RI 9243

REPORT OF INVESTIGATIONS/1989

Backfill Properties of Total Tailings

By C. M. K. Boldt, P. C. McWilliams,
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BUREAU OF MINES

UNITED STATES DEPARTMENT OF THE INTERIOR

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UNITED STATES DEPARTMENT OF THE INTERIOR
Manuel J. Lujan, Jr., Secretary

BUREAU OF MINES
T S Ary, Director

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

in	inch	pct	percent
lb/ft^3	pound per cubic foot	psi	pound per square inch
m^2/kg	square meter per kilogram	st/h	short ton per hour
min	minute	wt pct	weight percent
mm	millimeter		

BACKFILL PROPERTIES OF TOTAL TAILINGS

By C. M. K. Boldt,[1] P. C. McWilliams,[2] and L. A. Atkins[3]

ABSTRACT

This U.S. Bureau of Mines report presents a study of three typical tailings samples as potential cemented backfill in underground mines. The testing series was unique in that the pulp densities of the samples were all above 75 pct solids. Test results included dry density; slump; percent settling after 28 days of curing; tensile strength after 28, 120, and 180 days of curing; and unconfined compressive strengths after 7, 28, 120, and 180 days of curing. The physical properties of the various test mixtures were further analyzed using linear and nonlinear statistical methods to produce correlations and mathematical equations. Physical properties were used to determine the influence of mix additives and as input for numerical modeling studies of backfill. The mathematical relations were used as a predictive tool in determining the suitability of various materials as backfill.

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INTRODUCTION

Conventional room-and-pillar mining has been commonly used in the United States. However, the domestic mining industry has been hardpressed to maximize mineral productivity in order to compete with foreign suppliers. As a consequence, U.S. mines no longer have the luxury of leaving ore-rich pillars as ground support, and reserves tied up in highly fractured material cannot be left behind. Existing mines are also encountering greater ground stresses as mining progresses deeper, causing the openings to squeeze inward dramatically or suddenly burst. In certain regions of the country and particularly near urban areas, ground subsidence poses safety and environmental hazards.

Backfilling stopes allows removal of pillars in addition to controlling ground subsidence. The fill also acts as a medium with established engineering properties and predictable behavior. These advantages can allow mines to maximize their ore reserves.

Backfill has been extensively used worldwide. The Bureau was involved as far back as 1964 in defining the properties of hydraulically placed backfill (*1*).[4] From 1961 to 1970, Canadian researchers tested a multitude of mixes utilizing portland cement and mine tailings (*2*). These tests all used the common mode of hydraulic transport of materials that were typically <70 pct solids. At 45 pct water content, the backfill needed to be designed for high permeability where the excess water was drained and pumped out of the mine. Bleeding of the cement and aggregate fines through the drainage water was a common problem, resulting in greatly varied in-place strength.

Today, pumps and pneumatic blowers are capable of handling a mine's rugged environmental requirements while meeting a 100-st/h operating speed. These new pumps and pneumatic stowers may make it favorable to transport >80 pct solids, total tailings[5] material from the mill to the stope for use as backfill. This capability no longer limits the mix matrix to 70 pct solids or to the inclusion of only the sands fraction of mill tailings. The resulting decrease in water improves the strength, homogeneity, and curing time of the material, and makes lean, cemented total tailings backfill an attractive option.

This report summarizes laboratory work done by the Bureau to define the strength characteristics of lean, cemented backfill using total tailings as aggregate, and varying the cement and other additives as well as the water content. The mix matrix used simulated the higher pulp densities capable of being transported and placed by large concrete pumps, physical stowing equipment, pneumatic blowers, or gravity free fall.

TEST PROCEDURE

MIX COMPOSITION

The mill total tailings used as the basic aggregate in this test series came from three underground metal mines: Tailings A from a deep silver mine in Idaho, tailings B from a lead-zinc mine in Missouri, and tailings C from a copper-silver mine in Montana. Grain-size gradation curves are shown in figure 1. The fines content of the total tailings was retained to minimize the void ratio. This practice has been documented as improving strengths and decreasing fill consolidation (*3*). Mix matrices are summarized in appendix A.

Commercially available Type I and II portland cement and tap water were used in all mixes in the test series. The following additives were incorporated in the test mixes to determine their influence on some of the physical properties of the tailings.

1. Fly Ash.–Various mixtures of commercially available ASTM Class F fly ash (*4*) were added to the tailings to determine whether the pozzolanic influence would be sufficient to decrease the required amount of cement and still maintain the unconfined compressive strength.
2. Pit-Run and Ground Smelter Slag.–The cementing influence of the smelter slag was determined by Construction Technology Laboratories of Skokie, IL (*5*). The chemical analysis is shown in table 1. Since the hydraulicity, or the ability of the slag to react with water, is believed to increase when the slag is ground very fine (*6*), the tests included different gradations of ground slag. Slag samples of 400, 500, and 600 m^2/kg as determined by the Blaine test (*7*) were mixed with water and showed no unconfined compressive strengths through 28 days of curing time because the material remained in the original slurry state. Grain-size analyses of the pit-run and ground smelter slag are shown in figure 2.
3. Oil Shale Retorted Waste.–Because previous oil shale research had documented the cementing properties of certain retorted wastes (*8*), oil shale retorted waste was used as an additive to determine if its cementing properties could be used in the backfill. The grain-size gradation curve of the retorted waste is given in figure 2.
4. Kiln Dust.–A locally available source of kiln dust was used in a few mixes to determine its cementitious effects.
5. Superplasticizer.–An ASTM Category B superplasticizer (*9*) was added to a few mixes to determine its ability to decrease the amount of water necessary to initiate cementing action and maintain pumpability. Ten times the

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[4] Italic numbers in parentheses refer to items in the list of references preceding the appendixes at the end of this report.

[5] Total tailings, as used in this report, includes the full range of mine tailings, typically from 0.001 to 6.0 mm in diameter.

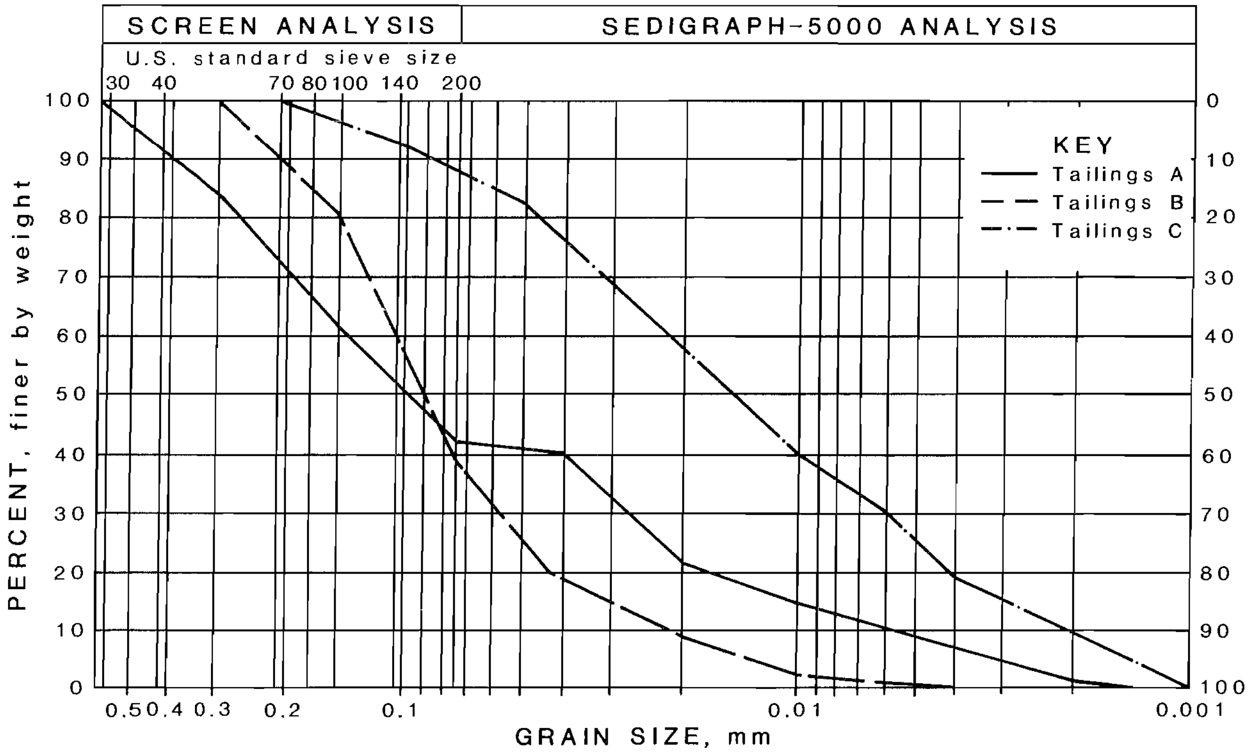

Figure 1.-Grain-size gradation curves for tailings A, B, and C.

