8202	7195	5211	8089	8072	4981	3655	6551
Class C	7503	9961	9807	6066	5511	4486	5356	4510	1446
Kiln dust	6336	7751	7723	6042	6809	4049	3060	2716	3825
Smelter slag	6578	5417	3527	7026	6189	3873	4335	5394	7475

TABLE 5.3 - Compressive strength of backfill samples using Class C pozzolan as the cementing agent

Aggregate - pozzolan ratio (weight percent)	90:10			80:20			50:50		
	28	60	90	28	60	90	28	60	90
Curing time (days)	28	60	90	28	60	90	28	60	90
Class C pozzolan									
Alluvial sand	25	26	26	94	116	110	466	582	672
Decomposed sandstone	26	27	24	52	50	*	91	128	149
Coal waste	15	12	11	46	52	28	87	95	81
Alluvium-coal waste	21	19	17	47	48	42	106	121	114
Sandstone-coal waste	27	20	19	42	50	33	99	104	120

* Sample broke (failed) before testing

TABLE 5.4 - Compressive strength of backfill samples using Portland cement as the primary cementing agent

Aggregate - pozzolan - cement ratio (weight percent)	94:0:6			84:10:6			74:20:6		
	28	60	90	28	60	90	28	60	90
Curing time (days)	28	60	90	28	60	90	28	60	90
	<u>Compressive Strength (psi)</u>								
Alluvial sand									
Class F-plant run	65	114	110	117	190	210	167	347	350
Class F-product II				127	208	222	203	325	343
Class C				85	246	311	164	410	550
Kiln dust				225	518	542	424	961	854
Smelter slag				87	130	139	124	243	231
Decomposed sandstone									
Class F-plant run	66	90	71	74	94	121	134	235	226
Class F-product II				142	244	210	243	277	362
Class C				123	202	191	215	481	666
Kiln dust				103	142	189	106	177	197
Smelter slag				118	160	150	240	252	450
Coal waste									
Class F-plant run	88	99	93	91	99	102	91	106	93
Class F-product II				82	92	96	66	86	94
Class C				132	123	133	138	178	224
Kiln dust				106	148	214	91	149	202
Smelter slag				70	111	125	80	73	98

TABLE 5.5 - Compressive strength of backfill samples using aggregates mixed with coal waste

Aggregate - pozzolan - cement ratio (weight percent)	94:0:6			84:10:6			74:20:6		
	28	60	90	28	60	90	28	60	90
	<u>Compressive Strength (psi)</u>								
Alluvial sand - coal waste (50/50)									
Class F - Plant Run	69	136	92	68	113	108	106	109	146
Class F - Product II				124	163	133	123	158	183
Class C				132	163	206	240	151	174
Kiln Dust				128	181	260	182	313	393
Smelter Slag				81	99	113	77	85	91
Decomposed sandstone - coal waste (50/50)									
Class F - Plant Run	82	137	162	92	103	86	88	138	130
Class F - Product II				97	112	114	108	126	149
Class C				167	172	192	244	327	431
Kiln Dust				109	130	131	163	198	208
Smelter Slag				76	94	81	96	*	84

* Sample broke before testing

TABLE 5.6 - Compressive strength of backfill samples using kiln dust as the primary cementing agent with Class F - Plant Run pozzolan

Aggregate - pozzolan - kiln dust ratio (weight percent)	92.4:0:7.6			82.4:10:7.6			72.4:20:7.6		
	28	60	90	28	60	90	28	60	90
	<u>Compressive strength (psi)</u>								
Alluvial sand Class F - plant run	*	14	*	12	12	22	22	18	33
Decomposed sandstone Class F - plant run	32	25	22	27	24	38	21	26	30
Coal waste Class F - plant run	29	17	10	16	16	9	14	18	13
Alluvial sand - coal waste (50/50) Class F - plant run	15	17	9	16	18	12	23	12	13
Decomposed sandstone - coal waste (50/50) Class F - plant run	19	15	25	24	19	20	21	21	22

* Samples broke before testing

20 and 50 wt. percent of the backfill aggregate. Increasing the pozzolan content increased the compressive strength by a factor of 2.7 for 10 to 20 percent and by a factor of 3.8 for 20 to 50 percent. Alluvial sand had the highest strength, with decomposed sandstone second and coal waste the weakest. The mixtures of 50 percent coal waste with either alluvial sand or decomposed sandstone both gave similar strengths, but were only slightly stronger than the coal waste alone.

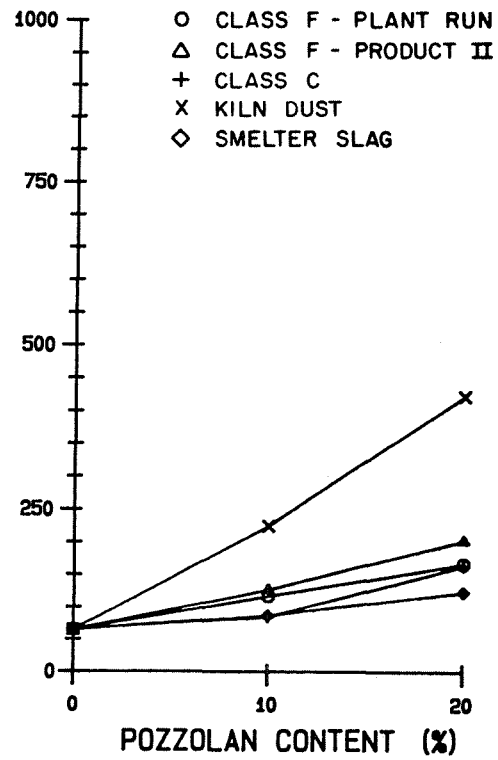
Table 5.4 lists the results of tests on backfill mixtures using 6 wt. percent Portland cement with pozzolan contents of 0, 10 and 20 wt. percent. Increasing the pozzolan content produced higher compressive strength for all mixtures using alluvial sand and decomposed sandstone. The coal waste material produced a lower strength backfill than the alluvial sand or decomposed sandstone. The strength increase with increasing pozzolan content was generally less with coal waste as an aggregate. Increasing Class F and smelter slag content in the coal waste backfill did not produce a noticeable increase in strength. The alluvial sand produced higher strength backfill than the decomposed sandstone.

The effects of mixing equal parts of coal wash plant waste with each part of the alluvial sand and decomposed sandstone are presented in Table 5.5. Increasing the pozzolan content produced an increase in strength; however, the rate of strength gain was less than with alluvial sand or decomposed sandstone alone. Class C pozzolan and kiln dust generally gave higher strength than Class F pozzolan, and the addition of the ground smelter slag did not produce any increase in strength.

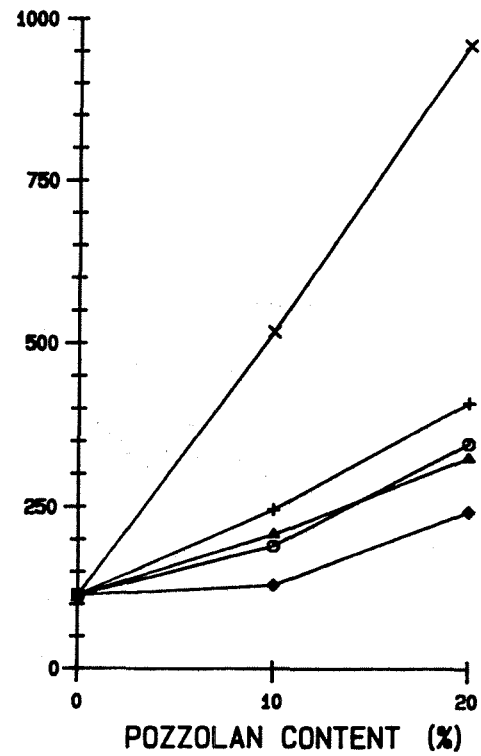
Table 5.6 lists the strength of samples where the kiln dust was used to replace the Portland cement as the primary cementing agent in combination with Class F - Plant Run pozzolan. The kiln dust content was set at 7.6 percent so that the CaO content in the mix would be equivalent to that of a 6.0 percent Portland cement mix. The resulting strengths were very low for all mixes tested, and did not show any strength increase with increasing Class F pozzolan content.

The compressive strength as a function of pozzolan content for three different curing intervals and the different backfill aggregate mixtures is shown in Figures 5.1 through 5.5. Figures 5.1 and 5.2 show strength increases with increasing pozzolan content for both alluvial sand and decomposed sandstone backfill aggregates. In general, the alluvial sand gave a higher strength than the decomposed sandstone.

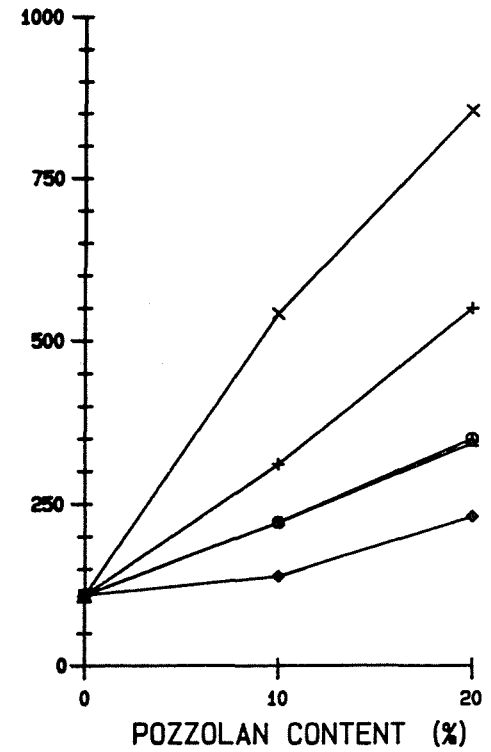
Figure 5.3 illustrates that the coal waste produced a lower strength backfill with a similar mixture of Portland cement and pozzolan. The average value of compressive strength for all coal waste samples was 100 psi as compared to 273 and 178 psi for the alluvial sand and decomposed sandstone, respectively. The effects of mixing coal waste and alluvial sand or decomposed sandstone are illustrated in Figures 5.4 and 5.5. The blending of coal waste produced a weaker backfill than when using the alluvial sand or decomposed sandstone alone. On the other hand, the blended mixtures average 20 percent stronger than the coal waste by itself.



28 days



60 days



90 days

FIGURE 5.1 - Uniaxial compressive strength versus pozzolan content for alluvial sand backfill with six percent Portland cement.

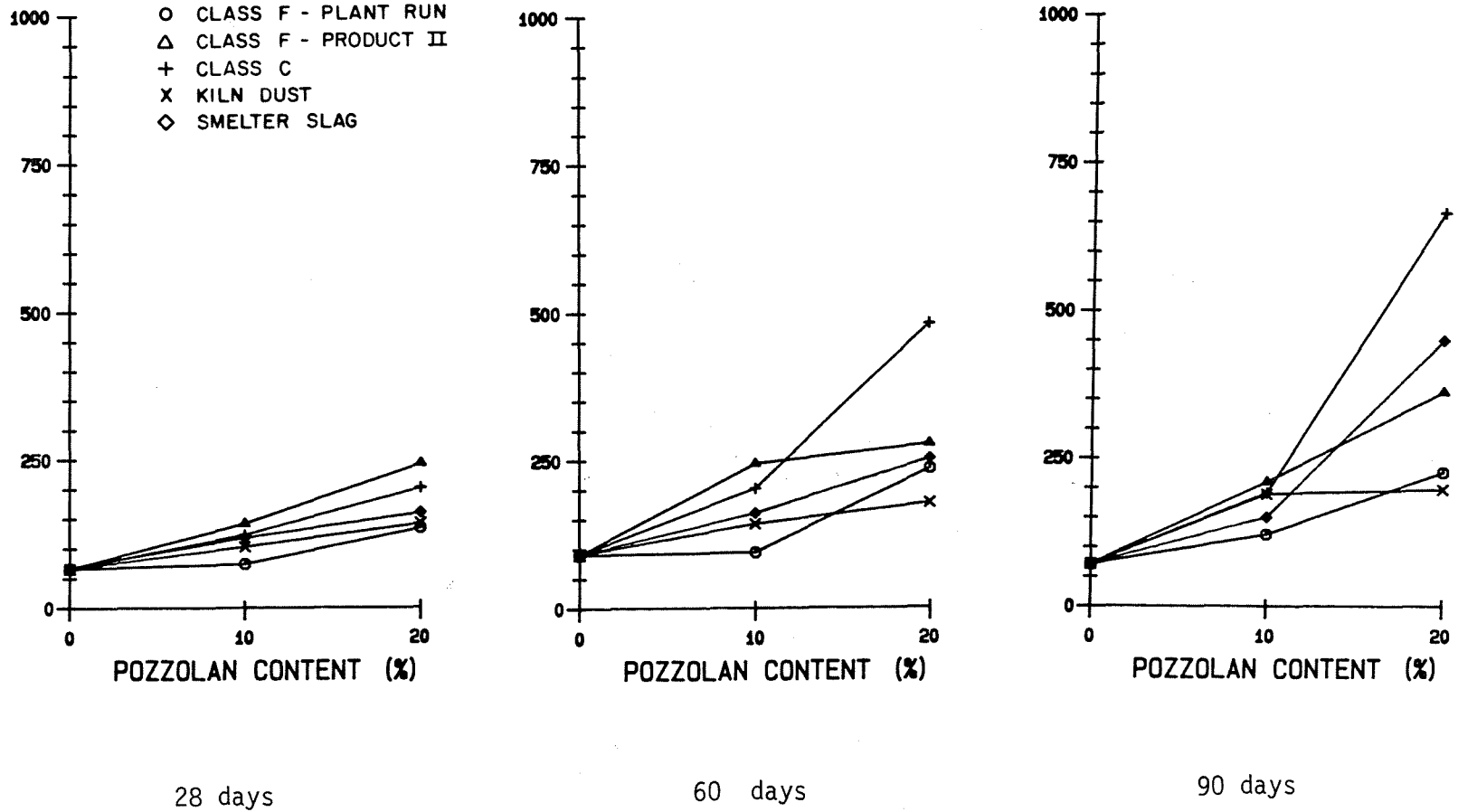
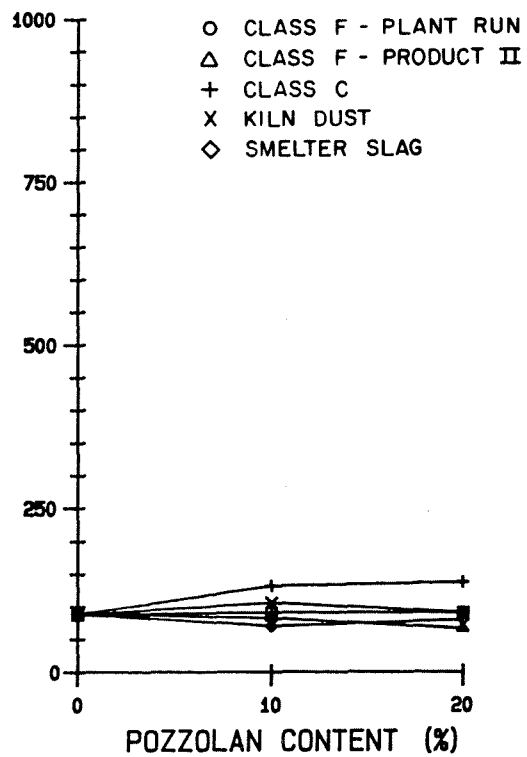
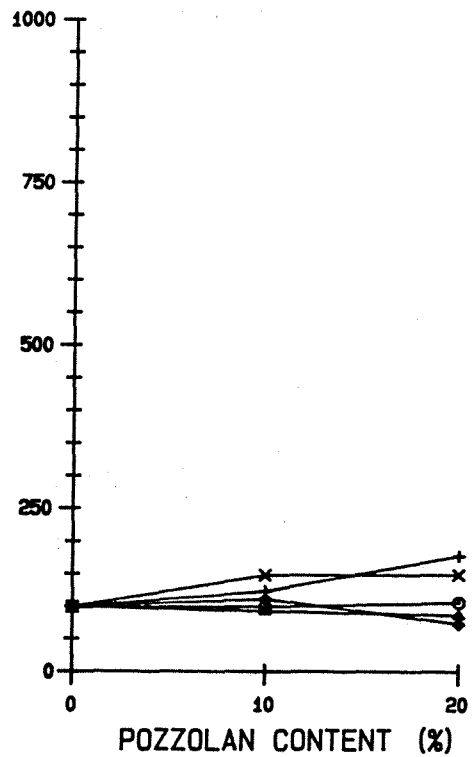


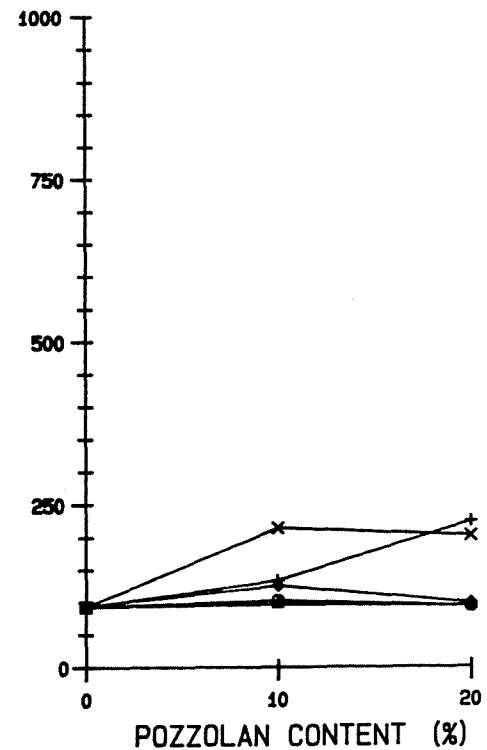
FIGURE 5.2 - Uniaxial compressive strength versus pozzolan content for decomposed sandstone backfill with six percent Portland cement.