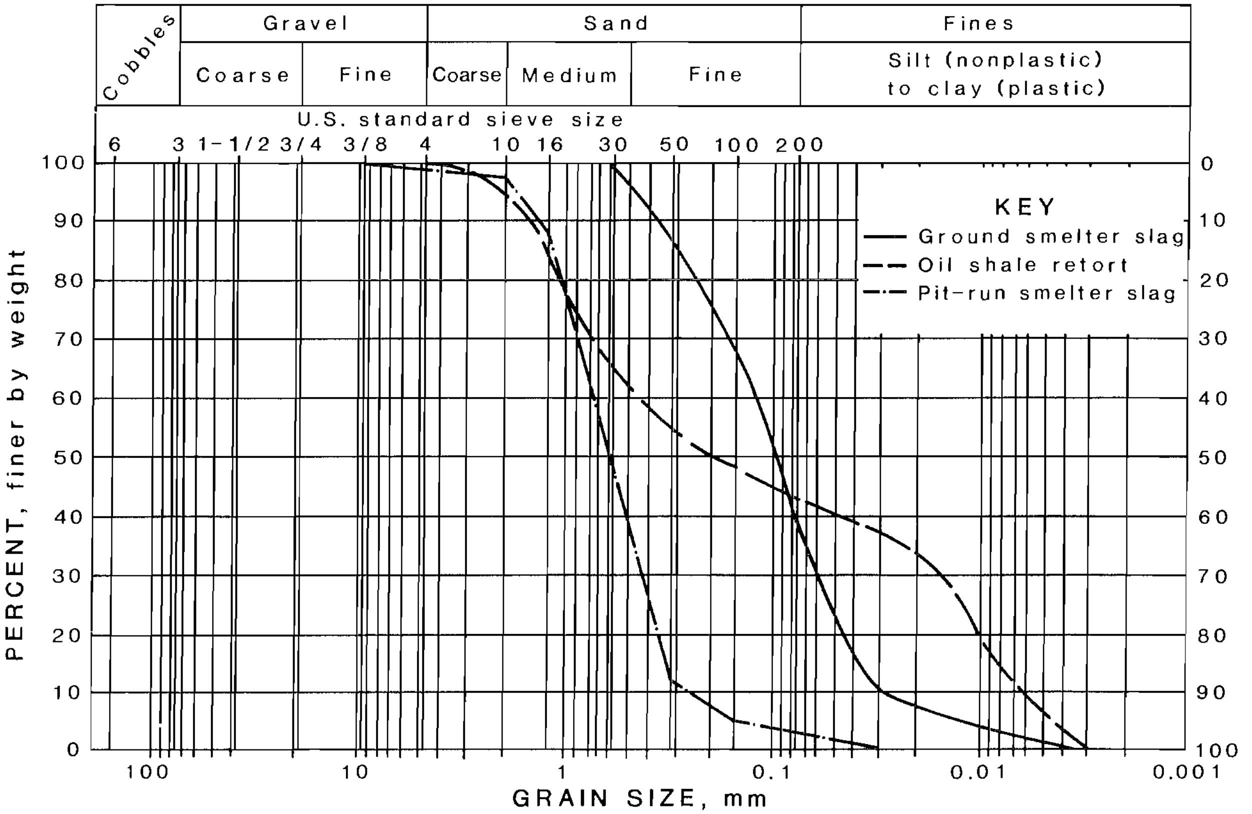

Figure 2.-Grain-size gradation curves for pit-run smelter slag, ground smelter slag, and oil shale retorted waste.

manufacturer's recommended dosage rate for concrete was needed before a measurable increase in slump was seen. Since results of the superplasticizer tests were not promising, no further tests were attempted.

Table 1.–Slag chemical analysis

Major oxides	Concentration, pct
Al_2O_3	6.15
BaO	.39
CaO	16.85
Cr_2O_3	.05
CuO	.06
Fe_2O_3	37.83
K_2O	.68
MgO	2.09
MnO	1.81
Na_2O	.5
P_2O_5	.01
SiO_2	30.95
TiO_2	.37
ZnO_2	.02

NOTE.–2.24 pct is accounted for by other concentrations or combustion losses.

MIX HANDLING

The mixing procedure for the test series included use of a portable cement mixer. After the oven-dried total tailings material and any additives were mixed for a minimum of 2 min and visually checked for homogeneity, a slump measurement was taken (*10*). Eight samples were taken from each test mix, packed into standard 3- by 6-in, waxed cardboard cylinders, and cured in a fog room (*11*). The slurry density was taken at the time of mixing, and the 28-day wet density was measured after 28 days of curing. Gang molds were cast using the various mixes for tailings B and C to obtain samples for determining tensile strength. These briquets were also cured in a fog room.

LABORATORY TESTING

The test series included unconfined compressive strength determinations after 7, 28, 120, and 180 days of moist curing. Each strength test was run on a duplicate cylinder sample and the two strength readings were averaged to minimize errors. Eight tailings A cylinder samples were tested: two each for 7-, 28-, and 120-day cured, unconfined compressive strength tests (*12*); one for the 120-day cured, confined compressive strength tests; and one for determination of the dry density. Eight tailings B and C samples were tested: two each for 7-, 28-, 120-, and 180-day cured, unconfined compressive strength tests. In addition, the test results of three briquet specimens were averaged to determine 28- and 120-day cured tensile strengths for tailings B and C (*13*).

Initial mixes of the total mill tailings were cast without benefit of binder (cement, fly ash, etc.). These samples remained in a slurry state and did not achieve a compressive strength. In addition, the saturated environment of the fog room prevented any evaporation from taking place.

Appendix A summarizes the mix proportions along with the various additives, the types of tests conducted, and the test results. Cement, fly ash, pit-run smelter slag, ground smelter slag, kiln dust, and oil shale retorted waste were measured as a percentage of the total tailings aggregate (dry weight of fly ash plus pit-run smelter slag plus ground smelter slag plus kiln dust divided by dry weight of total tailings times 100). The water-to-cement ratio was calculated as a proportion of the weight of the water to the weight of the cement. The water-to-binder ratio was used to determine if the additives influenced the cementing properties of the mix and was calculated as the proportion of the weight of the water to the combined weight of the cement, fly ash, kiln dust, and oil shale retorted waste. Because the slag was known as a nonhydraulic additive, it was not included as a "binder."

The slurry density of the mixes was determined by dividing the weight of the solids by the weight of the solids and water. Slump measurements were taken to determine possible pumpability of the various mixes and was measured in inches. The tensile and unconfined compressive strengths (measured in pounds per square inch) were averaged through use of replicate testing.

TEST ANALYSIS

LABORATORY TESTS

Category B superplasticizer did not seem to have an impact on reducing the water content and increasing the workability of the mixes. This may have resulted from the nature of the superplasticizer used in the tests. The particular superplasticizer used was Mighty 150,[6] a sulphonated naphthalene formaldehyde condensate. This type of superplasticizer reacts by increasing the charge of the cement particle, thereby repelling the individual cement particles from each other and resulting in better dispersion throughout the mix. It also decreases the surface tension of the water, making it "wetter." In these lean mixes (<15 pct cement content), the influence of Category B superplasticizers would be diminished.

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[6] Reference to specific products does not imply endorsement by the U.S. Bureau of Mines.

STATISTICAL ANALYSIS

At the beginning of the test series, tailings A results were statistically analyzed to determine if any meaningful relationships existed among the data. Ninety-five sample pairs were cast through the course of testing and included various additives such as pit-run smelter slag, ground smelter slag, and fly ash. Four candidate predicted variables (variables to be predicted from mixture information) were measured: average unconfined compressive strength at 7-, 28-, and 120-day curing increments and the resulting slump value. There were five predictor variables: pit-run smelter slag, ground smelter slag, fly ash, cement, and water-to-cement ratio. The predictor variables were mixed in varying proportions to test for fill properties of the tailings.

The Minitab statistical computer program was used for most of the analytic work and the primary statistical algorithm was a multivariate linear model (*14*). With 14 variables involved, it was necessary to perform a preanalysis of the variables that would sort out some of the more spurious prior to the multivariate model fitting. Therefore, pair-wise correlation coefficients between the variables involved were examined first. These values are summarized in table 2 and provide a quick method to determine which variables are most highly correlated.

The matrix in table 2 is a mixture of both predictor and predicted variables, as defined previously. An absolute value of 0.8 correlation coefficient was arbitrarily chosen to delineate significance (a 1.0 correlation coefficient is a perfect fit of the line to the data points). Using this criterion, 10 pair-wise relationships were deemed significant; however, three of these correlations were between the dependent variables themselves, i.e., 28-day average unconfined compressive strength (28DCOMP) versus 120-day average unconfined compressive strength (120DCOMP), with a correlation coefficient of 0.944.

Various combinations of variables were further analyzed by least squares fitting (*15*) a three-dimensional (3-D) hyperplane,[7] which yielded the following equation:

$$7DCOMP = -73.6 + 32.4\ CEMENT - 1.40\ W/C$$

where

7DCOMP = 7-day unconfined compressive strength, psi,

CEMENT = cement content, pct,

and W/C = water-to-cement ratio.

The analysis provided an R^2 value of 0.876.[8] The various goodness-of-fit parameters r, R^2, and I are discussed in appendix B. The results of the linear regression analysis are listed in appendix C.

Extreme scatter in some of these data is apparent in the itemized predicted variable (predicted Y-value, Fit column) versus the actual data (7DCOMP column) in appendix C. To illustrate, observation 30 of appendix C lists an actual 7-day observed strength of 160 psi. However, the predicted value using the regression equation produced a result of 343.35 psi. For this reason, two other modeling schemes were investigated: a multivariate, linear stepwise regression model and a univariate, nonlinear exponential model. The differences between these models are described in reference 15.

To determine a best multivariate linear model, stepwise regression was applied to the tailings A data. Briefly, this is a procedure that picks the predictor variables one at a time in order of relative importance. This approach has two advantages to the user: it produces a linear model to represent the data, and in so doing, it searches for the most important subset of dependent variables that will do the job. The Bureau's stepwise code has an additional advantage in that it allows the creation of variables that are derived from the original predictor variable set. For example, cement and fly ash content were predictor variables. Terms involving cement or fly ash squared, cubed, multiplied, raised to powers, etc., can be easily inserted in the model. There is one important aspect, however, which must be kept in mind when using this model. In forming the regression, the user is always fitting an additive model of the terms of interest.

The stepwise procedure was applied individually to each of the predicted variables involved: 7-, 28-, and 120-day cured, unconfined compressive strengths and the slump variable.

Mathematical representation of the stepwise regression model is given by

$$Y = P_1 + P_2Z_1 + P_3Z_2 + P_4Z_3 + \ldots + P_1Z_k,$$

where

Y = predicted variable (here, 7-day unconfined strength),

$P_1, P_2, \ldots, P_i$ = constants found by the stepwise process,

and

$Z_1, Z_2, \ldots, Z_k$ = selected predictor variables (cement, fly ash, etc.) chosen one at a time in order of importance.

It was necessary to use four predictor variables (cement, pit-run smelter slag, water-to-cement, and fly ash), of which only cement and pit-run smelter slag were deemed statistically significant, to produce an equation predicting the 7-day unconfined compressive strength with an R^2 value of 0.887 (table 3).

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[7] A three-dimensional linear model.

[8] In all multidimensional analyses, R^2 refers to the multivariate correlation coefficient (appendix B).

Table 2.–Linear correlation coefficients for tailings A variables

	CEMENT	FLYASH	PRSLAG	GRSLAG	W/C	W/B	SLUMP	SLDEN	DRYDEN	WETDEN	SETTL	7DCOMP	28DCOMP
FLYASH	0.106												
PRSLAG	.260	-0.222											
GRSLAG	.353	-.170	-0.222										
W/C	-.873	-.059	-.198	-0.259									
W/B	-.705	-.572	-.060	-.142	0.758								
SLUMP	-.336	.232	-.314	-.540	.283	0.057							
SLDEN	.487	-.099	.561	.477	-.388	-.257	-0.870						
DRYDEN	.398	-.102	.473	.457	-.548	-.408	-.726	0.820					
WETDEN	.315	-.519	.557	.353	-.325	-.015	-.603	.653	0.701				
SETTL	-.274	-.201	-.113	-.081	.143	.253	.334	-.328	-.096	0.001			
7DCOMP	.939	.168	.165	.325	-.821	-.680	-.346	.456	.432	.288	-0.255		
28DCOMP	.921	.182	.120	.389	-.781	-.671	-.358	.456	.450	.283	-.254	0.977	
120DCOMP	.848	.326	.023	.409	-.738	-.697	-.330	.420	.443	.166	-.288	.930	0.944

CEMENT	Cement content, percent of tailings.	SLDEN	Slurry density.
FLYASH	Fly ash content, percent of tailings.	DRYDEN	Dry density.
PRSLAG	Pit-run smelter slag content, percent of tailings.	WETDEN	Wet density.
GRSLAG	Ground smelter slag content, percent of tailings.	SETTL	Percent of settling.
W/C	Water-to-cement ratio	7DCOMP	7-day compressive strength.
W/B	Water-to-(cement-plus-fly ash) ratio.	28DCOMP	28-day compressive strength.
SLUMP	Inches of slump.	120DCOMP	120-day compressive strength.

Table 3.–Comparisons of goodness-of-fit for tailings A data

Model	Mathematical equation	Goodness-of-fit measure
3-D hyperplane	$7DAVG = -73.6 + 32.4\ CEMENT - 1.40\ W/C$	$R^2 = 0.876$.
Multivariate, linear stepwise regression	$7DAVG = -82.58 + 33.6\ CEMENT - 0.74\ PRSLAG$	$R^2 = 0.887$.
Nonlinear, exponential	$7DAVG = 1{,}515.53e^{-0.57\ W/C}$	I = 0.889.

7DAVG	7-day cured, unconfined compressive strength.	R^2	Multivariate correlation coefficient.
CEMENT	Percent cement in total aggregate contained in mix.	PRSLAG	Percent pit-run smelter slag contained in mix.
W/C	Water-to-cement ratio.	I	Index of determination.

Another modeling attempt was made using a two-dimensional model with the predicted and predictor variables fitted by an exponential curve. Figure 3 illustrates the data by plotting the 7-day unconfined compressive strengths to the water-to-cement ratio. This curve-fit procedure resulted in the following equation:

$$7DCOMP = 1{,}515.53e^{-0.57\ W/C}$$

where

7DCOMP = 7-day unconfined compressive strength, psi,

and W/C = water-to-cement ratio.

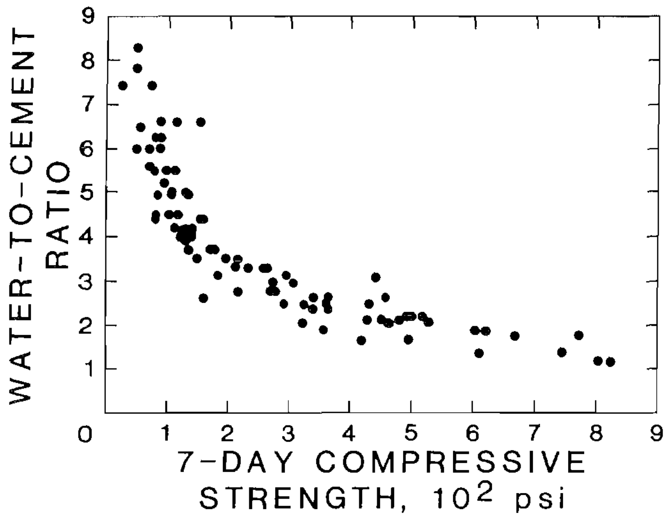

Figure 3.–Seven-day compressive strength versus water-to-cement ratio for tailings A.

Table 3 tabulates the various results of the three statistical methods used to determine goodness-of-fit for the tailings A test data as applied to predicting the 7-day unconfined compressive strengths. The 3-D hyperplane produces a correlation coefficient of 0.876. In the multivariate, linear stepwise regression model, the anticipated 7-day unconfined compressive strengths fit the observed compressive strengths of each test specimen with a correlation coefficient of 0.887. The predictor variables, listed by order of importance to determine the 7-day compressive strength, are cement and pit-run smelter slag. The nonlinear, exponential model produces an index of determination (see appendix B for definition) of 0.889, which is quite promising since it is based on only one input variable, the water-to-cement ratio.

After it was determined that the exponential model would best fit the data curves of the unconfined compressive strengths versus the water-to-cement ratio, the data from tailings A, B, and C were analyzed as a group for comparison. Plots of the compressive strengths versus water-to-cement ratios for the total data base are presented in figure 4. The mathematical representation of the curves along with their respective indices of determination are given in appendix D.

Further analysis of the tailings A, B, and C data included exponential curve fitting of the compressive strengths to water-to-cement ratios for the mixes grouped by tailings type and then by tailings type not containing any additives (pit-run smelter slag, ground smelter slag, fly ash, kiln dust, and oil shale retorted waste) (figs. 5-6). The mathematical representation of the curves along with their respective indices of determination are also given in appendix D.

As can be seen in appendix D, the goodness-of-fit increases as the data base becomes increasingly selective. For instance, the total data base index of determination, I, for 7-day compressive strength is 0.796. For the data base containing only tailings A, I is 0.889; and for the tailings A data base not containing any additives (pit-run smelter slag, fly ash, etc.), I is 0.982.

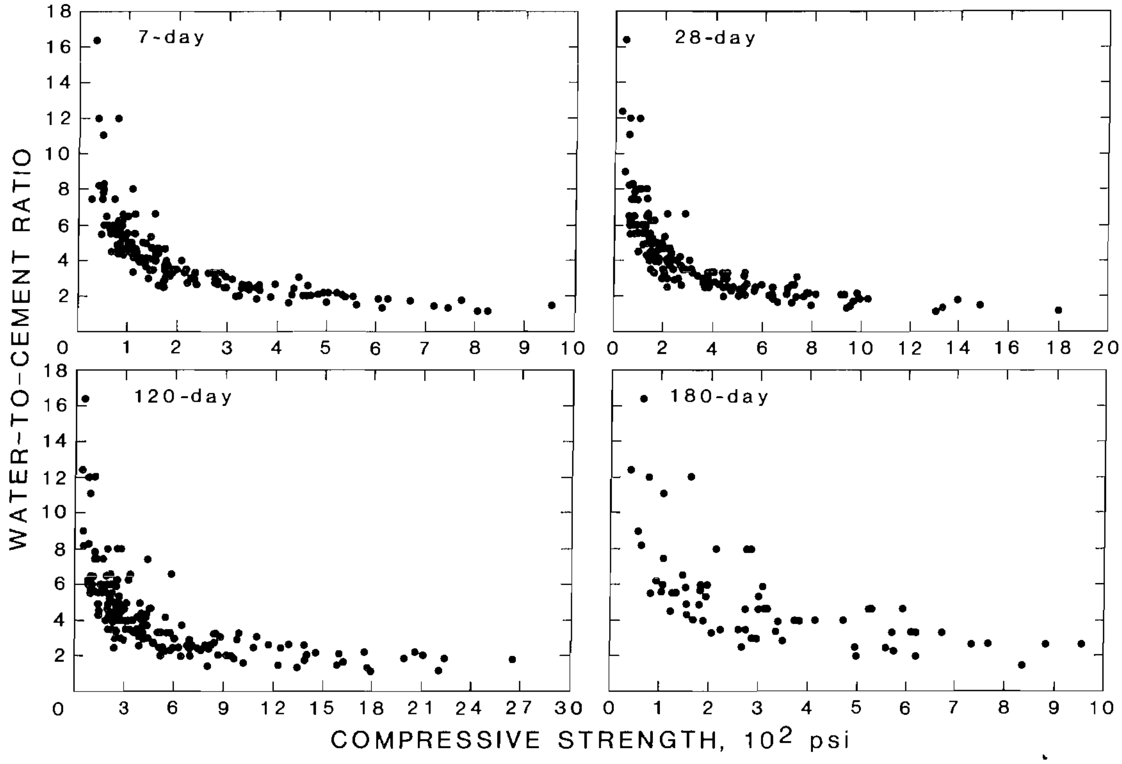

Figure 4.–Compressive strengths versus water-to-cement ratio for total tailings data base.

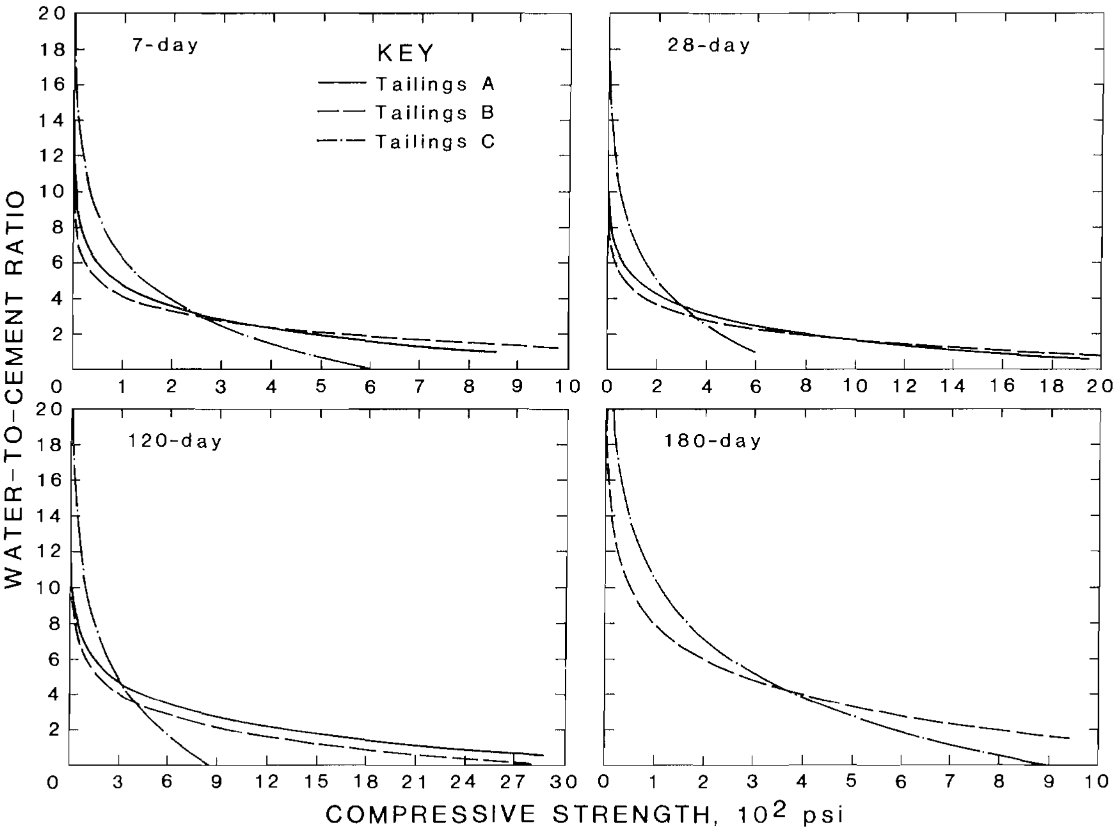

Figure 5.–Compressive strengths versus water-to-cement ratio for tailings A, B, and C.