28 days



60 days



90 days

FIGURE 5.3 - Uniaxial compressive strength versus pozzolan content for coal waste backfill with six percent Portland cement.

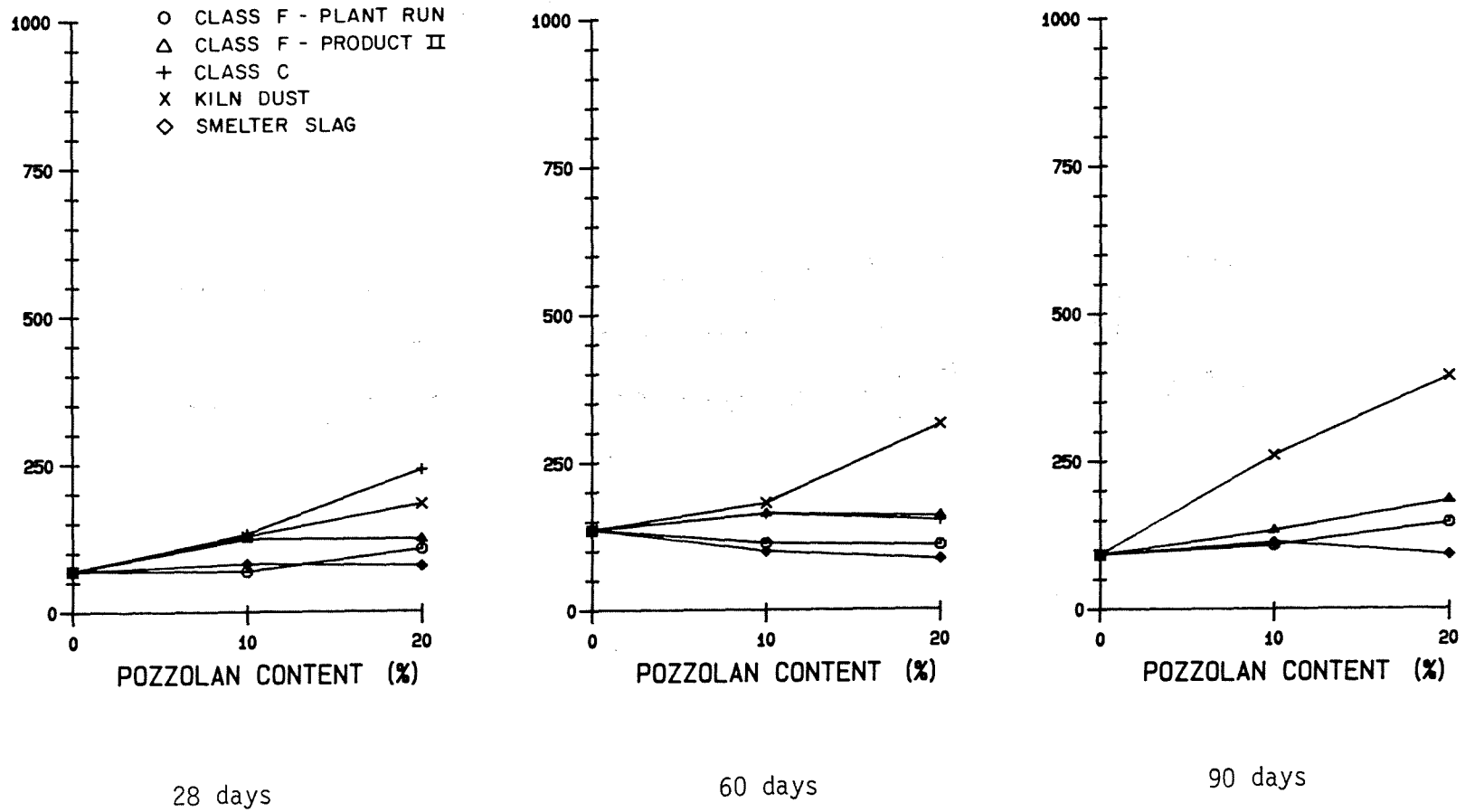


FIGURE 5.4 - Uniaxial compressive strength versus pozzolan content for a backfill mixture with 50 percent coal waste/50 percent alluvial sand, and 6 percent Portland cement.

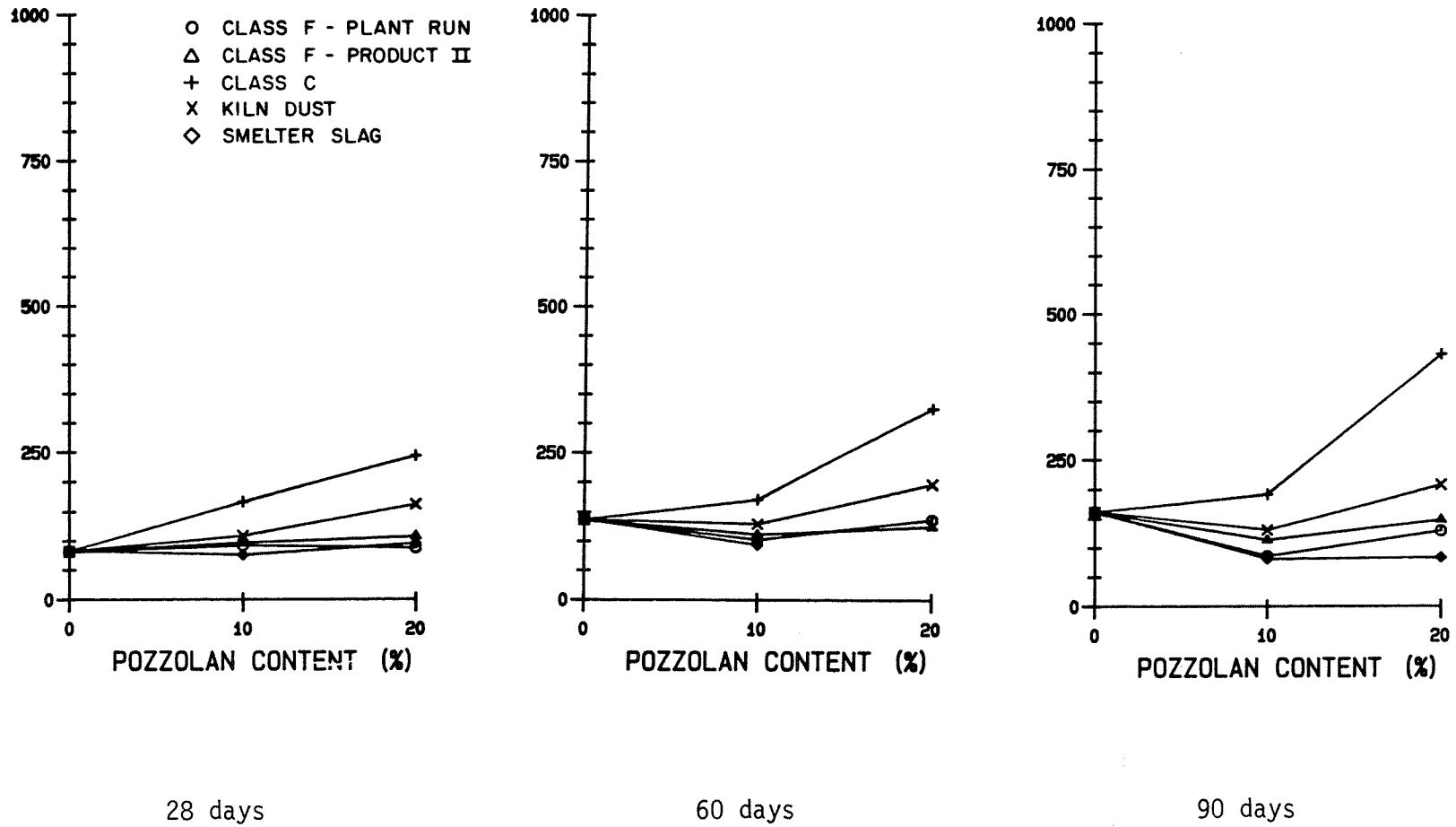


FIGURE 5.5 - Uniaxial compressive strength versus pozzolan content for a backfill mixture with 50 percent coal waste/50 percent decomposed sandstone, and 6 percent Portland cement.

The kiln dust and Class C pozzolans generally produced the highest strength backfill. Setting times of the mixtures containing the Class C pozzolan were significantly shorter (five minutes) than with any of the others. The Class F pozzolans were the next highest strength, with the Class F - Product II giving slightly higher strength than the Class F - Plant Run. Ground smelter slag produced the lowest strength backfill.

6.0 REPLICATED TESTING

6.1 INTRODUCTION

Replicated tests were performed on a group of mixtures, as specified in the contract, to establish a more controlled study of the effect of varying mixture design on compressive strength, and to establish a measure of the magnitude of the various components of data variance. The mix designs incorporate several components that directly affect strength, including:

- o aggregate:cementing agent ratio
- o Portland cement:pozzolan ratio
- o aggregate properties
- o water:cementing agent ratio
- o experimental data scatter

A test matrix was designed to isolate the effects of the cementing agent:pozzolan ratio and experimental data scatter. The matrix was designed to eliminate the other effects by using a single aggregate (alluvial sand) and a constant water:cementing agent ratio. The testing included four replications for each mix design.

6.2 TEST MATRIX

The test matrix is presented in Table 6.1. Mixture (1) was designed to illustrate the reactivity of Class F pozzolan with Portland cement. Mixtures (2) through (4) are alluvial sand mixtures with three ratios of aggregate:pozzolan:cement. Water content was 26 percent of the total weight. The aggregate:cementing agent ratios were held constant in each column of the test matrix. Class F pozzolan:Portland cement ratios were changed in mixtures (2) and (3), with

TABLE 6.1 - Replicated test matrix

Mixture no.	Aggregate	Additive (pozzolan)	Cement	Number of samples*			Total number of tests
				Ratio 1	Ratio 2	Ratio 3	
1	None	Class F - product II	Portland	$\frac{0:60:40}{4}$	$\frac{0:70:30}{4}$	$\frac{0:76:24}{4}$	12
2	Alluvial sand	Class F - product II	Portland	$\frac{79:13:8}{4}$	$\frac{74:16:10}{4}$	$\frac{69:19:12}{4}$	12
3	Alluvial sand	Class F - product II	Portland	$\frac{79:15:6}{4}$	$\frac{74:20:6}{4}$	$\frac{69:25:6}{4}$	12
4	Alluvial sand	Class C	---	$\frac{79:21:0}{4}$	$\frac{74:26:0}{4}$	$\frac{69:31:0}{4}$	12
5	Alluvial sand	Class F - product II	Kiln dust	$\frac{79:15:6}{4}$	$\frac{74:15:11}{4}$	$\frac{69:15:16}{4}$	12

* Four samples were made for each mix - all tested at 28 days. Ratio is expressed as a percentage of solid constituents (aggregate:pozzolan (additive):cement)

increasing Portland cement content in mixture (2), and with increasing Class F pozzolan content in mixture (3). In mixture (5), kiln dust is used as a replacement for Portland cement.

6.3 TEST RESULTS

Average values of the compressive strength are listed in Table 6.2. Correlations of compressive strength versus the change in cementing agent content are shown in Figures 6.1 through 6.5. Linear least-square curve fits were used to provide a uniform method of comparing the rates of strength increase due to increasing pozzolan content. The linear rates of strength increase are compared in Table 6.3. In Figure 6.3 and subsequent figures, the parameters A, B, index and S represent the intercept, slope, index of determination or the square of the correlation coefficient, and standard deviation, respectively.

The reactivity of Portland cement:Class F pozzolan is illustrated by the strong effect of changing pozzolan content in mixture (1). The rate of strength increase, 100 psi per percent Class F pozzolan, is largely due to the abundance of excess lime available to the pozzolan reaction from the Portland cement:water reaction. Reactivity of the Class F pozzolan is much lower in the alluvial sand mixtures [mixture nos. (2) and (3)] because the reduced Portland cement content provides less lime for formation of the pozzolan cements. In this range of Portland cement:pozzolan ratios, changing Portland cement content has 21 times the effect on strength increase as a change in pozzolan content. Class C pozzolan used as a primary cementing agent shows a larger rate of strength increase than Class F pozzolan, but has roughly one-half the effect of Portland cement. The kiln dust has a low rate of

TABLE 6.2 - Two factor experiment with replication - 28 day compressive strength results (psi)

Mixture no.	Mix constituents ¹	Aggregate - pozzolan - cement ratio (weight percent)		
1	Class F - product II Portland cement	<u>0:60:40</u>	<u>0:70:30</u>	<u>0:76:24</u>
		3099	2327	2535
		3838	2880	2165
		3732	1946	1858
		3596	2158	1660
2	Alluvial sand Class F - product II Portland cement	<u>79:13:8</u>	<u>74:16:10</u>	<u>69:19:12</u>
		297	490	700
		284	458	687
		263	395	536
		320	357	638
3	Alluvial sand Class F - product II Portland cement	<u>79:15:6</u>	<u>74:20:6</u>	<u>69:25:6</u>
		144	165	193
		138	139	150
		111	159	150
		122	156	185
4	Alluvial sand Class C	<u>79:21:0</u>	<u>74:26:0</u>	<u>69:31:0</u>
		123	248	625
		112	237	505
		96	352	595
		128	352	558
5	Alluvial sand Class F - product II Kiln dust (cement replacement)	<u>79:15:6</u>	<u>74:15:11</u>	<u>69:15:16</u>
		18	43	106
		19	35	103
		17	40	105
		17	37	98

¹ - All mixtures 26 percent water by total weight

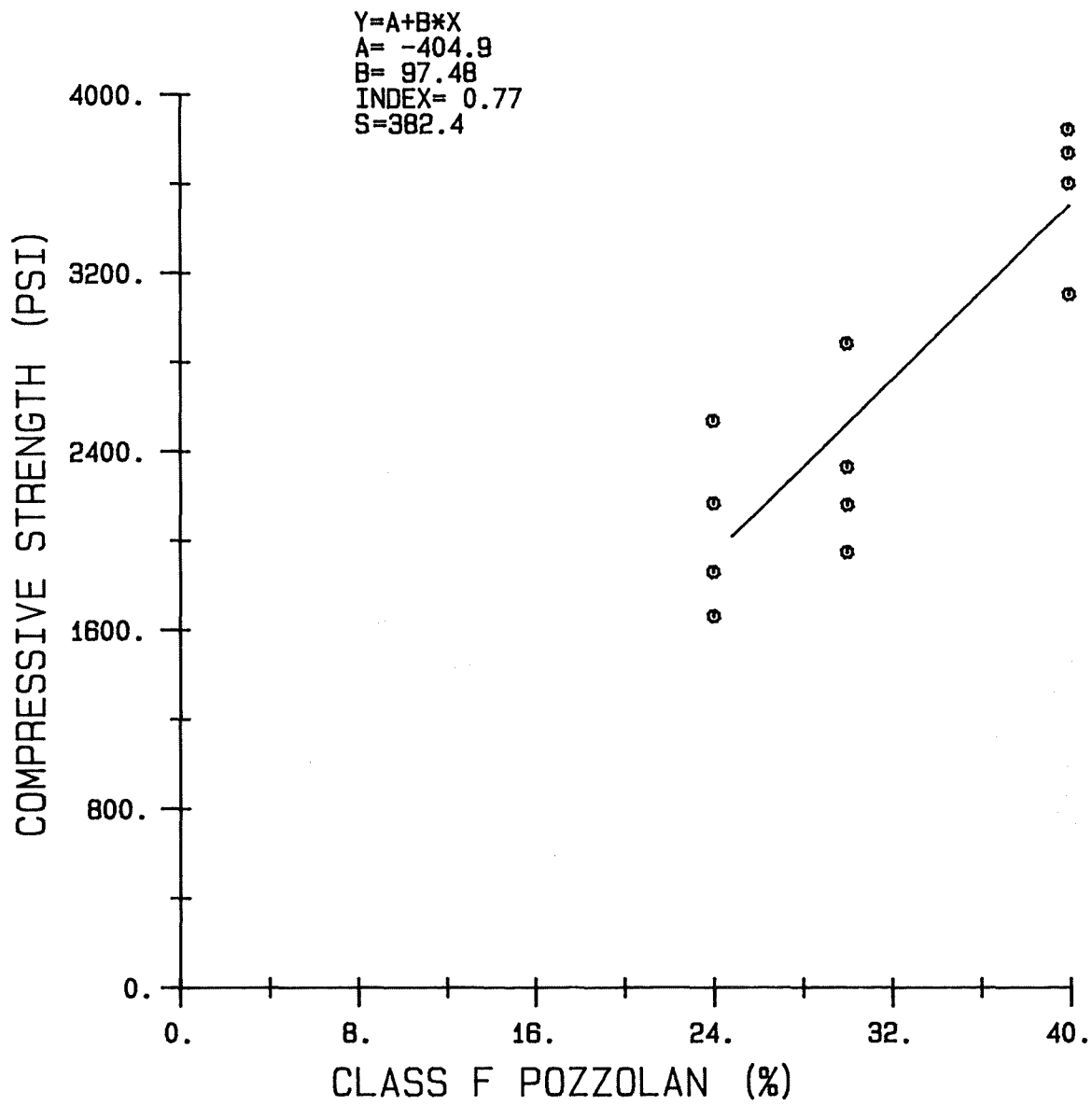


FIGURE 6.1 - Variation of compressive strength with increasing Class F pozzolan content - Portland cement: Class F pozzolan.