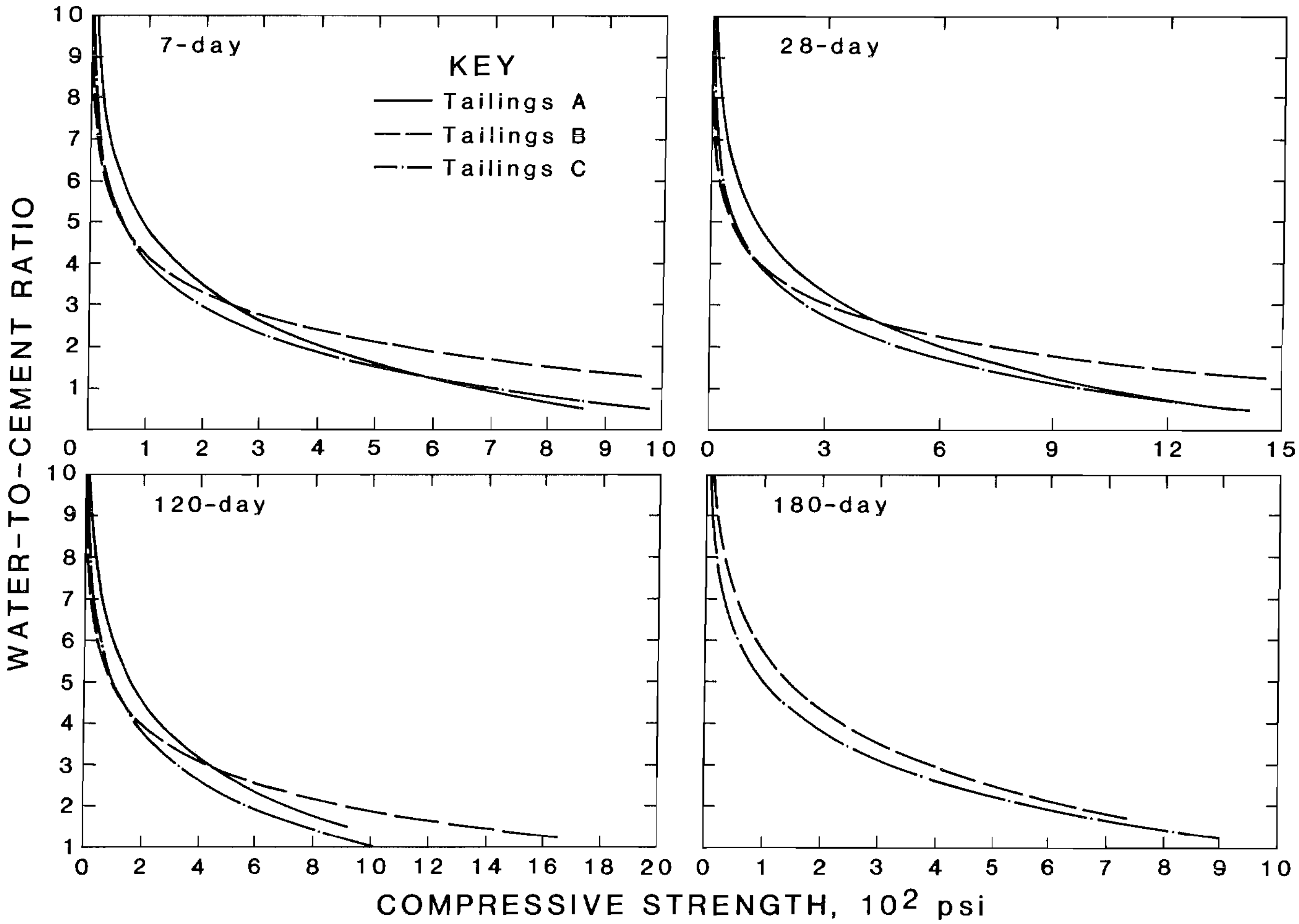

Figure 6.–Compressive strengths versus water-to-cement ratio for tailings A, B, and C (not containing additives).

DISCUSSION OF RESULTS

The results indicated that the addition of oil shale retorted waste without the benefit of cement produced compressive strengths on the order of 100 psi in 28 days. The cementing properties of the retorted waste were greater for the finer particles of tailings C. The addition of fly ash improved the compressive strength of the total tailings aggregate. As the tailings grain size fraction greater than 200 sieve increased, the influence of the fly ash decreased. The 28-day compressive strength of tailings A was increased by 25 pct, tailings B by 48 pct, and tailings C by 98 pct over the compressive strengths gained by the use of cement alone.

As the grain size of the tailings fraction greater than 200 sieve decreased, the compressive strengths also decreased for the various curing periods. The 7-day compressive strength for tailings A with 6 pct cement and a water-to-cement ratio of 4.5:1 was 118 psi; for tailings B it was 107 psi; and for tailings C it was 65 psi.

The linear relationship (based on least squares fitting) between the 7-day compressive strengths and those of 28 , 120-, and 180-day compressive strengths is presented in figure 7. In each case, the strength gained between each pair of relationships was greater as the grain size of the tailings material increased. This was just the opposite for the relationship between the 7-day compressive strength and the 28-day tensile strength (fig. 7). There was no significant difference in strength gain between the 28-, 120-, and 180-day compressive strengths and the 7-day compressive strength because of grain-size differences (fig. 8). However, grain size differences caused a marked difference between the 28-day tensile strength and the 7-day compressive strength (fig. 8). The finer-grained tailings C developed a higher tensile strength when compared to the 7-day compressive strength.

The ratios between compressive strength to tensile strength for the various days of curing ranged from 4.4 for

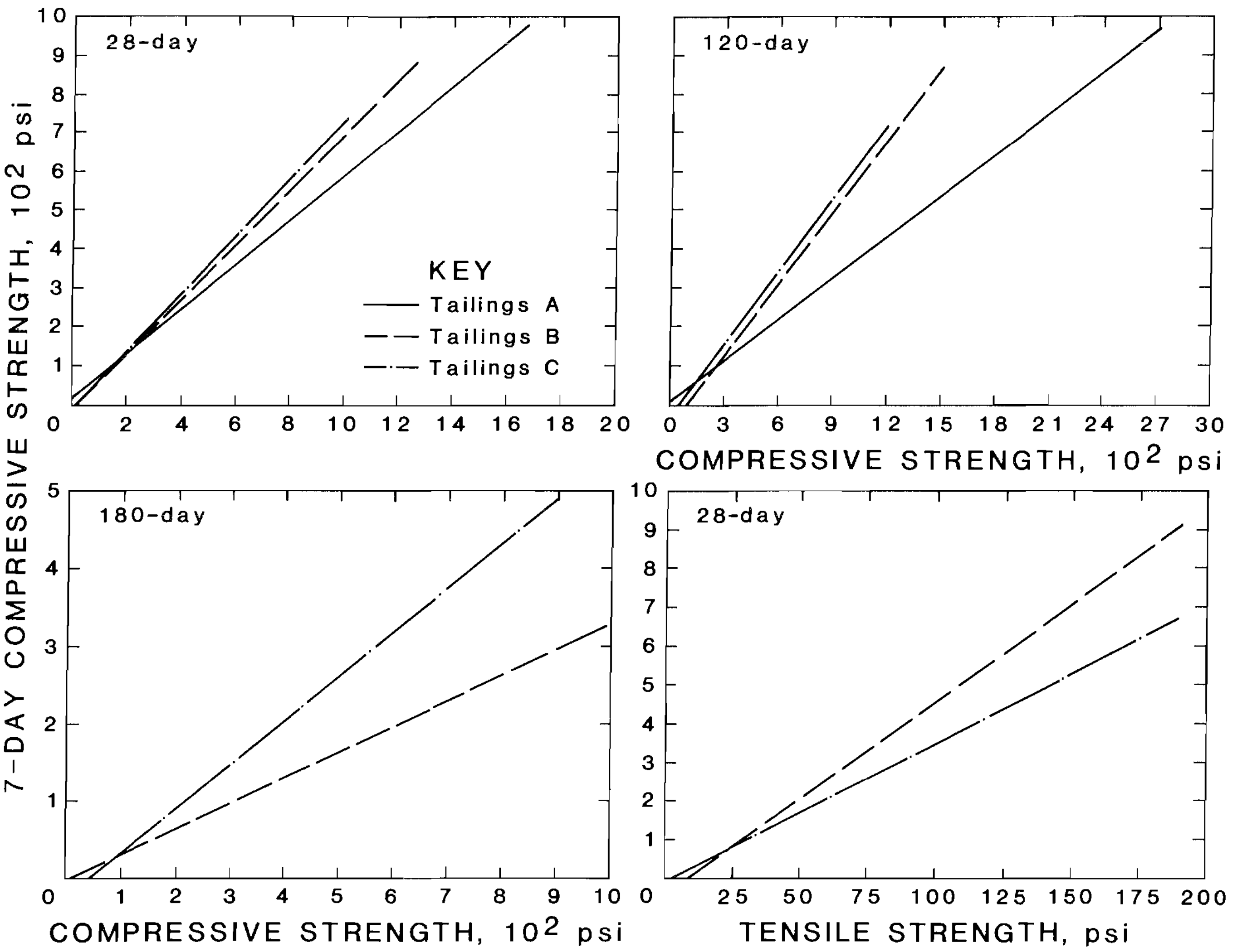

Figure 7.–Seven-day compressive strength versus 28-, 120-, 180-day compressive strengths, and 28-day tensile strength for tailings A, B, and C.

the total tailings not containing additives to 4.8 for the total data base.

The goodness-of-fit for calculating the compressive strengths using the water-to-cement ratio and the exponential formula is

$$Y = Ae^{-BX},$$

where Y = compressive strength, psi,

X = water-to-cement ratio,

and A and B are constants.

This goodness-of-fit progressively improves as the sample groupings become more restricted. Appendix D summarizes the indices of determination for the various groupings.