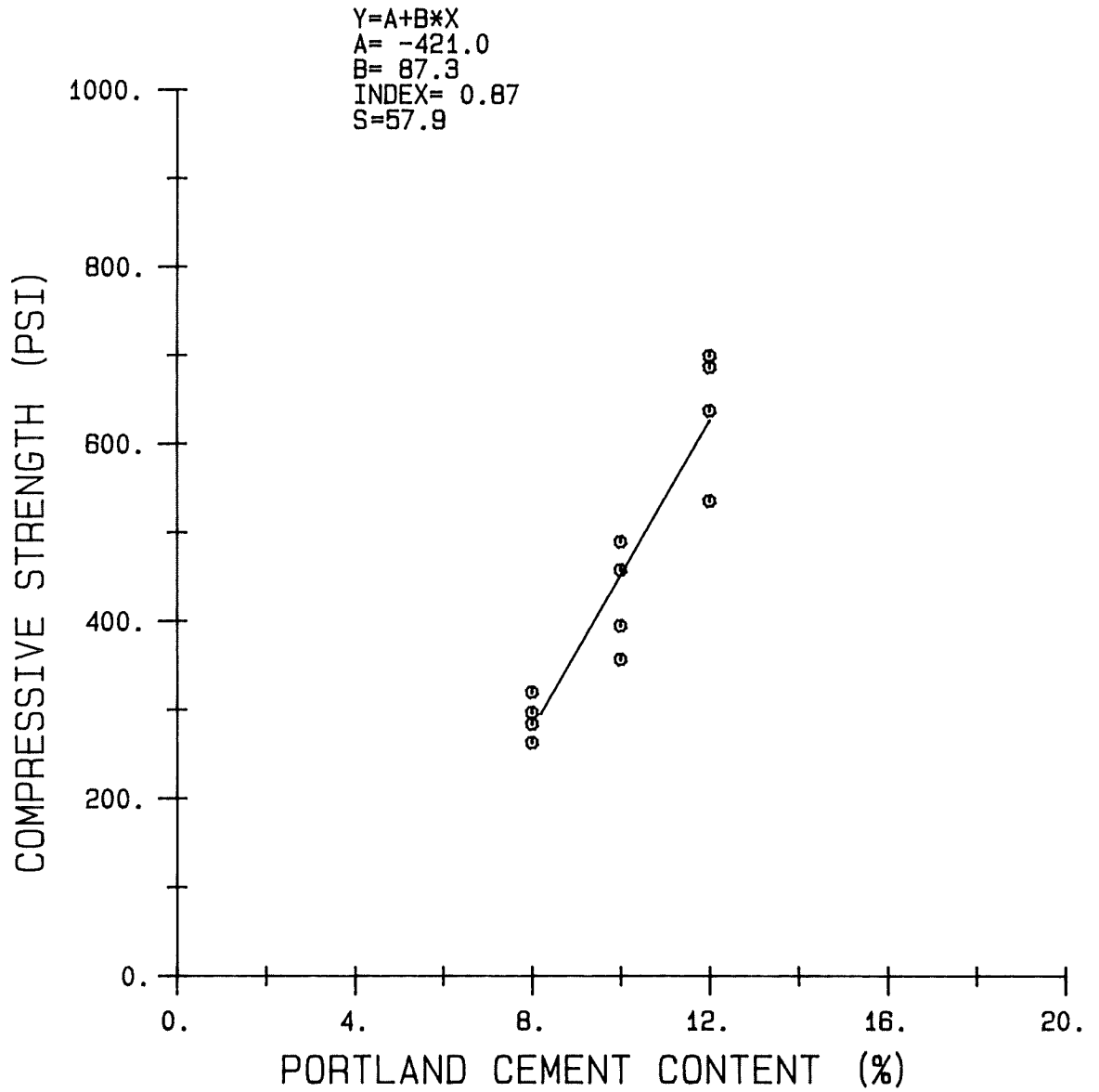


FIGURE 6.2 - Variation of compressive strength with increasing Portland cement content - alluvial sand: Class F pozzolan: Portland cement.

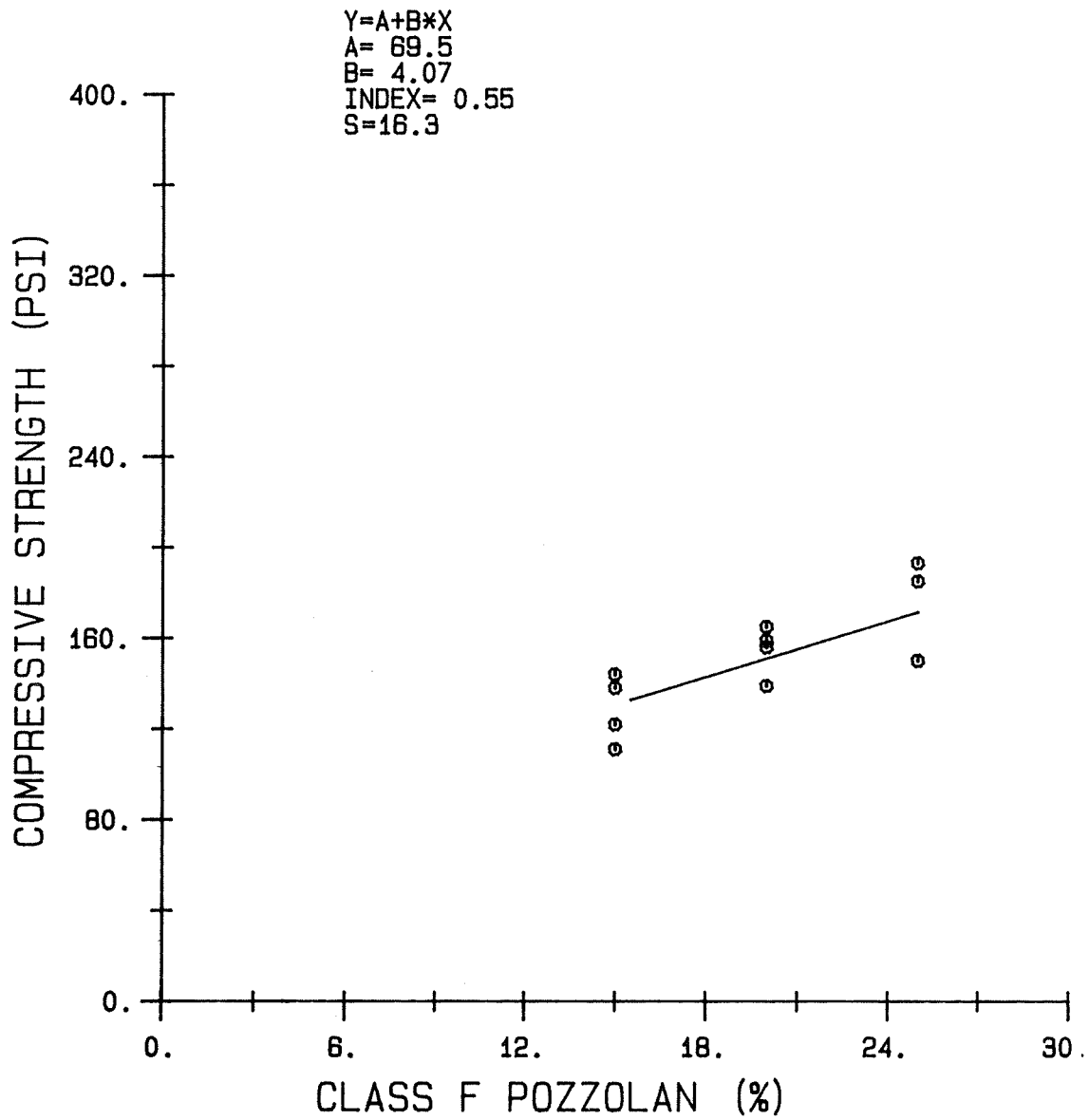


FIGURE 6.3 - Variation in compressive strength with increasing Class F pozzolan content - alluvial sand: Class F pozzolan: Portland cement.

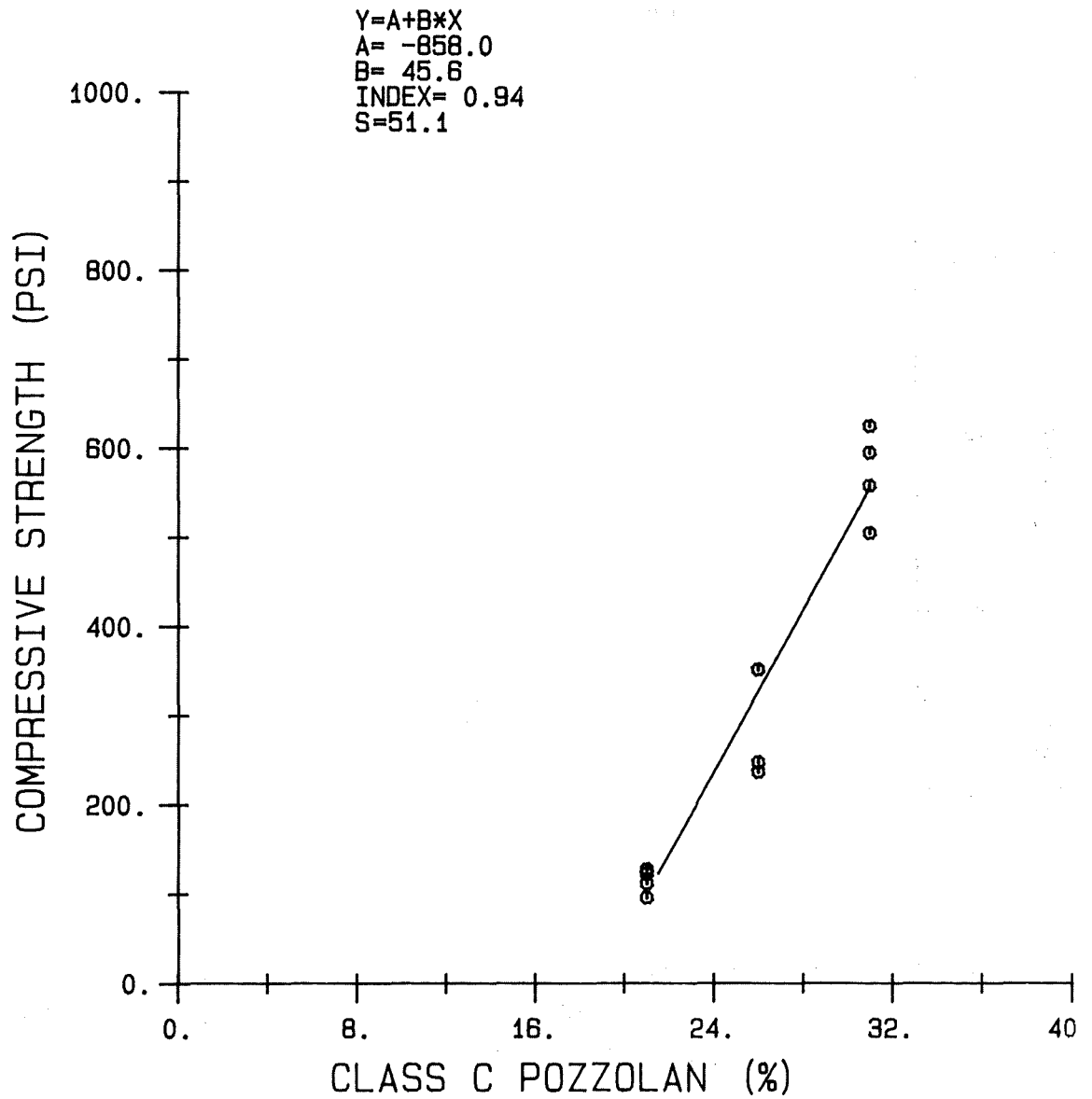


FIGURE 6.4 - Variation in compressive strength with increasing Class C pozzolan control - alluvial sand: Class C pozzolan.

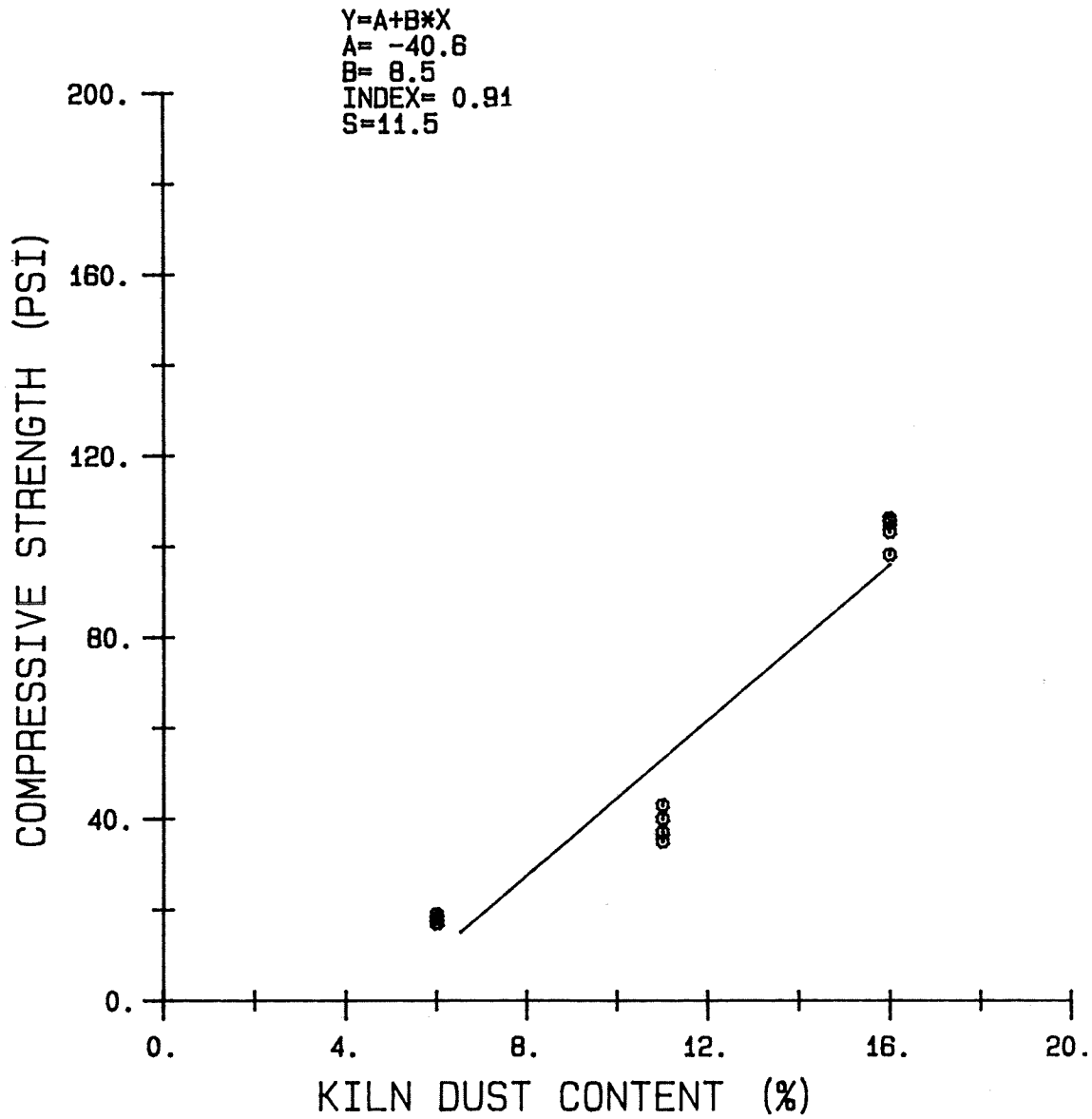


FIGURE 6.5 - Variation in compressive strength with increasing kiln dust content - alluvial sand: Class F pozzolan: kiln dust.