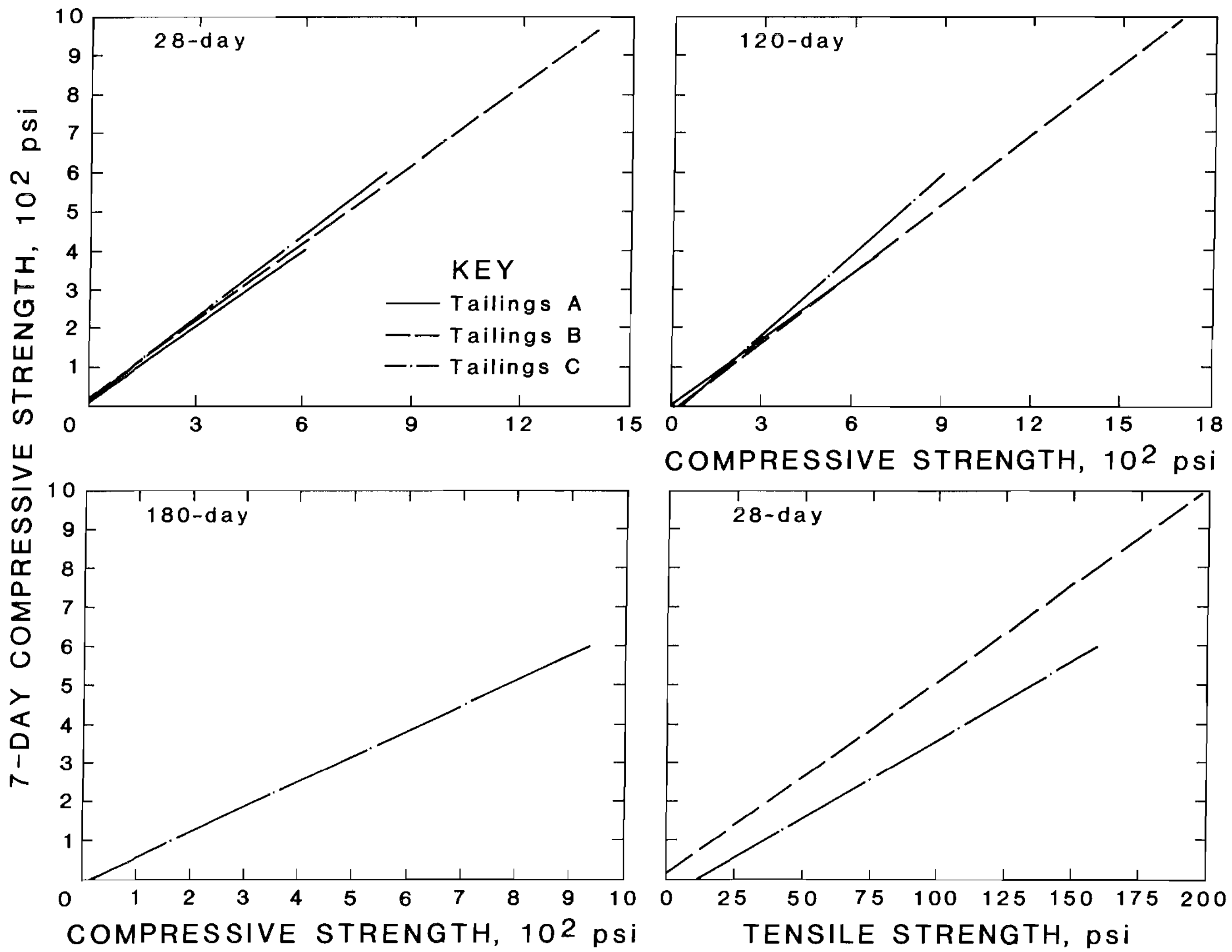

Figure 8.–Seven-day compressive strength versus 28-, 120-, 180-day compressive strengths, and 28-day tensile strength for tailings A, B, and C (not containing additives).

SUMMARY

This series of backfill material testing was initiated to determine what engineering properties could be expected from a variety of mill total tailings. The incorporation of additives was meant to define the extent of increased strength or workability of the resultant mix. None of the tailings tended to be self-cementing. However, as cement contents were increased, compressive strengths increased. The compressive strengths of the fly ash-and-cement combination increased after 28 days of curing as compared to the strength of cement alone after 28 days. The addition of pit-run smelter slag, which incorporated coarser particles into the mix, seemed to increase compressive strength, but the slag alone was not cementitious. In some cases, such as those where oil shale retorted waste was added to the tailings, a full range of mixes was not attempted since the problem was merely to determine whether or not the retorted waste was a detriment to the mix, thereby indicating possible uses of oil shale waste.

Further research will test the relationships found during this investigative test series. The effects of chemical additives such as superplasticizers, high-early-strength cements, water-reducing agents, and kiln dust will be examined. With further refinement, an accurate predictive tool will be developed that will assist the industry in analyzing the suitability and stability of dewatered, total-tailings backfill.

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APPENDIX A.–MIX MATRIX AND TEST RESULTS

Sample no.	Additive wt/tailings wt, pct						W/B	W/C	Slurry density, wt pct	Dry density, lb/ft3	28-day wet density, lb/ft3	Slump, in	28-day settlement, pct	Av tensile strength, psi			Av unconfined compressive strength, psi			
	Cement	Fly ash	Pit-run slag	Ground slag	Kiln dust	Retorted waste								28 day	120 day	180 day	7 day	28 day	120 day	180 day
											TAILINGS A									
1	4	0	0	0	0	0	8.3	8.3	76	98	123	11	3.7	NA	NA	NA	48	72	79	NA
2	6	0	0	0	0	0	5.6	5.6	75	100	123	11	6.2	NA	NA	NA	70	116	121	NA
3	8	0	0	0	0	0	4.2	4.2	76	101	124	11	6.8	NA	NA	NA	112	157	205	NA
4	10	0	0	0	0	0	3.33	3.33	77	102	125	11	3.2	NA	NA	NA	212	318	411	NA
5	12	0	0	0	0	0	2.78	2.78	77	100	124	11	4.3	NA	NA	NA	278	406	475	NA
6	14	0	0	0	0	0	2.38	2.38	77	102	126	11	6	NA	NA	NA	340	507	583	NA
7	4	0	0	0	0	0	5.5	5.5	83	109	129	1.2	1.9	NA	NA	NA	79	99	88	NA
8	4	0	0	0	0	0	6	6	81	104	126	2.7	2.1	NA	NA	NA	48	61	91	NA
9	4	0	0	0	0	0	6.5	6.5	80	100	125	4.7	4.2	NA	NA	NA	54	56	101	NA
10	6	0	0	0	0	0	3.5	3.5	83	116	131	1.7	2.9	NA	NA	NA	196	277	332	NA
11	6	0	0	0	0	0	4	4	82	116	128	4	2.4	NA	NA	NA	141	180	260	NA
12	6	0	0	0	0	0	4.5	4.5	80	107	127	8.5	3.8	NA	NA	NA	118	170	206	NA
13	4	11	0	0	0	0	2.12	7.43	78	106	129	11	0	NA	NA	NA	25	131	434	NA
14	7	11	0	0	0	0	1.86	4.95	78	NA	128	11	5	NA	NA	NA	106	170	392	NA
15	9	11	0	0	0	0	1.65	3.71	78	NA	125	11	4	NA	NA	NA	171	266	646	NA
16	11	11	0	0	0	0	1.49	2.97	79	NA	130	11	3	NA	NA	NA	274	442	974	NA
17	13	11	0	0	0	0	1.35	2.48	79	113	124	9.2	5	NA	NA	NA	431	701	1,241	NA
18	16	11	0	0	0	0	1.24	2.12	79	113	124	9.5	3	NA	NA	NA	481	815	1,593	NA
19	5	25	0	0	0	0	1.1	6.6	80	107	125	10.5	4.2	NA	NA	NA	114	213	336	NA
20	8	25	0	0	0	0	1.02	4.4	80	107	122	10	3	NA	NA	NA	159	233	401	NA
21	10	25	0	0	0	0	0.94	3.3	80	110	124	9.7	4.3	NA	NA	NA	259	435	840	NA
22	13	25	0	0	0	0	0.86	2.64	81	110	125	6	2	NA	NA	NA	459	729	1,380	NA
23	15	25	0	0	0	0	0.83	2.2	81	113	125	6	2	NA	NA	NA	518	776	1,744	NA
24	18	25	0	0	0	0	0.78	1.89	81	114	126	7.5	2	NA	NA	NA	603	1,024	2,235	NA
25	0	0	0	5	0	0	6.27	NA	76	NA	NA	11	NA	NA	NA	NA	14	13	10	NA
26	4	0	0	5	0	0	7.83	7.83	77	101	124	11	1	NA	NA	NA	47	78	115	NA
27	6	0	0	5	0	0	5.22	5.22	77	104	128	11	4.2	NA	NA	NA	95	150	211	NA
28	8	0	0	5	0	0	3.92	3.92	78	105	128	11	5.8	NA	NA	NA	130	227	228	NA
29	11	0	0	5	0	0	3.13	3.13	78	106	127	11	2	NA	NA	NA	183	335	389	NA
30	13	0	0	5	0	0	2.61	2.61	78	107	128	11	3.3	NA	NA	NA	160	270	389	NA
31	14	0	0	5	0	0	2.36	2.36	78	110	133	11	6.6	NA	NA	NA	365	566	765	NA
32	0	0	0	11	0	0	NA	NA	77	122	139	11	4.1	NA	NA	NA	0	0	49	NA
33	4	0	0	11	0	0	7.43	7.43	78	103	123	11	6.7	NA	NA	NA	72	85	166	NA
34	7	0	0	11	0	0	4.95	4.95	78	102	126	11	6.2	NA	NA	NA	83	126	313	NA
35	9	0	0	11	0	0	3.71	3.71	78	103	126	11	6.7	NA	NA	NA	135	227	439	NA
36	11	0	0	11	0	0	2.97	2.97	79	110	128	9	4.4	NA	NA	NA	308	452	695	NA
37	13	0	0	11	0	0	2.48	2.48	79	110	127	8	4.4	NA	NA	NA	324	570	806	NA
38	16	0	0	11	0	0	2.12	2.12	79	112	127	9	4.9	NA	NA	NA	428	696	936	NA
39	5	0	0	33	0	0	6.25	6.25	81	112	134	6	4	NA	NA	NA	79	160	325	NA
40	8	0	0	33	0	0	4.17	4.17	81	114	136	5.5	4	NA	NA	NA	131	263	434	NA
41	11	0	0	33	0	0	3.13	3.13	81	118	128	4.5	2	NA	NA	NA	295	523	1,093	NA
42	13	0	0	33	0	0	2.5	2.5	81	115	137	5.5	3.5	NA	NA	NA	361	641	1,076	NA
43	16	0	0	33	0	0	2.08	2.08	82	116	138	3	3.7	NA	NA	NA	529	930	1,399	NA
44	19	0	0	33	0	0	1.79	1.79	82	118	139	3.2	2	NA	NA	NA	772	1,391	2,653	NA
45	8	0	0	100	0	0	4.17	4.17	86	122	141	0	2.5	NA	NA	NA	129	221	545	NA
46	12	0	0	100	0	0	2.78	2.78	86	121	128	0	2	NA	NA	NA	270	363	842	NA
47	16	0	0	100	0	0	2.08	2.08	87	127	132	0	1	NA	NA	NA	457	916	2,108	NA

See explanatory notes at end of table.