TABLE 6.3 - Comparison of rate of strength change

Mixture no.	Description	Rate of strength increase/decrease (psi/%)	Index of determination
1	Portland cement - Class F*	100.0	0.80
2	Alluvial sand:Class F:Portland cement*	87.3	0.87
3	Alluvial sand:Class F*:Portland cement	4.1	0.55
4	Alluvial sand:Class C*	45.6	0.94
5	Alluvial sand:Kiln dust*:Class F	8.53	0.92

* Correlated parameter

strength increase over a range of 6 to 16 percent, even with 15 percent Class F pozzolan.

6.4 TWO FACTOR ANALYSIS OF VARIANCE

A two factor analysis of variance was performed to indicate whether the magnitude of the strength variations was due to changes in active components or due to random variations introduced by the replicated testing. The analysis was performed for mixtures 2, 3, 4 and 5 in Table 6.2. Mixture (1) was not included in the analysis because it did not contain the alluvial sand aggregate. The analysis, following the method outlined by Spiegel (6), was used to identify the variance in the data produced by the different mixtures, the different ratios, the interactions, the replications and the random error. Table 6.4 lists the results of the analysis. The analysis of variance indicated that the majority of variance in

TABLE 6.4 - Two factor analysis of variance of data from alluvial sand mixtures

Variation	Degree of freedom	Mean square (psi) ²	F ratio	F* critical
Between mixtures	3	381,343	239.5	2.89
Between ratios	2	220,283	138.4	3.29
Interaction	6	41,394	26.0	2.40
Replications	3	1,810	1.13	2.89
Random error	33	1,592	--	--
Total	47	--	--	--

* 95 percent level of confidence

the results is due to the different mixtures (aggregates and active ingredients) and the different pozzolan/cement ratios. This correlates well with the design of the experiment, which was to show the strong effect of the changing pozzolan content with the compressive strength, the dependent variable.

The components of variance are compared to the variance of random error by calculating the "F ratio," equal to the mean square value of the particular component of variance, divided by the mean square value of random error variance. The calculated "F ratio" is then compared to a "critical value" of F derived from a table of values tabulated for the degrees of freedom of the numerator and denominator, at a 95 percent level of confidence. A comparison of the "F ratio" to the F critical indicates whether the two variances are derived from the same population.

In Table 6.4, "F ratios" for the different mixtures, different pozzolan contents and the interactions are greater than the critical values, indicating that the strength of the samples for different groupings is significantly different. The large value of the interaction variance is significant since it indicates that superior performance (increases in strength) is dependent on both the proportions of active ingredients and the mixture of ingredients. The "F ratio" for the variance due to replications is less than the critical value, indicating that the replications did not introduce significant differences into the results.

The analysis of variance indicates that the random or experimental error is a small effect in data variance. The mean square variance attributed to experimental error is 0.4 and 0.7 percent of the mean square variance attributed to the main effects of mixture type and constituent ratios.

7.0 DESIGN AND TESTING OF AN OPTIMUM BACKFILL MIXTURE

An optimum backfill mixture was designed based upon the test results from Sections 5.0 and 6.0, and other considerations, including:

- o size of backfill resource;
- o availability of pozzolanic material; and
- o economics.

7.1 MIXTURE DESIGN

Alluvial sand was selected as the backfill aggregate. The alluvial sand backfill samples generally had higher compressive strength than decomposed sandstone and either the coal waste or blended coal waste samples. The alluvial sand resource is much larger than either the decomposed sandstone or coal waste resources. Decomposed sandstone is produced by the current surface mining of coal, and the majority of this material will be needed to refill the open cuts. Limited amounts of the coal waste, which tends to reduce compressive strength, are available but would require fairly extensive handling to recover the coal, then crush the material to an acceptable size.

Class F - Product II pozzolan was selected for the optimum mixture because it produced consistent strength increases at relatively low Portland cement content, and because it is readily available in large quantities from the power plant in Centralia, Washington. The Class C pozzolan produced higher compressive strength than the Class F Portland cement mixtures, but had a very short setting time. Samples began to set up within five minutes of mixing. This setting can be slowed using commercially available

can be slowed using commercially available retarding agents; however, the use of these chemicals is costly and complicates the mixing process. Furthermore, since the backfill is to be transported by pipeline, plugging due to faulty proportions of the retarding agents could ruin the entire system. Kiln dust performed well in combination with Portland cement, but is not available in large quantities. The smelter slag is available in large quantities, but would have to be transported a long distance and then ground to acceptable size fraction. The compressive strength of the mixtures using ground smelter slag was generally the lowest of all the pozzolans.

Mixture proportions were derived from the tests discussed in Sections 5.0 and 6.0. Figure 7.1a shows the compressive strength data versus time of cure for backfill mixtures of 84 percent alluvial sand: 10 percent Class F pozzolan: 6 percent Portland cement listed in Table 5.4. A best least-square curve fit of the data using 5 different curve types also is shown with the 95 percent confidence interval around the values predicted by the curve. The same curve is shown in Figure 7.1b where the strength has been normalized to the 28 day strength (123 psi) predicted by the best fit equation. The correspondence between the curves and data is very good, as indicated by the high value of the Index of Determination (0.97). This equation was used to extrapolate the testing from both the preliminary and replicated testing shown in Figure 7.2. Based upon a predicted 28 day strength of 118 psi from Figure 7.2, the 90 day strength of the 10 percent pozzolan: 6 percent Portland cement with alluvial sand would be 209 psi (1.77 times the 28 day strength).

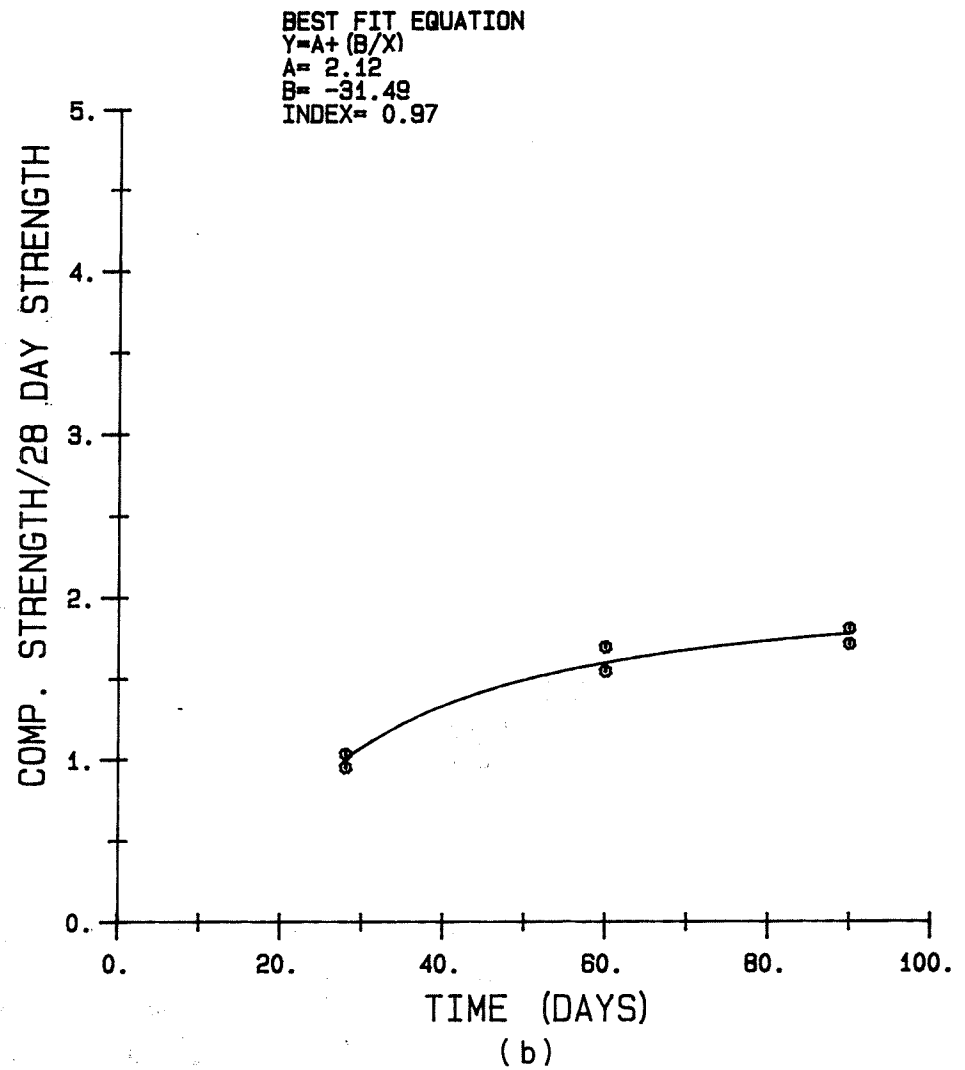
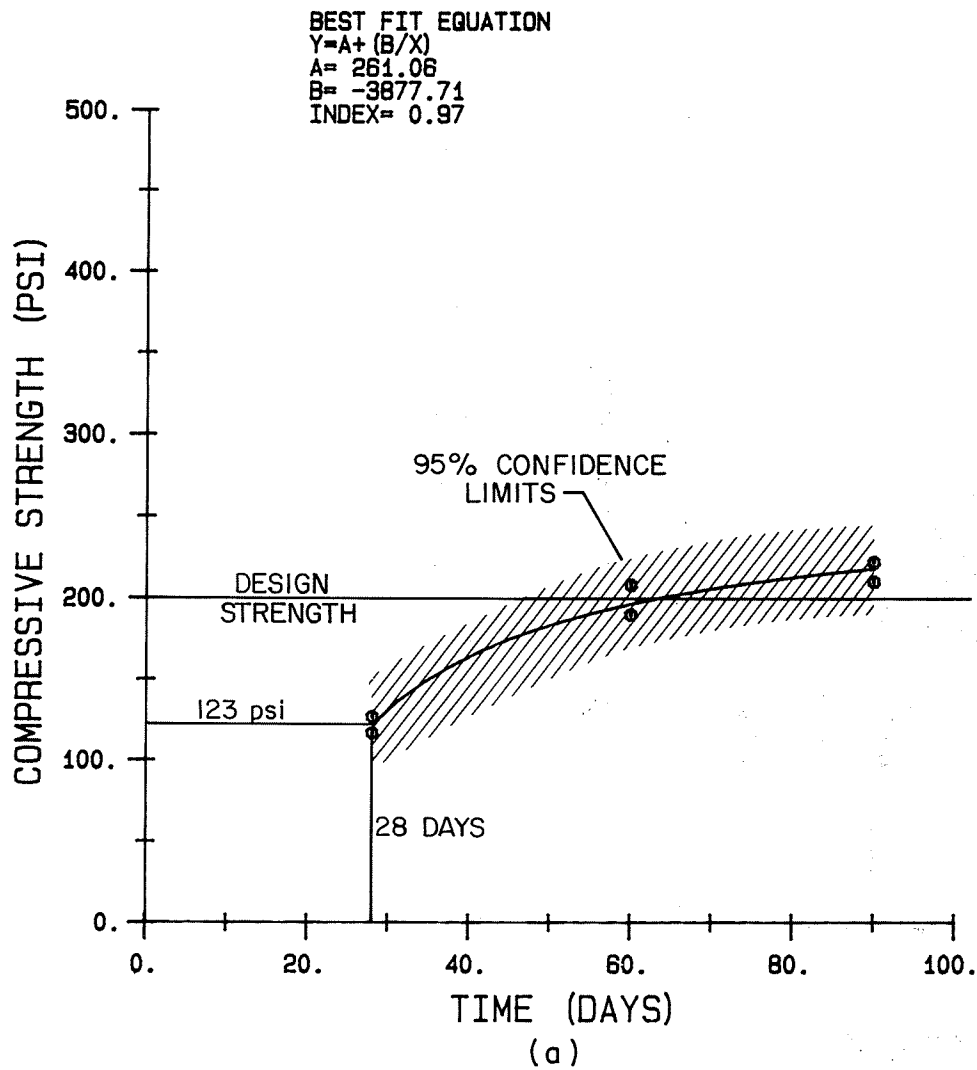


FIGURE 7.1 - Compressive strength versus curing time for preliminary testing of 84 percent alluvial sand: 10 percent Class F pozzolan: 6 percent Portland cement at 23 percent water by weight.

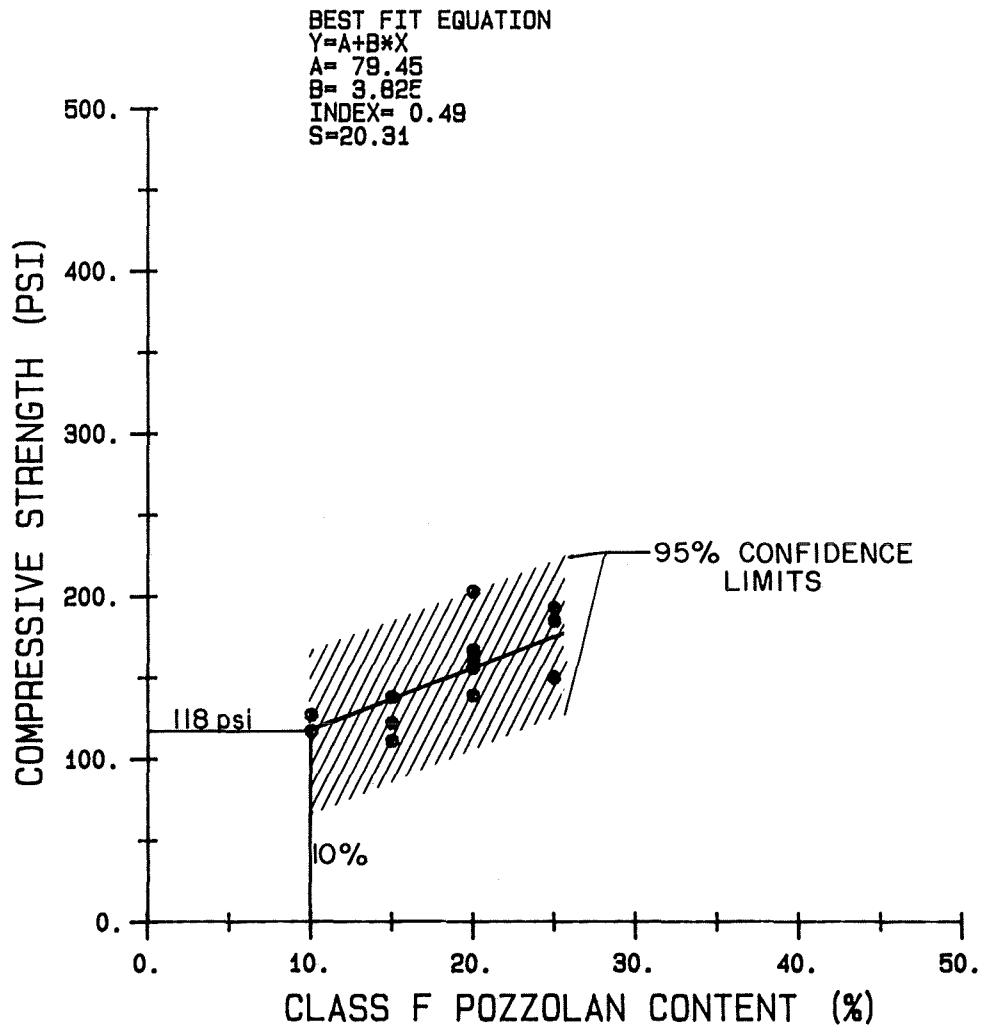


FIGURE 7.2 - 28 day compressive strength versus Class F pozzolan content for alluvial sand with six percent Portland cement.

On the basis of preliminary testing and the considerations outlined above, a design mixture of 84 percent alluvial sand, 10 percent Class F pozzolan and 6 percent Portland cement was selected as optimum.

Viscosity measurements on previous tests of this mixture had shown that at 23 percent water by weight (77 percent solids by weight), the viscosity was very near the 60 Marsh second specification. Therefore, the water content for the optimum mix design testing was varied to bracket this ratio at 20, 23 and 26 percent.

The resulting test matrix is presented in Table 7.1. The testing included both uniaxial compression tests and triaxial compression tests at confining pressures of 50, 100 and 200 psi. All samples of the optimum mixture were formed in the 2.0 in. diameter cardboard tubes.

7.2 VISCOSITY OF OPTIMUM MIXTURE

Viscosity measurements were made for the three different water contents. The data are presented in Table 7.2, and shown graphically in Figures 7.3a and b. The measurements indicate that the 23 percent water content is the minimum necessary to reach the design specifications of 60 Marsh seconds. This result compared well to the previous measurements.

7.3 RESULTS OF THE UNIAXIAL COMPRESSION TESTS

Uniaxial compressive strength was measured after the samples had cured for 28, 60 and 90 days. The test results are listed in Table 7.3. The 28 day strength of the mixture with 23 percent water was somewhat lower than expected, but within the range of the preliminary testing data. Based upon the average 28 day strength

TABLE 7.1 - Test matrix of optimum mixture

Test type	Water ¹ content (wt %)	Number of samples		
		Length of cure (days)		
		28	60	90
Uniaxial compressive	20	4	4	4
	23	4	4	4
	26	4	4	4
Triaxial @ 50 psi	20	2	2	2
	23	2	2	2
	26	2	2	2
Triaxial @ 100 psi	20	2	2	2
	23	2	2	2
	26	2	2	2
Triaxial @ 200 psi	20	2	2	2
	23	2	2	2
	26	2	2	2

¹ Wt. percent of total constituents (water, aggregate, pozzolan, Portland cement)

TABLE 7.2 - Measurements of viscosity of optimum mixtures

Water content (%)	Viscosity measurements	
	Marsh funnel (Marsh seconds)	Fann viscometer (centipoise)
20	122	3040
23	53	1520
26	43	1010

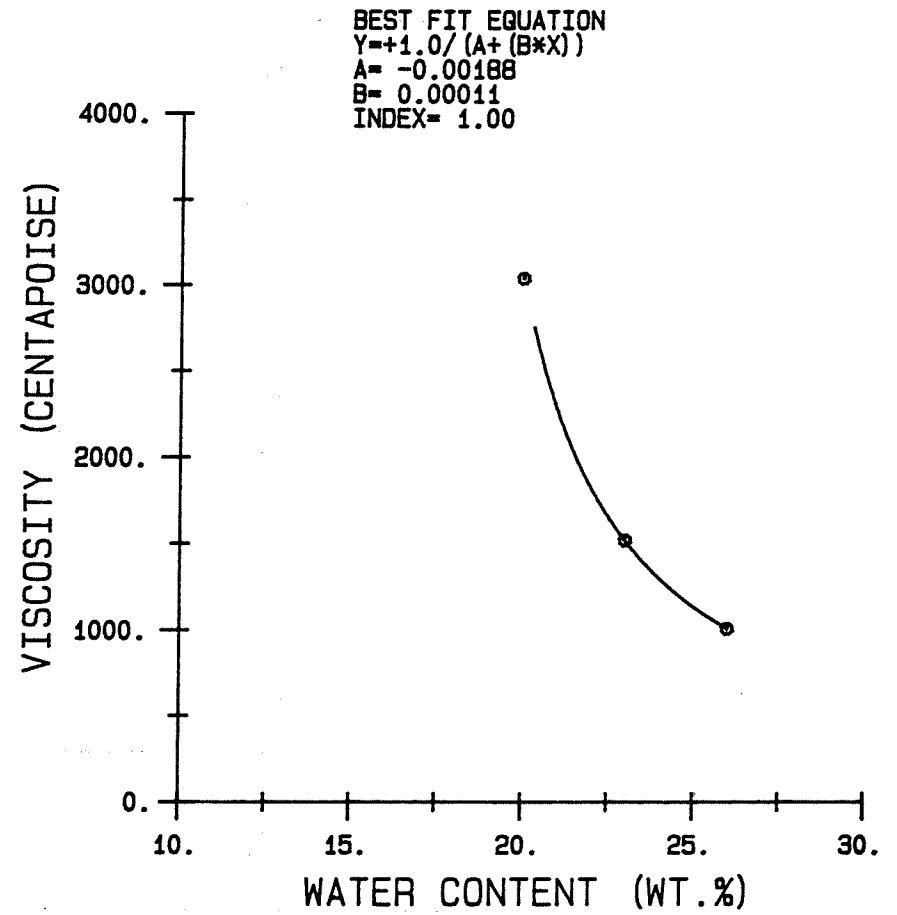
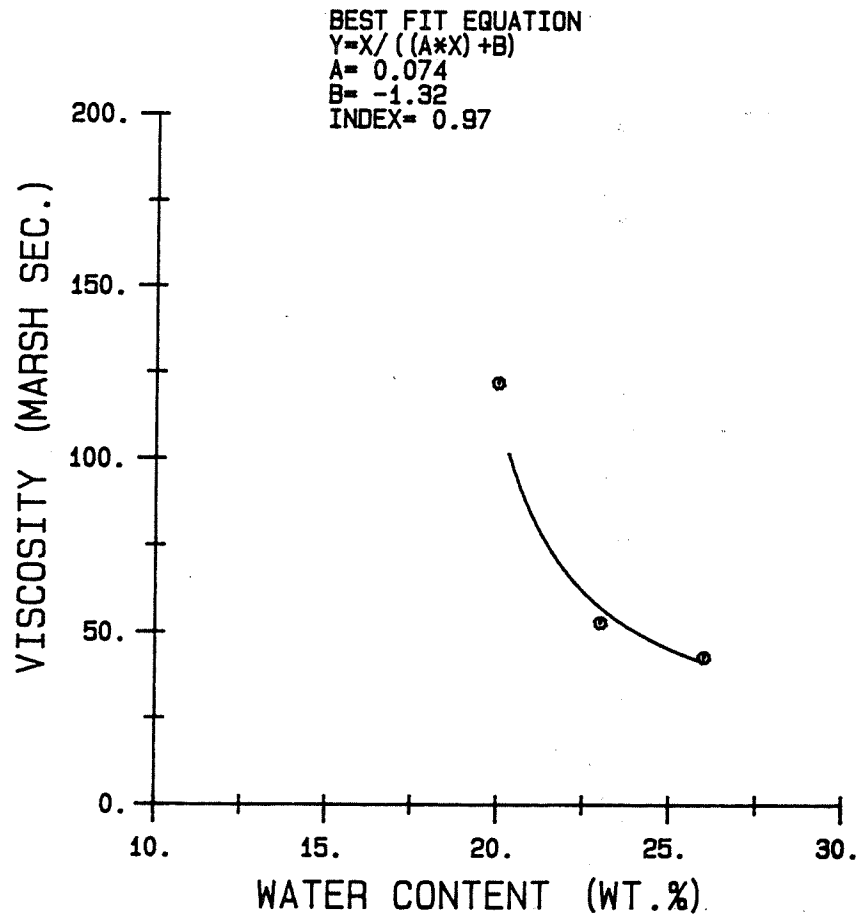


FIGURE 7.3 - Viscosity versus water content for the optimum mixture design.

TABLE 7.3 - Uniaxial compressive strength test results

Water content (percent)	Compressive strength (psi)		
	28 day	60 day	90 day
20	123	137	210
	132	105	185
	97	143	134
	105	121	*
	Average	114	127
23	108	94	117
	110	84	113
	91	97	121
	108	87	*
	Average	104	91
26	64	76	120
	54	67	102
	57	63	89
	56	62	*
	Average	58	67

* Samples broken during preparation

of 104 psi, and the relationship presented in Figure 7.1, the strength at 90 days would be 184 psi or 92 percent of the design strength. However, subsequent tests at 60 and 90 days did not show any strength increase in the 23 percent water mixture. The test results presented in Table 7.3 indicated a general reduction in strength with increasing water content. The 20 percent and 26 percent water mixtures showed gradual strength increases with 90 day strengths of 1.54 and 1.79 times the 28 day strength, respectively.

There is no apparent explanation as to why these mixtures showed lower uniaxial compressive strength than expected.

7.4 RESULTS OF TRIAXIAL COMPRESSION TESTING

Triaxial testing data is presented in Figures 7.4, 7.5 and 7.6 for each of the three water contents, respectively. The figures show the data scatter and linear least-square fits of the confining pressure (p) versus the axial stress (σ_1). Curve fitting produces parameters for equation (1):

$$\sigma_1 = C_0 + N P \quad (1)$$

where:

- σ_1 = axial stress
- C_0 = uniaxial compressive strength
- N = confinement factor
- P = confining pressure

The goodness of fit of the straight line is described by the Index of Determination, which is the square of the correlation

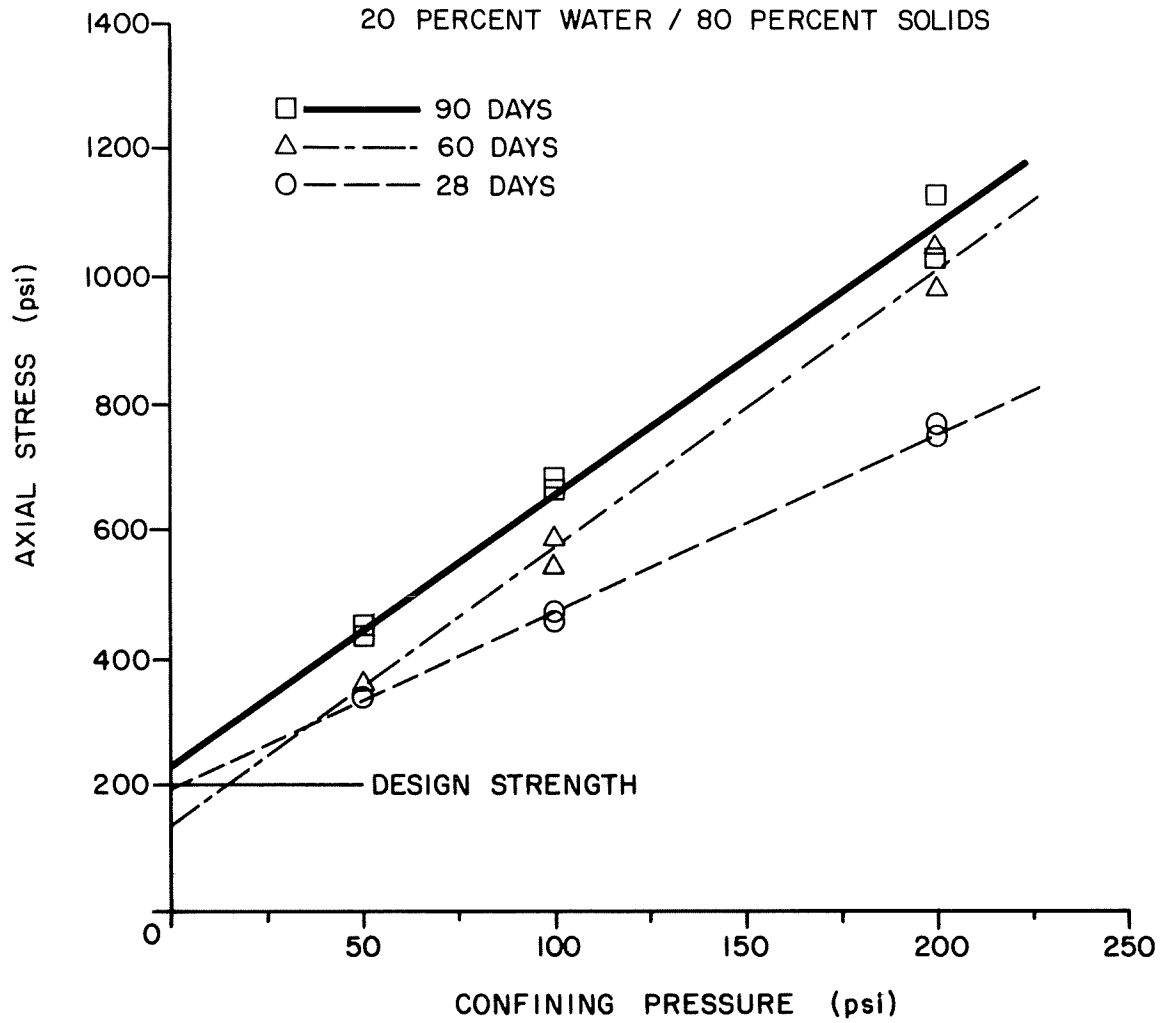


FIGURE 7.4 - Triaxial test results, 20 percent water.

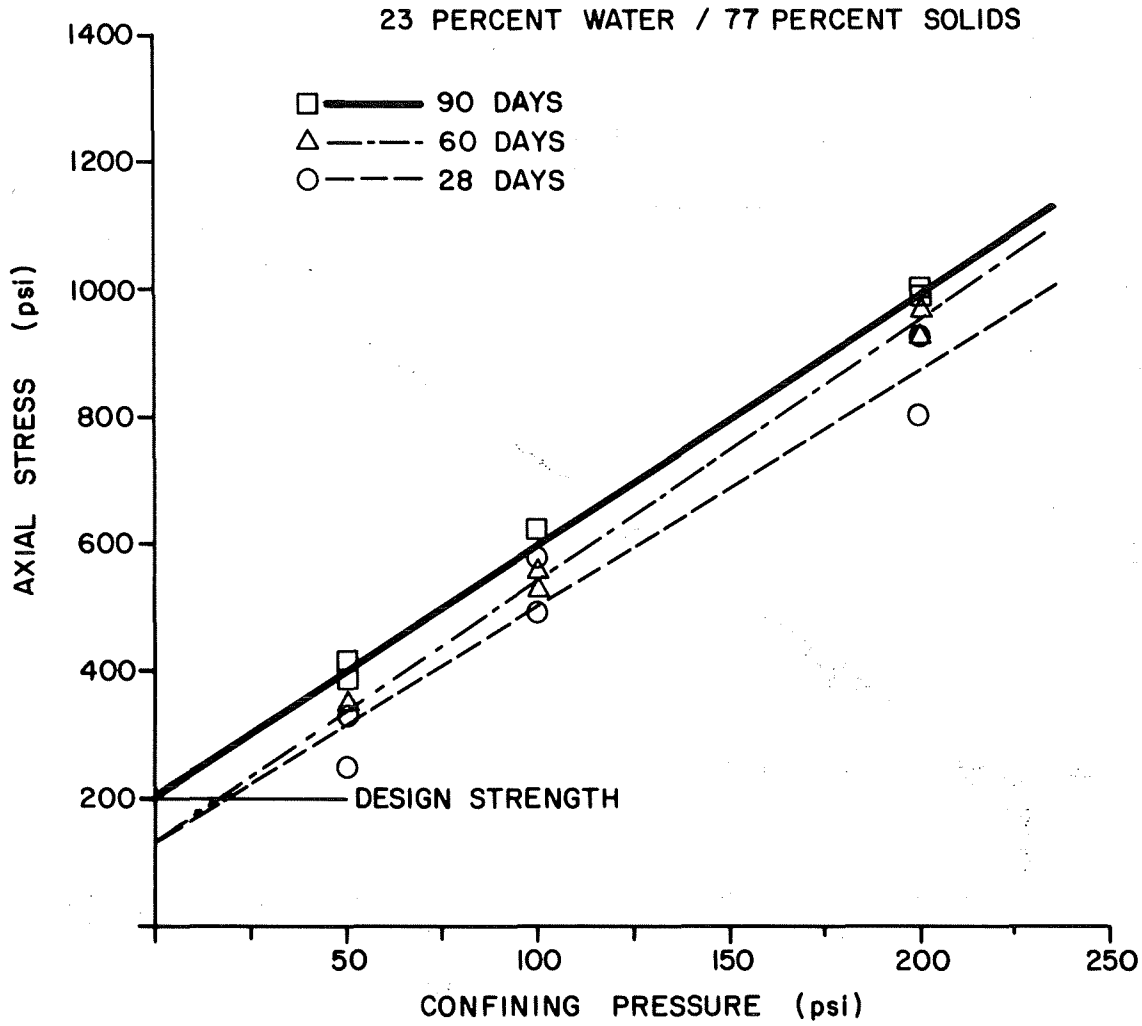


FIGURE 7.5 - Triaxial test results, 23 percent water.