MIX MATRIX AND TEST RESULTS–Continued

Sample no.	Additive wt/tailings wt, pct						W/S	W/C	Slurry density, wt pct	Dry density, lb/ft3	28-day wet density, lb/ft3	Slump, in	28-day settlement, pct	Av tensile strength, psi			Av unconfined compressive strength, psi			
	Cement	Fly ash	Pit-run slag	Ground slag	Kiln dust	Retorted waste								28 day	120 day	180 day	7 day	28 day	120 day	180 day
										TAILINGS A										
48	20	0	0	100	0	0	1.67	1.67	87	126	137	0	4.5	NA	NA	NA	497	659	1620	NA
49	24	0	0	100	0	0	1.39	1.39	87	126	136	0	3	NA	NA	NA	744	1,332	1,770	NA
50	28	0	0	100	0	0	1.19	1.19	87	126	139	0	3	NA	NA	NA	803	1,797	2,199	NA
51	0	0	0	13	0	0	NA	NA	77	122	NA	11	4.1	NA	NA	NA	0	0	0	NA
52	5	13	0	13	0	0	1.89	6.6	80	109	123	11	3.3	NA	NA	NA	88	136	206	NA
53	8	13	0	13	0	0	1.65	4.4	80	109	124	11	2.5	NA	NA	NA	154	230	441	NA
54	10	13	0	13	0	0	1.47	3.3	80	112	123	9	2.8	NA	NA	NA	264	527	985	NA
55	13	13	0	13	0	0	1.32	2.64	81	113	123	9	2.3	NA	NA	NA	341	722	1,192	NA
56	15	13	0	13	0	0	1.2	2.2	81	118	122	8.7	3.5	NA	NA	NA	501	981	2,058	NA
57	18	13	0	13	0	0	1.1	1.89	81	116	124	8.2	0.3	NA	NA	NA	357	639	962	NA
58	5	13	13	0	0	0	1.89	6.6	80	109	123	11	2	NA	NA	NA	152	281	578	NA
59	8	13	13	0	0	0	1.65	4.4	80	107	123	11	2	NA	NA	NA	80	162	337	NA
60	10	13	13	0	0	0	1.47	3.3	80	110	122	10.5	2.3	NA	NA	NA	233	456	851	NA
61	13	13	13	0	0	0	1.32	2.64	81	111	123	10.5	1.3	NA	NA	NA	363	532	1,165	NA
62	15	13	13	0	0	0	1.2	2.2	81	114	122	10	2	NA	NA	NA	492	782	1,449	NA
63	18	13	13	0	0	0	1.1	1.89	81	115	123	7.5	1.2	NA	NA	NA	623	991	1,988	NA
64	0	0	11	0	0	0	NA	NA	77	NA	NA	11	NA	NA	NA	NA	0	0	0	NA
65	4	0	11	0	0	0	7.43	7.43	78	104	125	11	4	NA	NA	NA	71	93	121	NA
66	7	0	11	0	0	0	4.95	4.95	78	105	126	11	3.3	NA	NA	NA	134	193	263	NA
67	9	0	11	0	0	0	3.71	3.71	78	105	125	11	1.7	NA	NA	NA	179	224	410	NA
68	11	0	11	0	0	0	2.97	2.97	79	107	129	11	2.7	NA	NA	NA	307	377	600	NA
69	13	0	11	0	0	0	2.48	2.48	79	106	NA	11	3.6	NA	NA	NA	292	380	594	NA
70	16	0	11	0	0	0	2.12	2.12	79	106	NA	11	1.7	NA	NA	NA	451	638	866	NA
71	4	0	11	0	0	0	5	5	84	118	134	2	1.7	NA	NA	NA	130	173	225	NA
72	4	0	11	0	0	0	5.5	5.5	83	116	129	3.5	2.1	NA	NA	NA	113	130	180	NA
73	4	0	11	0	0	0	6	6	81	111	128	7.5	2.7	NA	NA	NA	88	115	147	NA
74	7	0	11	0	0	0	3.5	3.5	83	119	133	2.2	3.8	NA	NA	NA	215	309	377	NA
75	7	0	11	0	0	0	4	4	82	114	132	5	4.2	NA	NA	NA	137	208	266	NA
76	7	0	11	0	0	0	4.5	4.5	80	NA	131	10.5	2.3	NA	NA	NA	103	166	281	NA
77	0	0	33	0	0	0	NA	NA	80	127	133	NA	16.8	NA	NA	NA	0	0	31	NA
78	5	0	33	0	0	0	6.25	6.25	81	111	133	11	4.5	NA	NA	NA	89	150	249	NA
79	8	0	33	0	0	0	4.17	4.17	81	113	135	11	4.3	NA	NA	NA	140	218	385	NA
80	11	0	33	0	0	0	3.09	3.09	81	117	136	9	3.5	NA	NA	NA	441	737	880	NA
81	13	0	33	0	0	0	2.48	2.48	82	115	134	10	4	NA	NA	NA	325	480	743	NA
82	16	0	33	0	0	0	2.06	2.06	82	115	135	9	3.2	NA	NA	NA	466	624	914	NA
83	19	0	33	0	0	0	1.77	1.77	82	117	136	8.7	2.7	NA	NA	NA	668	966	1,389	NA
84	4	0	33	0	0	0	5	5	84	121	NA	3.5	4.2	NA	NA	NA	107	138	224	NA
85	4	0	33	0	0	0	5.5	5.5	83	NA	NA	5.7	NA	NA	NA	NA	99	147	220	NA
86	4	0	33	0	0	0	6	6	81	112	NA	8.5	3.4	NA	NA	NA	69	116	159	NA
87	8	0	33	0	0	0	3.5	3.5	83	118	NA	2.2	3	NA	NA	NA	149	238	371	NA
88	8	0	33	0	0	0	4	4	82	115	NA	7	3.3	NA	NA	NA	122	168	278	NA
89	8	0	33	0	0	0	4.5	4.5	80	NA	NA	11	NA	NA	NA	NA	80	153	195	NA
90	8	0	100	0	0	0	4.13	4.13	86	122	140	2.5	1.8	NA	NA	NA	125	179	262	NA
91	12	0	100	0	0	0	2.75	2.75	87	125	139	2	1.8	NA	NA	NA	216	357	481	NA
92	16	0	100	0	0	0	2.06	2.06	87	126	140	1.7	2	NA	NA	NA	322	528	698	NA
93	20	0	100	0	0	0	1.65	1.65	87	125	141	2.5	2	NA	NA	NA	420	719	1,017	NA
94	24	0	100	0	0	0	1.38	1.38	87	123	138	2.7	1.5	NA	NA	NA	610	938	1,342	NA
95	28	0	100	0	0	0	1.18	1.18	87	123	140	2.5	2.8	NA	NA	NA	824	1,300	1,790	NA

See explanatory notes at end of table.

MIX MATRIX AND TEST RESULTS–Continued

Sample no.	Additive wt/tailings wt, pct						W/B	W/C	Slurry density, wt pct	Dry density, lb/ft3	28-day wet density, lb/ft3	Slump, in	28-day settlement, pct	Av tensile strength, psi			Av unconfined compressive strength, psi			
	Cement	Fly ash	Pit-run slag	Ground slag	Kiln dust	Retorted waste								28 day	120 day	180 day	7 day	28 day	120 day	180 day
											TAILINGS B									
1	4	0	0	0	0	0	5.5	5.5	83	NA	132	2.5	4.2	10	25	NA	98	120	151	NA
2	4	0	0	0	0	0	6	6	81	NA	129	8.25	3.8	22	19	NA	60	88	96	NA
3	4	0	0	0	0	0	6.5	6.5	80	NA	129	9.5	5.6	14	19	NA	55	77	91	NA
4	6	0	0	0	0	0	3.5	3.5	83	NA	130	2.25	3.8	48	59	NA	190	273	371	NA
5	6	0	0	0	0	0	4	4	82	NA	128	4.5	4.2	34	39	NA	154	206	285	NA
6	6	0	0	0	0	0	4.5	4.5	80	NA	129	10	4.9	34	40	NA	107	146	191	NA
7	8	0	0	0	0	0	2.5	2.5	84	NA	131	1.5	4.5	89	99	NA	356	456	631	NA
8	8	0	0	0	0	0	3	3	82	NA	127	4.25	3.6	64	76	NA	270	255	441	NA
9	8	0	0	0	0	0	3.5	3.5	79	NA	127	10	5.2	52	68	NA	173	201	303	NA
10	10	0	0	0	0	0	2	2	85	NA	131	1	4.5	113	153	NA	551	764	923	NA
11	10	0	0	0	0	0	2.5	2.5	81	NA	128	6.5	4.5	89	107	NA	365	526	692	NA
12	10	0	0	0	0	0	3	3	79	NA	125	11	4.5	68	87	NA	226	360	421	NA
13	12	0	0	0	0	0	1.5	1.5	84	NA	133	1.75	3.1	133	171	NA	716	952	1,231	NA
14	12	0	0	0	0	0	2	2	82	NA	134	4.25	3.8	122	160	NA	535	733	937	NA
15	12	0	0	0	0	0	2.5	2.5	79	NA	134	11	6.3	88	116	NA	325	440	522	NA
16	14	0	0	0	0	0	1.5	1.5	84	NA	137	1.5	4.2	186	244	NA	955	1,482	1,534	NA
17	4.5	1.5	0	0	0	0	3.5	4.67	83	NA	136	2.5	4.5	27	55	47	116	193	275	313
18	4.5	1.5	0	0	0	0	4	5.33	82	NA	134	7.5	4.5	26	47	41	86	141	206	191
19	4.5	1.5	0	0	0	0	4.5	6	80	NA	131	10	6.2	17	35	44	81	114	214	194
20	6	2	0	0	0	0	2.5	3.33	84	NA	132	1.25	4.2	54	112	105	110	200	356	203
21	6	2	0	0	0	0	3	4	82	NA	131	6	5.6	NA	64	91	130	223	404	381
22	6	2	0	0	0	0	3.5	4.67	79	NA	134	11	7.2	NA	51	42	104	175	252	297
23	7.5	2.5	0	0	0	0	2	2.67	85	NA	132	2	4.2	NA	140	136	278	371	766	880
24	7.5	2.5	0	0	0	0	2.5	3.33	81	NA	127	8	3.1	NA	79	55	188	162	577	611
25	7.5	2.5	0	0	0	0	3	4	79	NA	130	11	7.3	NA	62	66	134	212	332	371
26	9	3	0	0	0	0	2.5	3.33	79	NA	129	11	7.3	NA	100	111	190	314	519	569
27	9	3	0	0	0	0	2	2.67	82	NA	132	4.75	5.2	88	141	176	236	417	678	765
28	3	3	0	0	0	0	4	8	82	NA	132	9	7.3	13	27	30	50	99	192	211
29	2	2	0	0	0	0	6	12	81	NA	131	8.5	7.3	0	0	0	36	57	75	75
30	1	3	0	0	0	0	6	24	81	NA	132	8.5	7.3	0	0	0	28	40	52	52
31	6	6	0	0	0	0	2.3	4.67	80	NA	130	11	7.2	44	91	75	88	216	461	590
32	0	0	0	0	0	14	2	NA	80	NA	133	11	8	0	0	NA	0	35	30	NA
33	0	0	0	0	0	28	1.1	NA	80	NA	131	9	5.5	0	0	NA	0	70	71	NA
34	5.4	0	0	0	0.6	0	4.4	4.89	80	NA	128	10	6.2	27	34	30	101	151	192	178
35	4.8	0	0	0	1.2	0	4.4	5.53	80	NA	133	9.25	6.2	20	31	24	74	94	135	131
36	0	5	0	0	5	0	2.75	NA	80	NA	135	9.75	8.3	0	13	18	0	25	133	188
37	8	0	0	0	0	0	9	9	60	NA	114	11	6.3	17	24	29	NA	38	47	53
38	9	0	0	0	0	0	5.8	5.8	70	NA	123	11	2.6	34	34	56	NA	124	168	151
39	8	0	0	0	0	0	3.4	3.4	80	NA	131	3.5	3.7	47	63	75	NA	201	248	334
40	12	0	0	0	0	0	6.2	6.2	60	NA	115	11	6.5	20	25	25	NA	65	73	91
41	12	0	0	0	0	0	4	4	70	NA	118	11	4.2	31	33	33	NA	140	172	166
42	12	0	0	0	0	0	2.3	2.3	80	NA	132	11	4.7	97	99	131	NA	473	547	574
43	6	6	0	0	0	0	6.2	12.47	60	NA	120	11	NA	22	22	40	NA	23	33	37
44	6	6	0	0	0	0	4	8	70	NA	126	11	6	31	91	50	NA	107	252	282
45	6	6	0	0	0	0	2.3	4.67	80	NA	136	11	7.3	50	85	101	NA	202	455	523