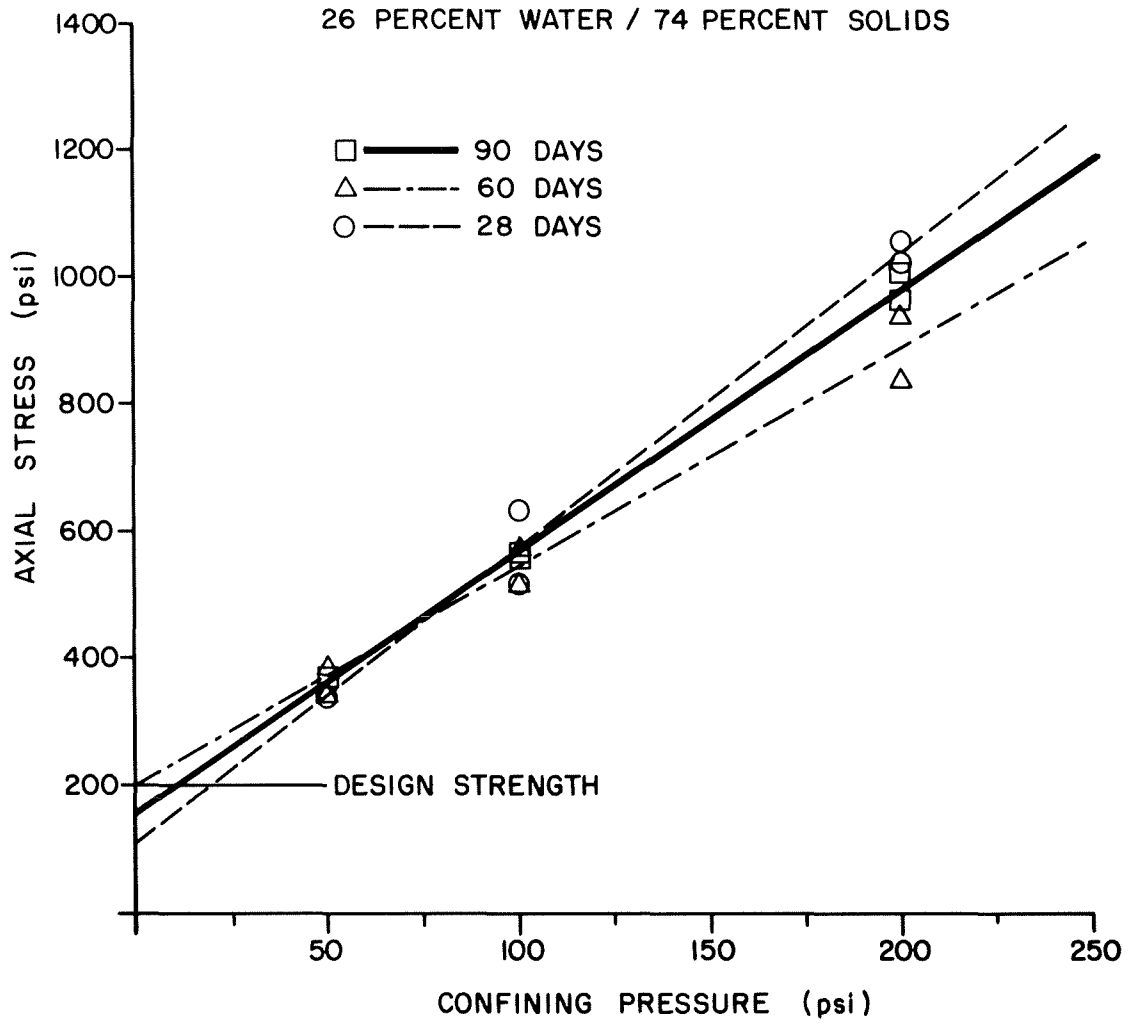


FIGURE 7.6 - Triaxial test results, 26 percent water.

coefficient. An index of 1.0 indicates a perfect fit between the data and the curve.

The Mohr-Coulomb failure criteria can be derived from the parameters of C_0 and N . The Mohr-Coulomb criterion relates the shear stress (τ) to the normal stress (σ) by equation (2):

$$\tau = S_0 + \sigma \tan \phi \quad (2)$$

where: τ = shear stress on the failure plane
 S_0 = intrinsic shear strength of cohesion
 σ = normal stress on the failure plane
 ϕ = angle of internal friction

and: $\phi = 2[(\tan^{-1} \sqrt{N}) - 45]$
 $S_0 = C_0 / 2 \sqrt{N}$

The parameters for equations 1 and 2 and the Indices of Determination for the data are listed in Table 7.4. The Indices of Determination are very high for all of the curve fits. Uniaxial compressive strength values predicted by the triaxial testing indicate an increase in strength between the 28 day and 90 day tests. The values of the confinement factor are variable but range between 3.93 and 4.24 for the 90 day tests. The corresponding range in angle of internal friction at 90 days is 36.5 to 38.2 degrees.

The triaxial data suggest the 23 percent water mixture will have a uniaxial strength of 206 psi at 90 days. This value agrees well

TABLE 7.4 - Coefficients of linear failure criteria and Indices of Determination

Water Content	Length of cure (days)	Index of Determination	$\sigma_1 = C_0 + N P$		$\tau = S_0 + \tan \phi$	
			C_0 (psi)	N	S_0 (psi)	ϕ (degrees)
20	28	0.998	188	2.79	56.2	28.2
	60	0.994	136	4.35	32.6	38.8
	90	0.989	232	4.24	56.3	38.2
23	28	0.947	128	3.71	33.2	35.2
	60	0.996	133	4.08	32.9	37.3
	90	0.997	206	3.93	52.0	36.5
26	28	0.986	111	4.64	25.8	40.2
	60	0.972	197	3.48	52.8	33.6
	90	0.996	163	4.11	40.2	37.5

with the results presented in Section 5.0 (preliminary testing) and the results of Section 6.0 (replicated testing).

7.5 DISCUSSION

The majority of the testing performed on the optimum mixture indicates that it meets the specifications required by the contract. Uniaxial compressive strength tests presented in Section 7.3 did not reach the design strength requirement, but identical mixtures tested earlier and discussed in sections 5.0 and 6.0 showed reproducible strengths at 28 days with an average of 122 psi. These values agreed well with strength versus Class F pozzolan content correlations performed in Section 6.0. Limited testing data for 60 and 90 days of curing showed the strength of the optimum mix increasing by a factor of 1.77 in the data presented in Section 5.0, and exceeding the design strength requirements. Linear fits of triaxial compressive strength versus confining pressure gave estimates of uniaxial compressive strength of 206 psi at 90 days for a mixture with 23 percent water/77 percent solids.

Viscosity of the optimum mixture with 23 percent water/77 percent solids was 53 Marsh seconds or very near the design specification. This water content is slightly lower than industry practice, which typically pumps backfill at 70 percent solids/30 percent water. The relatively high proportion of Class F pozzolan improves the pumpability without the addition of large quantities of water. The greater proportion of fines also acts to reduce cementing agent bleed-off.

8.0 REFERENCES

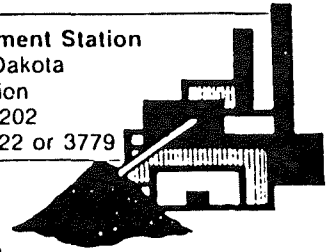
1. ASTM Book of Standards. American Society for Testing and Materials, Philadelphia, 1980.
2. Wayment, W. R. Backfill with Tailings, Mining with Backfill (12th Canadian Rock Mechanics Symposium, Canada). Inst. of Min. & Met., Montreal, 1978.
3. De Jongh, C. L. Design Parameters Used and Backfill Materials Selected for a New Base-Metal Mine in the Republic of South Africa (Applications of Rock Mechanics to Cut and Fill Mining, Lulea Conference). Inst. of Min. & Met., London, 1980.
4. Thomas, E. G. and R. Cowling. Pozzolanic Behavior of Ground Isa Mine Slag in Cemented Hydraulic Mine Fill at High Slag/Cement Ratios, Mining with Backfill (12th Canadian Rock Mechanics Symposium, Canada). Inst. of Min. & Met., Montreal, 1978.
5. McGuire, A. J. Falconbridge Slag as a Cementing Agent in Backfill, Mining with Backfill (12th Canadian Rock Mechanics Symposium, Canada). Inst. of Min. & Met., Montreal, 1978.
6. Spiegel, M. R. Theory and Problems of Probability and Statistics, Schaum's Outline Series, McGraw-Hill, New York, NY, 1975.

APPENDIX A

Chemical and Physical
Analyses of Additives

COAL BY-PRODUCTS UTILIZATION INSTITUTE

Engineering Experiment Station
University of North Dakota
8115 University Station
Grand Forks, ND 58202
Phone: (701) 777-4222 or 3779



CHEMICAL AND PHYSICAL ANALYSES OF FLY ASH

REPORT TO: Pozzolanic International DATE: 6/29/84

Laboratory No. 84-228

Sample Identification: Centralia Steam Plant, Comp #107, Dockets 15844-15875, 2/23/84

Date Received: 4/6/84

ASTM: C 618

SPECIFICATIONS

CLASS F

CLASS C

CHEMICAL COMPOSITION(%):

Silicon Oxide (SiO ₂)	<u>48.3</u>		
Aluminum Oxide (Al ₂ O ₃)	<u>24.4</u>		
Iron Oxide (Fe ₂ O ₃)	<u>5.8</u>		
Total (SiO ₂ + Al ₂ O ₃ + Fe ₂ O ₃)	<u>78.5</u>	<u>70.0 Min</u>	<u>50.0 Min</u>
Sulfur Trioxide (SO ₃)	<u>.75</u>	<u>5.0 Max</u>	<u>5.0 Max</u>
Calcium Oxide (CaO)	<u>8.6</u>		
Moisture Content	<u>.06</u>	<u>3.0 Max</u>	<u>3.0 Max</u>
Loss of Ignition	<u>.10</u>	<u>12.0 Max</u>	<u>6.0 Max</u>

PHYSICAL TEST RESULTS:

Fineness			
Retained on #325 sieve, (%)	<u>12.65</u>	<u>34 Max</u>	<u>34 Max</u>
Pozzolanic Activity Index			
With Portland Cement (%)			
Ratio to Control @ 28 days	<u>85</u>	<u>75 Min</u>	<u>75 Min</u>
With Lime @ 7 days (psi)	<u>1083</u>	<u>800 Min</u>	<u>800 Min</u>
Water Requirement, % of Control	<u>92</u>	<u>105 Max</u>	<u>105 Max</u>
Soundness			
Autoclave Expansion (%)	<u>.06</u>	<u>0.8 Max</u>	<u>0.8 Max</u>
Specific Gravity	<u>2.25</u>		

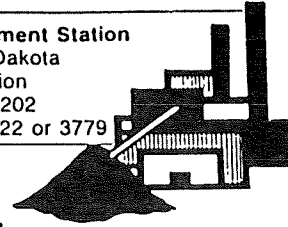
REMARKS:

Coal By-Products Utilization Institute

Oscar E. Manz
Oscar E. Manz, Director

COAL BY-PRODUCTS UTILIZATION INSTITUTE

Engineering Experiment Station
University of North Dakota
8115 University Station
Grand Forks, ND 58202
Phone: (701) 777-4222 or 3779



CHEMICAL AND PHYSICAL ANALYSES OF FLY ASH

REPORT TO: Pozzolanlc International DATE: 3/09/84

Laboratory No. 83-733

Sample Identification: Boardman, BM-315-83, 4th week, 11/29/83

Date Received: 12/12/83

ASTM: C 618
SPECIFICATIONS
CLASS F CLASS C

CHEMICAL COMPOSITION(%):

Silicon Oxide (SiO ₂)	<u>36.5</u>		
Aluminum Oxide (Al ₂ O ₃)	<u>14.9</u>		
Iron Oxide (Fe ₂ O ₃)	<u>6.7</u>		
Total (SiO ₂ + Al ₂ O ₃ + Fe ₂ O ₃)	<u>58.1</u>	70.0 Min	50.0 Min
Sulfur Trioxide (SO ₃)	<u>3.30</u>	5.0 Max	5.0 Max
Calcium Oxide (CaO)	<u>28.8</u>		
Moisture Content	<u>.05</u>	3.0 Max	3.0 Max
Loss of Ignition	<u>.23</u>	12.0 Max	6.0 Max

PHYSICAL TEST RESULTS:

Fineness			
Retained on #325 sieve, (%)	<u>14.97</u>	34 Max	34 Max
Pozzolanic Activity Index			
With Portland Cement (%)			
Ratio to Control @ 28 days	<u>86</u>	75 Min	75 Min
With Lime @ 7 days (psi)	<u>1835</u>	800 Min	800 Min
Water Requirement, % of Control	<u>87</u>	105 Max	105 Max
Soundness			
Autoclave Expansion (%)	<u>.26</u>	0.8 Max	0.8 Max
Specific Gravity	<u>2.67</u>		

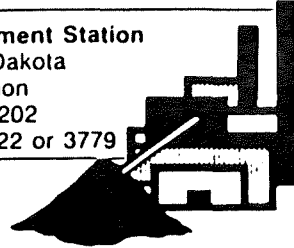
REMARKS:

Coal By-Products Utilization Institute

Oscar E. Manz
Oscar E. Manz, Director

COAL BY-PRODUCTS UTILIZATION INSTITUTE

Engineering Experiment Station
University of North Dakota
8115 University Station
Grand Forks, ND 58202
Phone: (701) 777-4222 or 3779



REPORT OF: Slag

REPORT TO: JFT Agapito Associates Inc. DATE: December 4, 1984

Laboratory No. 84-579

Sample Identification: _____

Date Received: 10/01/84

CHEMICAL COMPOSITION (%):

Silicon Oxide (SiO ₂)	<u>32.8</u>
Aluminum Oxide (Al ₂ O ₃)	<u>8.3</u>
Iron Oxide (Fe ₂ O ₃)	<u>37.6</u>
Total (SiO ₂ + Al ₂ O ₃ + Fe ₂ O ₃)	<u>78.6</u>
Sulfur Trioxide (SO ₃)	<u>2.85</u>
Calcium Oxide (CaO)	<u>20.1</u>
Magnesium Oxide (MgO)	<u>2.5</u>
Moisture Content	<u>1.20</u>
Loss on Ignition	<u>- .59</u>

REMARKS:

Coal By-Products Utilization Institute

Oscar E. Manz
Oscar E. Manz, Director

**Ideal Basic Industries
Cement Division**

Seattle Plant
5400 West Marginal Way S.W.
Seattle, Washington 98106
206 937 8025

August 21, 1980

IDEALTYPICAL WASTE DUST ANALYSIS

SiO	12.5	
Al ₂ O ₃	2.9	
Fe ₂ O ₃	1.9	
CaO	49.7	
MgO	0.7	
SO ₃	4.8	
Na ₂ O	0.5	
K ₂ O	1.4	
Loss	24.8	
Fineness	-325	86%
	-200	95%

APPENDIX B

Viscosity and Compressive
Strength Test Data

Sample Identification			Water/Cement Ratio		Viscosity		Compressive Strength (psi)
No.	Constituent	(%)	Portland	Total ⁽¹⁾	Marsh (seconds)	Fann (centipoise)	
11A1	Portland Cement	80	.63	.50	114.2	4050	28 day - 7279
11A2	Class F - Plant Run	20					28 day - 7783
11A3	Water Content	50					60 day - 7455
11A4							90 day - 7602
11B1	Portland Cement	65	.77	.50	66.3	2790	28 day - 4681
11B2	Class F - Plant Run	35					28 day - 6865
11B3	Water Content	50					60 day - 7956
11B4							90 day - 8382
11C1	Portland Cement	50	1.00	.50	57.3	1770	28 day - 5434
11C2	Class F - Plant Run	50					28 day - 4405
11C3	Water Content	50					60 day - 4435
11C4							90 day - 5116
12A1	Portland Cement	80	.63	.50	117.3	3550	28 day - 6905
12A2	Class F - Product II	20					28 day - 8054
12A3	Water Content	50					60 day - 8202
12A4							90 day - 7195
12B1	Portland Cement	65	.77	.50	68.4	2030	28 day - 5455
12B2	Class F - Product II	35					28 day - 5027
12B3	Water Content	50					60 day - 8089
12B4							90 day - 8072
12C1	Portland Cement	50	1.00	.50	54.2	1770	28 day - 5484
12C2	Class F - Product II	50					28 day - 4478
12C3	Water Content	50					60 day - 3655
12C4							90 day - 6551

(1) Total water cement ratio + pozzolan
Water content expressed as a percentage of weight of solid constituents

Sample Identification			Water/Cement Ratio		Viscosity		Compressive Strength (psi)
No.	Constituent	(%)	Portland	Total ⁽¹⁾	Marsh (seconds)	Fann (centipoise)	
13A1	Portland Cement	80	.60	.48	135.2	4310	28 day - 8276
13A2	Class C	20					28 day - 6730
13A3	Water Content	48					60 day - 9961
13A4							90 day - 9807
13B1	Portland Cement	65	.79	.52	57.3	2530	28 day - 5762
13B2	Class C	35					28 day - 6249
13B3	Water Content	52					60 day - 5511
13B4							90 day - 4486
13C1	Portland Cement	50	1.03	.52	50.0	2030	28 day - 4895
13C2	Class C	50					28 day - 5817
13C3	Water Content	52					60 day - 4510
13C4							90 day - 1446
14A1	Portland Cement	80	.63	.50	177.3	5830	28 day - 6722
14A2	Kiln Dust	20					28 day - 5949
14A3	Water Content	50					60 day - 7751
14A4							90 day - 7723
14B1	Portland Cement	65	.77	.50	166.8	5570	28 day - 5611
14B2	Kiln Dust	35					28 day - 6472
14B3	Water Content	50					60 day - 6809
14B4							90 day - 4049
14C1	Portland Cement	50	1.07	.53	124.7	4560	28 day - 3307
14C2	Kiln Dust	50					28 day - 2808
14C3	Water Content	53					60 day - 2716
14C4							90 day - 3825