See explanatory notes at end of table.

MIX MATRIX AND TEST RESULTS–Continued

Sample no.	Cement	Additive wt/tailings wt, pct					W/B	W/C	Slurry density, wt pct	Dry density, lb/ft3	28-day wet density, lb/ft3	Slump, in	28-day settlement, pct	Av tensile strength, psi			Av unconfined compressive strength, psi			
		Fly ash	Pit-run slag	Ground slag	Kiln dust	Retorted waste								28 day	120 day	180 day	7 day	28 day	120 day	180 day
											TAILINGS C									
1	4	0	0	0	0	0	5.2	5.5	83	NA	113	0	3.1	20	23	24	44	61	180	80
2	4	0	0	0	0	0	6	6	81	NA	118	1	4.2	20	24	28	56	77	186	105
3	4	0	0	0	0	0	6.5	6.5	80	NA	119	1.625	2.6	23	23	29	100	130	186	145
4	6	0	0	0	0	0	3.5	3.5	83	NA	121	0	3.1	50	94	82	192	285	191	272
5	6	0	0	0	0	0	4	4	82	NA	123	1.5	4.2	41	72	71	127	176	183	187
6	6	0	0	0	0	0	4.5	4.5	80	NA	119	3	4.2	33	45	45	65	95	138	121
7	8	0	0	0	0	0	2.5	2.5	84	NA	123	0	2.1	71	89	83	171	213	238	265
8	8	0	0	0	0	0	3	3	82	NA	125	1.125	4.2	45	69	69	174	213	280	295
9	8	0	0	0	0	0	3.5	3.5	79	NA	123	3	2.08	50	56	60	144	148	221	222
10	10	0	0	0	0	0	2	2	85	NA	124	0	1.04	128	177	164	386	501	645	619
11	10	0	0	0	0	0	2.5	2.5	81	NA	125	1.125	3.1	82	111	144	295	367	506	495
12	10	0	0	0	0	0	3	3	79	NA	124	4.25	6.3	55	67	82	140	195	242	284
13	12	0	0	0	0	0	1.5	1.5	84	NA	125	0	2.1	142	168	168	558	796	809	833
14	12	0	0	0	0	0	2	2	82	NA	124	0	4.2	78	117	130	314	442	519	498
15	12	0	0	0	0	0	2.5	2.5	79	NA	124	2.25	3.1	96	114	127	335	438	509	558
16	4.5	1.5	0	0	0	0	3.52	4.69	83	NA	127	0	3.1	44	77	82	146	194	293	312
17	4.5	1.5	0	0	0	0	4	5.33	82	NA	127	0.5	3.1	37	46	66	145	202	267	299
18	4.5	1.5	0	0	0	0	4.5	6	80	NA	125	3.25	4.2	32	44	58	69	113	180	180
19	6	2	0	0	0	0	2.5	3.33	84	NA	130	0	4.2	79	114	135	286	393	556	607
20	6	2	0	0	0	0	3	4	92	NA	127	0	3.1	55	102	121	206	300	410	469
21	6	2	0	0	0	0	3.5	4.67	79	NA	124	1.75	3.1	40	80	80	159	223	303	316
22	7.5	2.5	0	0	0	0	2	2.67	85	NA	127	0	2.1	79	118	102	327	435	712	732
23	7.5	2.5	0	0	0	0	2.5	3.33	81	NA	126	0	3.1	88	124	145	276	399	571	672
24	7.5	2.5	0	0	0	0	3	4	79	NA	123	2.5	3.5	45	84	85	175	250	350	413
25	9	3	0	0	0	0	2.5	3.33	79	NA	125	2.25	3.8	89	109	104	271	376	506	617
26	9	3	0	0	0	0	2	2.67	82	NA	127	0	3.1	128	157	185	394	596	820	953
27	3	3	0	0	0	0	4	8	82	NA	126	0.5	3.1	23	46	50	109	131	277	272
28	2	2	0	0	0	0	6	12	81	NA	125	0.75	3.8	0	0	0	77	94	109	159
29	6	6	0	0	0	0	2.33	4.66	80	NA	125	1.75	3.1	48	83	105	173	188	454	526
30	4	0	0	0	0	0	8.2	8.2	76	NA	120	7	3.1	16	19	19	39	55	50	59
31	6	0	0	0	0	0	5.6	5.6	76	NA	117	7.25	1	28	25	33	63	100	90	101
32	8	0	0	0	0	0	4.3	4.3	76	NA	118	7.25	1	35	48	51	91	129	136	153
33	10	0	0	0	0	0	3.5	3.5	76	NA	121	7.5	3.5	50	54	60	143	195	240	258
34	12	0	0	0	0	0	2.9	2.9	76	NA	120	7.5	2.4	56	71	82	171	243	299	347
35	4.5	1.5	0	0	0	0	5.6	7.44	76	NA	118	7.5	3.1	15	21	NA	46	67	113	106
36	6	2	0	0	0	0	4.3	5.69	76	NA	119	8.25	3.5	25	51	47	83	120	177	180
37	7.5	2.5	0	0	0	0	3.5	4.63	76	NA	120	9.5	4.1	52	57	74	114	179	250	271
38	9	3	0	0	0	0	2.95	3.93	76	NA	121	10	4.2	NA	NA	NA	132	207	317	338
39	3	3	0	0	0	0	5.58	11.15	76	NA	122	11	6.2	13	6	10	46	54	83	105
40	2	2	0	0	0	0	8.21	16.42	76	NA	121	11	6.6	0	0	0	32	39	47	63
41	1	3	0	0	0	0	8.21	32.85	76	NA	123	11	7.3	0	0	0	27	37	52	56
42	6	6	0	0	0	0	2.92	5.9	76	NA	123	11	6.2	25	89	62	81	129	241	306
43	5.4	0	0	0	0.6	0	4.4	4.89	80	NA	123	2	3.1	20	37	45	78	115	135	151
44	4.8	0	0	0	1.2	0	4.42	5.52	80	NA	124	2.25	4.7	21	34	43	67	82	113	124
45	0	5	0	0	5	0	2.77	NA	80	NA	125	3.75	5.7	0	0	18	0	78	165	199
46	0	0	0	0	0	14	2.04	NA	80	NA	122	2.75	5.2	0	0	NA	0	39	43	NA
47	0	0	0	0	0	28	1.14	NA	80	NA	122	2.5	5.5	11	0	NA	0	103	130	NA

NA Not available.
W/B Ratio of water-to-cement, fly ash, kiln dust, and oil shale retorted waste.
W/C Water-to-cement ratio.

APPENDIX B.–STATISTICAL DEFINITIONS FOR GOODNESS-OF-FIT

Linear Correlation Coefficient.–Given a set of data (x_i, y_i), the linear correlation coefficient, r, is defined by

$$r = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n} (x_i - \bar{x})^2 \sum_{i=1}^{n} (y_i - \bar{y})^2}},$$

where $\bar{x}$ and $\bar{y}$ are the respective means of the input data.

Multiple Correlation Coefficient.–As stated in reference 15, when using a multiple-regression model, there exists one dependent and 'p' predictor variables. The multiple correlation coefficient, R, measures the percent of variation accounted for by the model. It is defined by

$$R^2 = \frac{\sum_{i=1}^{n} (\tilde{y}_i - \bar{y})^2}{\sum_{i=1}^{n} (y_i - \bar{y})^2},$$

where y_i = dependent variable,

$\tilde{y}_i$ = fitted (derived) dependent variable,

and $\bar{y}$ = sample mean of y_i.

If there is only one predictor variable, R reduces to r. An R-value of 1 indicates that the model provides all necessary information; R = 0 implies that the p-dimensional hyperplane is an inadequate model.

Index of Determination.–The index of determination, I, is defined by

$$I = 1 - \frac{\sum_{i=1}^{n} (y_i - \tilde{y}_i)^2}{\sum_{i=1}^{n} (y_i - \bar{y})^2}.$$

If the model being tested is linear, I is equivalent to either r or R. The index is useful in that it can be used to compare goodness-of-fit of nonlinear models.

APPENDIX C.–LINEAR REGRESSION RESULTS FOR TAILINGS A

The following abbreviations are used in this appendix:

7DCOMP	7-day compressive strength
CEMENT	Cement content, percent of tailings
Coef	Coefficient of variation
DF	Degrees of freedom
MS	Mean squares
NAp	Not applicable
Obs	Observation
R-sq	R^2 (multivariate correlation coefficient)
R-sq(adj)	R_2 adjusted for degrees of freedom
s	Estimated standard deviation about the regression line
SEQ SS	Sequential sum of squares
SS	Sum of squares
Stdev	Standard deviation
Stdev fit	Standard deviation of fitted value
St resid	Standardized residual
t-ratio	Coefficient/standard deviation
W/C	Water-to-cement ratio

The regression equation is 7DCOMP = -73.6 + 32.4 CEMENT - 1.40 W/C. Of the 95 observations, only 90 were used; the remaining five observations contained missing values.

Predictor	Coef	Stdev	t-ratio
Constant	-73.64	59.73	-1.23
CEMENT	32.356	2.672	12.11
W/C	-1.396	8.729	-.16

s = 69.42 R-sq = 87.9 pct R-sq(adj) = 87.6 pct

Analysis of Variance

Source	DF	SS	MS
Regression	2	3,032,842	1,516,421
Error	87	419,299	4,820
Total	89	3,452,140	NAp

Source	DF	SEQ SS
CEMENT	1	3,032,719
W/C	1	123

Obs.	CEMENT	7DCOMP	Fit	Stdev fit	Residual	St resid
1	4.0	48.00	44.20	26.66	3.80	0.06X
2	6.0	70.00	112.68	10.83	-42.68	-.62
3	8.0	112.00	179.35	8.41	-67.35	-.98
4	10.0	212.00	245.28	9.04	-33.28	-.48
5	12.0	278.00	310.76	9.27	-32.76	-.48
6	14.0	340.00	376.03	9.53	-36.03	-.52
7	4.0	79.00	48.11	11.33	30.89	.45
8	4.0	48.00	47.41	12.03	.59	.01
9	4.0	54.00	46.71	14.12	7.29	.11
10	6.0	196.00	115.61	16.17	80.39	1.19
11	6.0	141.00	114.91	12.89	26.09	.38
12	6.0	118.00	114.22	10.44	3.78	.06
13	4.0	25.00	45.41	20.05	-20.41	-.31
14	7.0	106.00	145.95	8.91	-39.95	-.58
15	9.0	171.00	212.39	8.73	-41.39	-.60
16	11.0	274.00	278.13	9.52	-4.13	-.06
17	13.0	431.00	343.53	9.77	87.47	1.27
18	16.0	481.00	441.10	10.30	39.90	.58
19	5.0	114.00	78.93	15.58	35.07	.52
20	8.0	158.00	179.07	8.10	-21.07	-.31
21	10.0	259.00	245.32	9.20	13.68	.20
22	13.0	459.00	343.31	9.03	115.69	1.68
23	15.0	518.00	408.63	9.91	109.37	1.59
24	18.0	603.00	506.14	12.12	96.86	1.42
25	0.0	14.00	*	*	*	*
26	4.0	47.00	44.86	23.02	2.14	.03X
27	6.0	95.00	113.21	9.67	-18.21	-.26
28	8.0	130.00	179.74	9.38	-49.74	-.72
29	11.0	183.00	277.91	8.69	-94.91	-1.38
30	13.0	160.00	343.35	9.16	-183.35	-2.66R
31	14.0	365.00	376.05	9.61	-11.05	-.16
32	0.0	0.00	*	*	*	*
33	4.0	72.00	45.41	20.05	26.59	.40
34	7.0	83.00	145.95	8.91	-62.95	-.91
35	9.0	135.00	212.39	8.73	-77.39	-1.12
36	11.0	308.00	278.13	9.52	29.87	.43
37	13.0	324.00	343.53	9.77	-19.53	-.28
38	16.0	428.00	441.10	10.30	-13.10	-.19
39	5.0	79.00	79.42	13.45	-.42	-.01
40	8.0	131.00	179.39	8.48	-48.39	-.70
41	11.0	295.00	277.91	8.69	17.09	.25
42	13.0	361.00	343.50	9.67	17.50	.25
43	16.0	529.00	441.16	10.37	87.84	1.28
44	19.0	772.00	538.63	13.35	233.37	3.43R
45	8.0	129.00	179.39	8.48	-50.39	-.73
46	12.0	270.00	310.76	9.27	-40.76	-.59
47	16.0	457.00	441.16	10.37	15.84	.23
48	20.0	497.00	571.16	14.70	-74.16	-1.09
49	24.0	744.00	700.97	21.62	43.03	.65
50	28.0	803.00	830.68	29.88	-27.68	-.44X
51	0.0	0.00	*	*	*	*
52	5.0	88.00	78.93	15.58	9.07	.13
53	8.0	154.00	179.07	8.10	-25.07	-.36
54	10.0	264.00	245.32	9.20	18.68	.27
55	13.0	341.00	343.31	9.03	-2.31	-.03
56	15.0	501.00	408.63	9.91	92.37	1.34
57	18.0	357.00	506.14	12.12	-149.14	-2.18R
58	5.0	152.00	78.93	15.58	73.07	1.08
59	8.0	80.00	179.07	8.10	-99.07	-1.44
60	10.0	233.00	245.32	9.20	-12.32	-.18

Obs.	CEMENT	7DCOMP	Fit	Stdev fit	Residual	St resid
61	13.0	363.00	343.31	9.03	19.69	0.29
62	15.0	492.00	408.63	9.91	83.37	1.21
63	18.0	623.00	506.14	12.12	116.86	1.71
64	0.0	0.00	*	*	*	*
65	4.0	71.00	45.41	20.05	25.59	.38
66	7.0	134.00	145.95	8.91	-11.95	-.17
67	9.0	179.00	212.39	8.73	-33.39	-.48
68	11.0	307.00	278.13	9.52	28.87	.42
69	13.0	292.00	343.53	9.77	-51.53	-.75
70	16.0	451.00	441.10	10.30	9.90	.14
71	4.0	130.00	48.81	12.25	81.19	1.19
72	4.0	113.00	48.11	11.33	64.89	.95
73	4.0	88.00	47.41	12.03	40.59	.59
74	7.0	215.00	147.97	13.85	67.03	.99
75	7.0	137.00	147.27	10.81	-10.27	-.15
76	7.0	103.00	146.57	8.95	-43.57	-.63
77	0.0	0.00	*	*	*	*
78	5.0	89.00	79.42	13.45	9.58	.14
79	8.0	140.00	179.39	8.48	-39.39	-.57
80	11.0	441.00	277.97	8.89	163.03	2.37R
81	13.0	325.00	343.53	9.77	-18.53	-.27
82	16.0	466.00	441.19	10.41	24.81	.36
83	19.0	668.00	538.66	13.32	129.34	1.90
84	4.0	107.00	48.81	12.25	58.19	.85
85	4.0	99.00	48.11	11.33	50.89	.74
86	4.0	69.00	47.41	12.03	21.59	.32
87	8.0	149.00	180.33	11.68	-31.33	-.46
88	8.0	122.00	179.63	9.04	-57.63	-.84
89	8.0	80.00	178.93	8.08	-98.93	-1.43
90	8.0	125.00	179.45	8.59	-54.45	-.79
91	12.0	216.00	310.80	9.42	-94.80	-1.38
92	16.0	322.00	441.19	10.41	-119.19	-1.74
93	20.0	420.00	571.18	14.66	-151.18	-2.23R
94	24.0	610.00	700.99	21.58	-90.99	-1.38
95	28.0	824.00	830.69	29.83	-66.69	-.11X

* Calculation not possible. Zero value involved.
R Denotes observation with large standardized residual.
X Denotes observation whose X value gives it large influence.

APPENDIX D.–MATHEMATICAL REPRESENTATIONS AND INDICES OF DETERMINATION FOR EXPONENTIAL CURVES RELATING COMPRESSIVE STRENGTH TO WATER-TO-CEMENT RATIO

	Index of determination, I
Tailings A, B, and C:	
$7DCOMP = 1{,}541.04e^{-0.58\ W/C}$	0.796
$28DCOMP = 2{,}782.30e^{-0.64\ W/C}$	.764
$120CDOMP = 3{,}690.00e^{-0.58\ W/C}$	.658
$180DCOMP = 1{,}035.80e^{-0.25\ W/C}$	.410
Tailings A, total:	
$7DCOMP = 1{,}515.53e^{-0.57\ W/C}$	.889
$28DCOMP = 2{,}836.17e^{-0.62\ W/C}$	.843
$120DCOMP = 4{,}008.05e^{-0.55\ W/C}$	.711
Tailings B, total:	
$7DCOMP = 2{,}632.73e^{-0.79\ W/C}$	.944
$28DCOMP = 3{,}734.56e^{-0.79\ W/C}$	.893
$120DCOMP = 2{,}969.06e^{-0.57\ W/C}$	.866
$180DCOMP = 1{,}587.58e^{-0.35\ W/C}$	.632
Tailings C, total:	
$7DCOMP = 610.85e^{-0.29\ W/C}$	.343
$28DCOMP = 792.36e^{-0.27\ W/C}$	.283
$120DCOMP = 862.11e^{-0.22\ W/C}$	.358
$180DCOMP = 891.91e^{-0.21\ W/C}$	.312
Tailings A, no additives:	
$7DCOMP = 1{,}106.35e^{-0.50\ W/C}$	.982
$28DCOMP = 1{,}812.46e^{-0.54\ W/C}$	.975
$120DCOMP = 1{,}940.58e^{-0.50\ W/C}$	.976
Tailings B, no additives:	
$7DCOMP = 2{,}692.67e^{-0.79\ W/C}$	.956
$28DCOMP = 4{,}392.84e^{-0.88\ W/C}$	.920
$120DCOMP = 4{,}316.19e^{-0.77\ W/C}$	.950
$180DCOMP = 1{,}772.37e^{-0.50\ W/C}$	.948
Tailings C, no additives:	
$7DCOMP = 1{,}352.77e^{-0.65\ W/C}$	.892
$28DCOMP = 2{,}004.24e^{-0.69\ W/C}$	.879
$120DCOMP = 1{,}832.01e^{-0.58\ W/C}$	.839
$180DCOMP = 1{,}860.52e^{-0.58\ W/C}$	.904

DCOMP 7-, 28-, 120-, or 180-day compressive strength.
W/C Water-to-cement ratio.

* U.S. GOVERNMENT PRINTING OFFICE: 611-012/00,081

INT.BU.OF MINES,PGH.,PA 28913