(1) Total water cement ratio + pozzolan
Water content expressed as a percentage of weight of solid constituents

No.	Sample Identification		Water/Cement Ratio		Viscosity		Compressive Strength (psi)
	Constituent	(%)	Portland	Total ⁽¹⁾	Marsh (seconds)	Fann (centipoise)	
15A1	Portland Cement	80	.63	.50	77.9	2790	28 day - 6739
15A2	Smelter Slag	20					28 day - 6417
15C3	Water Content	50					60 day - 5417
15C4							90 day - 3527
15B1	Portland Cement	65	.77	.50	56.3	2030	28 day - 6489
15B2	Smelter Slag	35					28 day - 7563
15B3	Water Content	50					60 day - 6189
15B3							90 day - 3873
15C1	Portland Cement	50	1.00	.50	43.1	1520	28 day - 4999
15C2	Smelter Slag	50					28 day - 3670
15C3	Water Content	50					60 day - 5394
15C4							90 day - 7475
1-1	Alluvial Sand	94	5.0	5.0	*	*	28 day - 67
1-2	Class F - Plant Run	0					28 day - 63
1-3	Cement	6					60 day - 114
1-4	Water Content	30					90 day - 110
2-1	Alluvial Sand	84	5.0	1.9	*	2290	28 day - 124
2-2	Class F - Plant Run	10					28 day - 110
2-3	Cement	6					60 day - 190
2-4	Water Content	30					90 day - 210
3-1	Alluvial Sand	74	5.0	1.2	*	2290	28 day - 171
3-2	Class F - Plant Run	20					28 day - 162
3-3	Cement	6					60 day - 347
3-4	Water Content	30					90 day - 350

(1) Total water cement ratio + pozzolan

* Not measureable due to aggregate - water separation

Water content expressed as a percentage of weight of solid constituents

Sample Identification			Water/Cement Ratio		Viscosity		Compressive Strength (psi)
No.	Constituent	(%)	Portland	Total ⁽¹⁾	Marsh (seconds)	Fann (centipoise)	
4-1	Alluvial Sand	94	5.0	5.0	140.5	2530	28 day - 64
4-2	Class F - Product II	0					28 day - 77
4-3	Portland Cement	6					60 day - 116
4-4	Water Content	30					90 day - 94
5-1	Alluvial Sand	84	5.0	1.9	64.7	2030	28 day - 120
5-2	Class F - Product II	10					28 day - 134
5-3	Portland Cement	6					60 day - 208
5-4	Water Content	30					90 day - 222
6-1	Alluvial Sand	74	5.0	1.2	53.7	2030	28 day - 229
6-2	Class F - Product II	20					28 day - 177
6-3	Portland Cement	6					60 day - 325
6-4	Water Content	30					90 day - 343
7-1	Alluvial Sand	94	5.0	5.0	*	*	28 day - 59
7-2	Class C	0					28 day - 66
7-3	Portland Cement	6					60 day - 87
7-4	Water Content	30					90 day - 104
8-1	Alluvial Sand	84	5.0	1.9	48.9	1770	28 day - 87
8-2	Class C	10					28 day - 82
8-3	Portland Cement	6					60 day - 246
8-4	Water Content	30					90 day - 311
9-1	Alluvial Sand	74	5.0	1.2	43.7	1770	28 day - 173
9-2	Class C	20					28 day - 155
9-3	Portland Cement	6					60 day - 410
9-4	Water Content	30					90 day - 550

(1) Total water cement ratio + pozzolan

* Not measureable due to aggregate - water separation

Water content expressed as a percentage of weight of solid constituents

Sample Identification			Water/Cement Ratio		Viscosity		Compressive Strength (psi)
No.	Constituent	(%)	Portland	Total ⁽¹⁾	Marsh (seconds)	Fann (centipoise)	
10-1	Alluvial Sand	84	5.0	1.9	63.7	2280	28 day - 210
10-2	Kiln Dust	10					28 day - 239
10-3	Portland Cement	6					60 day - 518
10-4	Water Content	30					90 day - 542
11-1	Alluvial Sand	74	5.0	1.2	74.2	2280	28 day - 426
11-2	Kiln Dust	20					28 day - 422
11-3	Portland Cement	6					60 day - 961
11-4	Water Content	30					90 day - 854
12-1	Alluvial Sand	84	5.0	1.9	76.8	2530	28 day - 85
12-2	Smelter Slag	10					28 day - 89
12-3	Portland Cement	6					60 day - 130
12-4	Water Content	30					90 day - 139
13-1	Alluvial Sand	74	5.0	1.2	62.6	1770	28 day - 123
13-2	Smelter Slag	20					28 day - 125
13-3	Portland Cement	6					60 day - 243
13-4	Water Content	30					90 day - 231

(1) Total water cement ratio + pozzolan
Water content expressed as a percentage of weight of solid constituents

Sample Identification			Water/Cement Ratio		Viscosity		Compressive Strength (psi)
No.	Constituent	(%)	Portland	Total ⁽¹⁾	Marsh (seconds)	Fann (centipoise)	
14-1	Decomposed Sandstone	94	5.0	5.0	237.2	8100	28 day - 57
14-2	Class F - Plant Run	0					28 day - 74
14-3	Portland Cement	6					60 day - 90
14-4	Water Content	30					90 day - 71
15-1	Decomposed Sandstone	84	6.7	2.5	58.9	2790	28 day - 77
15-2	Class F - Plant Run	10					28 day - 71
15-3	Portland Cement	6					60 day - 94
15-4	Water Content	40					90 day - 121
16-1	Decomposed Sandstone	74	6.7	1.5	55.2	2790	28 day - 130
16-2	Class F - Plant Run	20					28 day - 137
16-3	Portland Cement	6					60 day - 235
16-4	Water Content	40					90 day - 226
17-1	Decomposed Sandstone	84	5.8	2.2	80.0	3800	28 day - 132
17-2	Class F - Product II	10					28 day - 152
17-3	Portland Cement	6					60 day - 244
17-4	Water Content	35					90 day - 210
18-1	Decomposed Sandstone	74	5.8	1.3	67.9	3040	28 day - 248
18-2	Class F - Product II	20					28 day - 237
18-3	Portland Cement	6					60 day - 277
18-4	Water Content	35					90 day - 362

(1) Total water cement ratio + pozzolan
Water content expressed as a percentage of weight of solid constituents

Sample Identification			Water/Cement Ratio		Viscosity		Compressive Strength
					Marsh	Fann	
No.	Constituent	(%)	Portland	Total ⁽¹⁾	(seconds)	(centipoise)	(psi)
19-1	Decomposed Sandstone	84	6.7	2.5	89.4	2790	28 day - 131
19-2	Class C	10					28 day - 114
19-3	Portland Cement	6					60 day - 202
19-4	Water Content	40					90 day - 191
20-1	Decomposed Sandstone	74	6.7	1.5	51.6	2530	28 day - 236
20-2	Class C	20					28 day - 194
20-3	Portland Cement	6					60 day - 481
20-4	Water Content	40					90 day - 666
21-1	Decomposed Sandstone	84	5.0	1.9	129.9	5570	28 day - 101
21-2	Kiln Dust	10					28 day - 105
21-3	Portland Cement	6					60 day - 142
21-4	Water Content	30					90 day - 189
22-1	Decomposed Sandstone	74	5.0	1.2	88.9	4560	28 day - 109
22-2	Kiln Dust	20					28 day - 102
22-3	Portland Cement	6					60 day - 177
22-4	Water Content	30					90 day - 197
23-1	Decomposed Sandstone	84	5.8	2.2	91.0	4560	28 day - 128
23-2	Smelter Slag	10					28 day - 107
23-3	Portland Cement	6					60 day - 160
23-4	Water Content	35					90 day - 150
24-1	Decomposed Sandstone	74	5.8	1.3	67.9	4050	28 day - 259
24-2	Smelter Slag	20					28 day - 221
24-3	Portland Cement	6					60 day - 252
24-4	Water Content	35					90 day - 450

(1) Total water cement ratio + pozzolan
Water content expressed as a percentage of weight of solid constituents

No.	Sample Identification		Water/Cement Ratio		Viscosity		Compressive Strength (psi)
	Constituent	(%)	Portland	Total ⁽¹⁾	Marsh (seconds)	Fann (centipoise)	
25-1	Coal Wash Waste	94	5.8	5.8	199.4	5570	28 day - 102
25-2	Class F - Plant Run	0					28 day - 74
25-3	Portland Cement	6					60 day - 99
25-4	Water Content	35					90 day - 93
26-1	Coal Wash Waste	84	5.8	2.2	107.8	4310	28 day - 93
26-2	Class F - Plant Run	10					28 day - 88
26-3	Portland Cement	6					60 day - 99
26-4	Water Content	35					90 day - 102
27-1	Coal Wash Waste	74	5.8	1.3	100.5	3800	28 day - 86
27-2	Class F - Plant Run	20					28 day - 95
27-3	Portland Cement	6					60 day - 106
27-4	Water Content	35					90 day - 93
28-1	Coal Wash Waste	84	5.8	2.2	96.3	3800	28 day - 91
28-2	Class F - Product II	10					28 day - 73
28-3	Portland Cement	6					60 day - 92
28-4	Water Content	35					90 day - 96
29-1	Coal Wash Waste	74	5.8	1.3	98.4	4050	28 day - 61
29-2	Class F - Product II	20					28 day - 70
29-3	Portland Cement	6					60 day - 86
29-4	Water Content	35					90 day - 94

(1) Total water cement ratio + pozzolan
Water content expressed as a percentage of weight of solid constituents

Sample Identification			Water/Cement Ratio		Viscosity		Compressive Strength (psi)
No.	Constituent	(%)	Portland	Total ⁽¹⁾	Marsh (seconds)	Fann (centipoise)	
30-1	Coal Wash Waste	84	5.8	2.2	97.3	4310	28 day - 135
30-2	Class C	10					28 day - 129
30-3	Portland Cement	6					60 day - 123
30-4	Water Content	35					90 day - 133
31-1	Coal Wash Waste	74	5.8	1.3	77.9	3800	28 day - 141
31-2	Class C	20					28 day - 134
31-3	Portland Cement	6					60 day - 178
31-4	Water Content	35					90 day - 224
32-1	Coal Wash Waste	84	5.8	2.2	200.4	6080	28 day - 94
32-2	Kiln Dust	10					28 day - 117
32-3	Portland Cement	6					60 day - 148
32-4	Water Content	35					90 day - 214
33-1	Coal Wash Waste	74	5.8	1.3	184.1	5830	28 day - 101
33-2	Kiln Dust	20					28 day - 80
33-3	Portland Cement	6					60 day - 149
33-4	Water Content	35					90 day - 202
34-1	Coal Wash Waste	84	5.8	2.2	95.7	4310	28 day - 76
34-2	Smelter Slag	10					28 day - 63
34-3	Portland Cement	6					60 day - 111
34-4	Water Content	35					90 day - 125
35-1	Coal Wash Waste	74	5.8	1.3	90.0	2790	28 day - 77
35-2	Smelter Slag	20					28 day - 82
35-3	Portland Cement	6					60 day - 73
35-4	Water Content	35					90 day - 98

(1) Total water cement ratio + pozzolan
Water content expressed as a percentage of weight of solid constituents

Sample Identification			Water/Cement Ratio		Viscosity		Compressive Strength
					Marsh	Fann	
No.	Constituent	(%)	Portland	Total ⁽¹⁾	(seconds)	(centipoise)	(psi)
36-1	Alluvial Sand	47	5.8	5.8	98.4	2530	28 day - 71
36-2	Coal Wash Waste	47					28 day - 66
36-3	Class F - Plant Run	0					60 day - 136
36-4	Portland Cement	6					90 day - 92
	Water Content	35					
37-1	Alluvial Sand	42	5.8	2.2	86.3	2030	28 day - 57
37-2	Coal Wash Waste	42					28 day - 78
37-3	Class F - Plant Run	10					60 day - 113
37-4	Portland Cement	6					90 day - 108
	Water Content	35					
38-1	Alluvial Sand	37	5.8	1.3	76.8	2280	28 day - 102
38-2	Coal Wash Waste	37					28 day - 109
38-3	Class F - Plant Run	20					60 day - 109
38-4	Portland Cement	6					90 day - 146
	Water Content	35					
39-1	Alluvial Sand	42	5.8	2.2	62.6	2030	28 day - 120
39-2	Coal Wash Waste	42					28 day - 127
39-3	Class F - Product II	10					60 day - 163
39-4	Portland Cement	6					90 day - 133
	Water Content	35					
40-1	Alluvial Sand	37	5.8	1.3	50.5	1770	28 day - 108
40-2	Coal Wash Waste	37					28 day - 137
40-3	Class F - Product II	20					60 day - 158
40-4	Portland Cement	6					90 day - 183
	Water Content	35					

(1) Total water cement ratio + pozzolan
Water content expressed as a percentage of weight of solid constituents

Sample Identification			Water/Cement Ratio		Viscosity		Compressive Strength (psi)
No.	Constituent	(%)	Portland	Total ⁽¹⁾	Marsh (seconds)	Fann (centipoise)	
41-1	Alluvial Sand	42	5.8	2.2	65.2	2790	28 day - 120
41-2	Coal Wash Waste	42					28 day - 143
41-3	Class C	10					60 day - 163
41-4	Portland Cement	6					90 day - 206
	Water Content	35					
42-1	Alluvial Sand	37	5.8	1.3	46.3	1520	28 day - 117
42-2	Coal Wash Waste	37					28 day - 123
42-3	Class C	20					60 day - 151
42-4	Portland Cement	6					90 day - 174
	Water Content	35					
43-1	Alluvial Sand	42	5.8	2.2	87.9	3290	28 day - 119
43-2	Coal Wash Waste	42					28 day - 137
43-3	Kiln Dust	10					60 day - 181
43-4	Portland Cement	6					90 day - 260
	Water Content	35					
44-1	Alluvial Sand	37	5.8	1.3	81.5	3290	28 day - 201
44-2	Coal Wash Waste	37					28 day - 163
44-3	Kiln Dust	20					60 day - 313
44-4	Portland Cement	6					90 day - 393
	Water Content	35					
45-1	Alluvial Sand	42	5.8	2.2	66.8	2280	28 day - 79
45-2	Coal Wash Waste	42					28 day - 83
45-3	Smelter Slag	10					60 day - 99
45-4	Portland Cement	6					90 day - 113
	Water Content	35					
46-1	Alluvial Sand	37	5.8	1.3	57.9	1770	28 day - 86
46-2	Coal Wash Waste	37					28 day - 68
46-3	Smelter Slag	20					60 day - 85
46-4	Portland Cement	6					90 day - 91
	Water Content	35					

(1) Total water cement ratio + pozzolan

Sample Identification			Water/Cement Ratio		Viscosity		Compressive Strength (psi)
No.	Constituent	(%)	Portland	Total ⁽¹⁾	Marsh (seconds)	Fann (centipoise)	
47-1	Decomposed Sandstone	47	5.8	5.8	438.7	11650	28 day - 76
47-2	Coal Wash Waste	47					28 day - 88
47-3	Class F - Plant Run	0					60 day - 137
47-4	Portland Cement	6					90 day - 162
	Water Content	35					
48-1	Decomposed Sandstone	42	5.8	2.2	185.7	6840	28 day - 91
48-2	Coal Wash Waste	42					28 day - 92
48-3	Class F - Plant Run	10					60 day - 103
48-4	Portland Cement	6					90 day - 86
	Water Content	35					
49-1	Decomposed Sandstone	37	5.8	1.3	144.7	5570	28 day - 82
49-2	Coal Wash Waste	37					28 day - 93
49-3	Class F - Plant Run	20					60 day - 138
49-4	Portland Cement	6					90 day - 130
	Water Content	35					
50-1	Decomposed Sandstone	42	5.8	2.2	99.4	4810	28 day - 100
50-2	Coal Wash Waste	42					28 day - 94
50-3	Class F - Production II	10					60 day - 112
50-4	Portland Cement	6					90 day - 114
	Water Content	35					
51-1	Decomposed Sandstone	37	5.8	1.3	84.7	4310	28 day - 103
51-2	Coal Wash Waste	37					28 day - 113
51-3	Class F - Product II	20					60 day - 126
51-4	Portland Cement	6					90 day - 149
	Water Content	35					

(1) Total water cement ratio + pozzolan
Water content expressed as a percentage of weight of solid constituents

Sample Identification			Water/Cement Ratio		Viscosity		Compressive Strength (psi)
No.	Constituent	(%)	Portland	Total ⁽¹⁾	Marsh (seconds)	Fann (centipoise)	
52-1	Decomposed Sandstone	42	5.8	2.2	118.4	5830	28 day - 164
52-2	Coal Wash Waste	42					28 day - 170
52-3	Class C	10					60 day - 172
52-4	Portland Cement	6					90 day - 192
	Water Content	35					
53-1	Decomposed Sandstone	37	5.8	1.3	77.9	2530	28 day - 279
53-2	Coal Wash Waste	37					28 day - 208
53-3	Class C	20					60 day - 327
53-4	Portland Cement	6					90 day - 431
	Water Content	35					
54-1	Decomposed Sandstone	42	5.8	2.2	232.0	7850	28 day - 119
54-2	Coal Wash Waste	42					28 day - 98
54-3	Kiln Dust	10					60 day - 130
54-4	Portland Cement	6					90 day - 131
	Water Content	35					
55-1	Decomposed Sandstone	37	5.8	1.3	177.3	7350	28 day - 184
55-2	Coal Wash Waste	37					28 day - 142
55-3	Kiln Dust	20					60 day - 198
55-4	Portland Cement	6					90 day - 208
	Water Content	35					
56-1	Decomposed Sandstone	42	5.8	2.2	124.1	5570	28 day - 71
56-2	Coal Wash Waste	42					28 day - 81
56-3	Smelter Slag	10					60 day - 94
56-4	Portland Cement	6					90 day - 81
	Water Content	35					
57-1	Decomposed Sandstone	37	5.8	1.3	92.1	4310	28 day - 83
57-2	Coal Wash Waste	37					28 day - 108
57-3	Smelter Slag	20					60 day - Broke
57-4	Portland Cement	6					90 day - 84
	Water Content	35					

(1) Total water cement ratio + pozzolan of weight of solid constituents

No.	Sample Identification		Water/Cement Ratio		Viscosity		Compressive Strength (psi)
	Constituent	(%)	Portland	Total ⁽¹⁾	Marsh (seconds)	Fann (centipoise)	
58-1	Alluvial Sand	92.4	0.0	4.6	50.5	2030	28 day - Broke
58-2	Class F - Plant Run	0					28 day - Broke
58-3	Kiln Dust	7.6					60 day - 14
58-4	Water Content	35					90 day - 15
59-1	Alluvial Sand	82.4	0.0	2.0	47.3	2030	28 day - 11
59-2	Class F - Plant Run	10.0					28 day - 12
59-3	Kiln Dust	7.6					60 day - 12
59-4	Water Content	35					90 day - 22
60-1	Alluvial Sand	72.4	0.0	1.3	49.5	1520	28 day - 22
60-2	Class F - Plant Run	20.0					28 day - 21
60-3	Kiln Dust	7.6					60 day - 18
60-4	Water Content	35					90 day - 33
61-1	Decomposed Sandstone	92.4	0.0	4.6	82.6	4310	28 day - 37
61-2	Class F - Plant Run	0					28 day - 27
61-3	Kiln Dust	7.6					60 day - 25
61-4	Water Content	35					90 day - 22
62-1	Decomposed Sandstone	82.4	0.0	2.0	71.0	3550	28 day - 26
62-2	Class F - Plant Run	10.0					28 day - 28
62-3	Kiln Dust	7.6					60 day - 24
62-4	Water Content	35					90 day - 38
63-1	Decomposed Sandstone	72.4	0.0	1.3	55.8	2530	28 day - 21
63-2	Class F - Plant Run	20.0					28 day - 21
63-3	Kiln Dust	7.6					60 day - 26
63-4	Water Content	35					90 day - 30

(1) Total water cement ratio + pozzolan
Water content expressed as a percentage of weight of solid constituents

No.	Sample Identification Constituent	Water/Cement Ratio (%)	Water/Cement Ratio		Viscosity		Compressive Strength (psi)
			Portland	Total ⁽¹⁾	Marsh (seconds)	Fann (centipoise)	
64-1	Coal Wash Waste	92.4	0.0	4.6	301.4	7350	28 day - 29
64-2	Class F - Plant Run	0					28 day - Broke
64-3	Kiln Dust	7.6					60 day - 17
64-4	Water Content	35					90 day - 10
65-1	Coal Wash Waste	82.4	0.0	2.0	138.9	3800	28 day - 16
65-2	Class F - Plant Run	10.0					28 day - Broke
65-3	Kiln Dust	7.6					60 day - 16
65-4	Water Content	35					90 day - 9
66-1	Coal Wash Waste	72.4	0.0	1.3	144.1	*	28 day - 13
66-2	Class F - Plant Run	20.0					28 day - 15
66-3	Kiln Dust	7.6					60 day - 18
66-4	Water Content	35					90 day - 13
67-1	Alluvial Sand	46.2	0.0	4.6	89.4	3040	28 day - 17
67-2	Coal Wash Waste	46.2					28 day - 13
67-3	Class F - Plant Run	0					60 day - 17
67-4	Kiln Dust	7.6					90 day - 9
	Water Content	35					
68-1	Alluvial Sand	41.2	0.0	2.0	73.6	2790	28 day - 16
68-2	Coal Wash Waste	41.2					28 day - 16
68-3	Class F - Plant Run	10.0					60 day - 18
68-4	Kiln Dust	7.6					90 day - 12
	Water Content	35					
69-1	Alluvial Sand	36.2	0.0	1.3	84.7	2790	28 day - Broke
69-2	Coal Wash Waste	36.2					28 day - 23
69-3	Class F - Plant Run	20.0					60 day - 12
69-4	Kiln Dust	7.6					90 day - 13
	Water Content	35					

(1) Total water cement ratio + pozzolan
Water content expressed as a percentage of weight of solid constituents

* No data record

No.	Sample Identification Constituent (%)		Water/Cement Ratio		Viscosity		Compressive Strength (psi)
			Portland	Total ⁽¹⁾	Marsh (seconds)	Fann (centipoise)	
70-1	Decomposed Sandstone	46.2	0.0	4.6	167.8	6080	28 day - 19
70-2	Coal Wash Waste	46.2					28 day - 18
70-3	Class F - Plant Run	0					60 day - 21
70-4	Kiln Dust	7.6					90 day - 22
	Water Content	35					
71-1	Decomposed Sandstone	41.2	0.0	2.0	137.3	4560	28 day - 25
71-2	Coal Wash Waste	41.2					28 day - 23
71-3	Class F - Plant Run	10.0					60 day - 15
71-4	Kiln Dust	7.6					90 day - 25
	Water Content	35					
72-1	Decomposed Sandstone	36.2	0.0	1.3	136.2	5570	28 day - 20
72-2	Coal Wash Waste	36.2					28 day - 22
72-3	Class F - Plant Run	20.0					60 day - 19
72-4	Kiln Dust	7.6					90 day - 20
	Water Content	35					
73-1	Alluvial Sand	90.0	0.0	3.5	*	*	28 day - 24
73-2	Class C	10.0					28 day - 25
73-3	Water Content	35					60 day - 26
73-4							90 day - 26
74-1	Alluvial Sand	80.0	0.0	1.8	34.7	760	28 day - 91
74-2	Class C	20.0					28 day - 97
74-3	Water Content	35					60 day - 116
74-4							90 day - 110
75-1	Alluvial Sand	70.0	0.0	1.2	37.9	1010	28 day - 555
75-2	Class C	30.0					28 day - 376
75-3	Water Content	35					60 day - 582
75-4							90 day - 672

(1) Total water cement ratio + pozzolan
Water content expressed as a percentage of weight of solid constituents

* Not measurable due to aggregate - water separation

Sample Identification			Water/Cement Ratio		Viscosity		Compressive Strength (psi)
No.	Constituent	(%)	Portland	Total ⁽¹⁾	Marsh (seconds)	Fann (centipoise)	
76-1	Decomposed Sandstone	90.0	0.0	3.5	78.4	4810	28 day - 26
76-2	Class C	10.0					28 day - 25
76-3	Water Content	35					60 day - 27
76-4							90 day - 24
77-1	Decomposed Sandstone	80.0	0.0	1.8	111.5	8110	28 day - 44
77-2	Class C	20.0					28 day - 59
77-3	Water Content	35					60 day - 50
77-4							90 day - Broke
78-1	Decomposed Sandstone	70.0	0.0	1.2	55.8	4050	28 day - 91
78-2	Class C	30.0					28 day - 91
78-3	Water Content	35					60 day - 128
78-4							90 day - 149
79-1	Coal Wash Waste	90.0	0.0	3.5	115.7	4050	28 day - 17
79-2	Class C	10.0					28 day - 12
79-3	Water Content	35					60 day - 12
79-4							90 day - 11
80-1	Coal Wash Waste	80.0	0.0	1.8	128.4	5070	28 day - 49
80-2	Class C	20.0					28 day - 43
80-3	Water Content	35					60 day - 52
80-4							90 day - 28
81-1	Coal Wash Waste	70.0	0.0	1.2	87.3	4560	28 day - 90
81-2	Class C	30.0					28 day - 83
81-3	Water Content	35					60 day - 95
81-4							90 day - 81

(1) Total water cement ratio + pozzolan
Water content expressed as a percentage of weight of solid constituents

No.	Sample Identification		Water/Cement Ratio		Viscosity		Compressive Strength (psi)
	Constituent	(%)	Portland	Total ⁽¹⁾	Marsh (seconds)	Fann (centipoise)	
82-1	Alluvial Sand	45.0	0.0	3.5	56.8	2280	28 day - Broke
82-2	Coal Wash Waste	45.0					28 day - 21
82-3	Class C	10.0					60 day - 19
82-4	Water Content	35					90 day - 17
83-1	Alluvial Sand	40.0	0.0	1.8	51.6	2280	28 day - 47
83-2	Coal Wash Waste	40.0					28 day - Broke
83-3	Class C	20.0					60 day - 48
83-4	Water Content	35					90 day - 42
84-1	Alluvial Sand	35.0	0.0	1.2	56.3	2280	28 day - 116
84-2	Coal Wash Waste	35.0					28 day - 95
84-3	Class C	30.0					60 day - 121
84-4	Water Content	35					90 day - 114
85-1	Decomposed Sandstone	45.0	0.0	3.5	115.2	5570	28 day - 24
85-2	Coal Wash Waste	45.0					28 day - 30
85-3	Class C	10.0					60 day - 20
85-4	Water Content	35					90 day - 19
86-1	Decomposed Sandstone	40.0	0.0	1.8	157.3	6330	28 day - 44
86-2	Coal Wash Waste	40.0					28 day - 39
86-3	Class C	20.0					60 day - 50
86-4	Water Content	35					90 day - 33
87-1	Decomposed Sandstone	35.0	0.0	1.2	83.1	4810	28 day - 102
87-2	Coal Wash Waste	35.0					28 day - 96
87-3	Class C	30.0					60 day - 104
87-4	Water Content	35					90 day - 120

(1) Total water cement ratio + pozzolan
Water content expressed as a percentage of weight of solid constituents

APPENDIX C

Factorial Experiment -
Individual Test Results

Sample Identification			Water/Cement Ratio		Viscosity		Compressive Strength (psi)
No.	Constituent	(%)	Portland	Total ⁽¹⁾	Marsh (seconds)	Fann (centipoise)	
88-1	Class F - Product II	60.0	0.9	0.4	408.7	9880	28 day - 3099
88-2	Portland Cement	40.0					28 day - 3838
88-3	Water Content	35					60 day - 3732
88-4							90 day - 3596
89-1	Class F - Product II	70.0	1.2	0.4	172.0	5570	28 day - 2327
89-2	Portland Cement	30.0					28 day - 2880
89-3	Water Content	35					60 day - 1946
89-4							90 day - 2158
90-1	Class F - Product II	76.0	1.5	0.4	266.7	7090	28 day - 2352
90-2	Portland Cement	24.0					28 day - 2165
90-3	Water Content	35					60 day - 1858
90-4							90 day - 1660
91-1	Alluvial Sand	89.0	8.9	3.2	47.9	1520	28 day - 39
91-2	Class F - Product II	7.0					28 day - 37
91-3	Portland Cement	4.0					60 day - 38
91-4	Water Content	35					90 day - 45
92-1	Alluvial Sand	84.0	8.9	2.2	44.2	1520	28 day - 61
92-2	Class F - Product II	12.0					28 day - 57
92-3	Portland Cement	4.0					60 day - 61
92-4	Water Content	35					90 day - 63

(1) Total water cement ratio + pozzolan
Water content expressed as a percentage of weight of solid constituents

Sample Identification		Water/Cement Ratio	Viscosity		Compressive Strength		
			Marsh	Fann			
No.	Constituent	(%)	Portland	Total ⁽¹⁾	(seconds)	(centipoise)	(psi)
93-1	Alluvial Sand	79.0	4.4	1.7	41.6	1270	28 day - 297
93-2	Class F - Product II	13.0					28 day - 284
93-3	Portland Cement	8.0					60 day - 263
93-4	Water Content	35					90 day - 320
94-1	Alluvial Sand	74.0	3.5	1.4	39.5	1010	28 day - 490
94-2	Class F - Product II	16.0					28 day - 458
94-3	Portland Cement	10.0					60 day - 395
94-4	Water Content	35					90 day - 357
95-1	Alluvial Sand	69.0	2.9	1.1	40.5	1270	28 day - 700
95-2	Class F - Product II	19.0					28 day - 687
95-3	Portland Cement	12.0					60 day - 536
95-4	Water Content	35					90 day - 638
96-1	Alluvial Sand	79.0	5.8	1.7	41.0	1270	28 day - 144
96-2	Class F - Product II	15.0					28 day - 138
96-3	Portland Cement	6.0					60 day - 111
96-4	Water Content	35					90 day - 122
97-1	Alluvial Sand	74.0	5.8	1.4	40.0	1010	28 day - 165
97-2	Class F - Product II	20.0					28 day - 139
97-3	Portland Cement	6.0					60 day - 159
97-4	Water Content	35					90 day - 156
98-1	Alluvial Sand	69.0	5.8	1.1	41.0	1270	28 day - 193
98-2	Class F - Product II	25.0					28 day - 150
98-3	Portland Cement	6.0					60 day - 150
98-4	Water Content	35					90 day - 185

(1) Total water cement ratio + pozzolan
Water content expressed as a percentage of weight of solid constituents

Sample Identification			Water/Cement Ratio		Viscosity		Compressive Strength (psi)
No.	Constituent	(%)	Portland	Total ⁽¹⁾	Marsh (seconds)	Fann (centipoise)	
99-1	Alluvial Sand	79.0		1.7	36.8	1270	28 day - 123
99-2	Class C	21.0					28 day - 112
99-3	Water Content	35					60 day - 96
99-4							90 day - 128
100-1	Alluvial Sand	74.0		1.4	37.4	1270	28 day - 248
100-2	Class C	26.0					28 day - 237
100-3	Water Content	35					60 day - 352
100-4							90 day - 352
101-1	Alluvial Sand	69.0		1.1	38.9	1520	28 day - 625
101-2	Class C	31.0					28 day - 505
101-3	Water Content	35					60 day - 595
101-4							90 day - 558
102-1	Alluvial Sand	79.0		1.7	42.6	1270	28 day - 18
102-2	Class F - Product II	15.0					28 day - 19
102-3	Kiln Dust	6.0					60 day - 17
102-4	Water Content	35					90 day - 17
103-1	Alluvial Sand	74.0		1.4	42.6	1010	28 day - 43
103-2	Class F - Product II	15.0					28 day - 35
103-3	Kiln Dust	11.0					60 day - 40
103-4	Water Content	35					90 day - 37
104-1	Alluvial Sand	69.0		1.1	46.3	1520	28 day - 106
104-2	Class F - Product II	15.0					28 day - 103
104-3	Kiln Dust	16.0					60 day - 105
104-4	Water Content	35					90 day - 98

(1) Total water cement ratio + pozzolan
Water content expressed as a percentage of weight of solid constituents

APPENDIX D

Optimum Test Mixture -
Individual Test Results

Sample Identification			Water/Cement Ratio		Viscosity		Compressive Strength		
					Marsh	Fann			
No.	Constituent	(%)	Portland	Total ⁽¹⁾	(seconds)	(centipoise)	(psi)		
							Days		
							28	60	90
105-1	Alluvial Sand	84.0	4.2	1.6	122.0	3040	123	137	210
105-2	Class F - Product II	10.0					132	105	134
105-3	Portland Cement	6.0					97	143	185
105-4	Water Content (%)	25.0					105	121	
106-1	Alluvial Sand	84.0	5.0	1.9	53.1	1520	108	94	117
106-2	Class F - Product II	10.0					110	84	113
106-3	Portland Cement	6.0					91	97	121
106-4	Water Content (%)	30.0					108	87	
107-1	Alluvial Sand	84.0	5.8	2.2	43.1	1010	64	76	102
107-2	Class F - Product II	10.0					54	67	89
107-3	Portland Cement	6.0					57	63	120
107-4	Water Content (%)	35.0					56	62	

(1) Total water cement ratio + pozzolan
Water content expressed as a percentage of weight of solid constituents