SURFACE MINE LAND RECLAMATION ENHANCEMENT THROUGH DISPOSAL OF COAL PROCESSING AND UTILIZATION WASTES

by

James G. Smith and Philip K. Davis

Abstract. This research is an investigation of the use of slurried coal processing and utilization wastes as a filler for reclaiming both pre-law abandoned mine lands and post law surface mine lands. The disposal of these wastes in an environmentally acceptable way can be beneficial to both the mining and the utilization industries as well as the general public. Returning these filler by products to the voids left by extracting the coal or placing them into abandoned mine pits can help return mined land to its original elevation and surface quality and thus, assist in the reclamation process. It will also allow thousands of acres of surface land presently being used for landfills and settling ponds to be put to a more productive use. Bench top tests were carried out to determine a suitable mixture of coal processing wastes, fly ash and FGD sludge. Processing and utilization wastes from Illinois No. 6 coal were used. Various mixtures were characterized in regard to pH, settling stability, relative density, particle size distribution, electrokinetic dewatering and compaction, chemicals and metals in leachates, and compressive strength as a function of time. A slurry with a mixture ratio of approximately that of the production ratio was chosen to input into the last cut of a laboratory size surface mine model constructed for this purpose. The same slurry was placed in a field pit (10 ft. x 10 ft. x 5 ft. deep), and wells were drilled for monitoring the groundwater and leachates. Preliminary results show the selected slurry to be suitable except for stabilizing (hardening) characteristics. Future research will include investigating ways to improve the compressive strength.

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Introduction

It has been estimated that 80% of all extracted coal is used as an energy

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source to generate electricity. The mining industry must process the coal between the mining and selling stages. This creates 20% to 30% wastes, a portion which is normally acidic in Illinois mines. During the utilization process, power plants are burdened with the disposal of large amounts of alkaline fly ash and FGD sludge. For each million tons of clean, AMAX mined coal (Illinois No. 6), there are 60,000 tons of processing residues (fine circuit), 86,000 tons of fly ash and 120,000 tons of FGD sludge generated. It is important to both industries to dispose of these wastes in an economical and environmentally acceptable manner. This project involves mixing the acidic and alkaline by products in appropriate amounts with water as a slurry to provide a pipeline-transportable product with suitable pH and hardening characteristics. This technique should facilitate the reclamation process associated with the last cut of surface mines and of pre-law abandoned mine lands.

In 1987 the annual rate of production of coal processing wastes in the U.S. was in excess of 100 million tons, over 50 million tons of scrubber sludge, and over 60 million tons of coal ash (Burnet and Gokhale, 1987). Although fly ash and bottom ash have separately been dumped into pit bottoms in either a dry or moist state [San Juan Station (New Mexico), Four Corners Station (New Mexico), Hayden Station (Colorado) and Montrose Station (Missouri)] (Duvel, Jr. et al. 1980), the method of mixing coal processing waste, FGD sludge, and fly ash together in either slurry form or a moist mix of solids for deposit in pit bottoms and pre-law abandoned mine pits as an environmentally acceptable filler remains untried. Mixing the alkaline fly ash and FGD sludge with coal processing wastes which are normally acidic can yield a material with suitable pH that can be made to stabilize so that heavy equipment can be safely driven over it. Reclamation costs should be reduced as a result of reduction in rough grading and reduction of work on the unmined side of the last cut. Restored land quantity (last cut restoration) and quality (long- and short-term underground environmental conditions) should improve, as well. This method should benefit both the mining industry (waste disposal and reclamation) and the utilization industries (waste disposal). It will also benefit the general public by leaving thousands of acres of surface land for uses other than waste disposal.

Twelve slurry mixtures, each having different ratios of FGD sludge, fly ash, and coal processing residues (fine circuit) were tested to determine the following characteristics: density, particle size distribution, settling time, compaction, compressive strength and hydrogeochemical content of the decant water. Electrokinetic techniques to speed settling and increase compaction were examined also.

The sample selected for further testing in the last cut of a laboratory mine model (1:70 scale) and a proof-of-concept field pit (10 ft. x 10 ft. x 5 ft. deep) turned out to be the one that most nearly approximates the rate at which the three products are generated. This particular sample consists of 50 wt. % FGD sludge, 30 wt. % fly ash and 20 wt. % coal processing waste. When this proportion of solids was mixed with an equal weight of water to form a 50 wt. % solids concentration slurry, the pH measured 8.59. Three wells were installed to monitor leachates, the surrounding groundwater and watertable depth. The scale model was designed to monitor leachates. The compressive strength of the solids is also being monitored as a function of time in both the model and the field pit.

Research Objectives

The main objective of this research was to determine a mixture of coal processing (fine circuit) and utilization (FGD sludge and fly ash) wastes to be used as an environmentally acceptable fill material for reclaiming both pre-law abandoned mine lands and post-law surface mine lands. Special emphasis was placed on developing an acceptable fill material which could be input into the last cut of surface mines or abandoned mine land pits in slurry form. It was to be determined if mixing acidic and alkaline by products in an appropriate amount of water, will lead to a pipeline transportable product with suitable hardening characteristics (at least 50 psi) and pH within EPA limits of 6.5-9.0 (IEPA, 1991).

In addition to the identification of a suitable waste mixture, factors which were to be investigated included, chemical composition of the decant water, pH, slurry settling stability, compaction of the fill material and its compressive strength, and the feasibility of using electrokinetics/ electroosmosis to enhance settling and compaction. After the bench-top experiments, the chosen mix was deposited into the last cut of a surface mine model which was constructed as a part of this study. The slurry was also input into a small (10 ft. x 10 ft. x 5 ft. deep) proof-of- concept field pit so that the groundwater and compaction could be monitored in the field.

Research Methodology

The first step in this research was to collect the materials needed for the bench-top studies. Fly ash and FGD sludge samples were obtained from the Central Illinois Public Service Company Newton Power Plant near Newton, Illinois. Coal processing waste samples from the fine circuit were obtained from the AMAX Delta mine near Marion, Illinois. The processing and utilization samples were all from Illinois No. 6 coal, mined and processed at the AMAX Delta mine.

The second step was to characterize the materials in regard to particle size distribution, specific gravity (relative density) and chemical content.

The next step was to bench-test 12 predetermined slurry mixtures (see Table 1) to determine the (1) pH, (2) natural settling stability, (3) electrokinetically-assisted settling stability, (4) natural compaction (hardening capacity) and (5) electroosmostically- assisted compaction.

The last step was to deposit the selected slurry mixture into the last cut of a laboratory surface mine model and into a proof-of-concept field pit so that leachates, groundwater and the compressive strength of the filler material could be monitored.

Laboratory Mine Model

A laboratory-size surface mine model was designed and constructed. The selected slurry was then desposited into the last cut for observation and studies. Davis (1989) has experience in designing, constructing and using underground mine models. The scale factor for this model is 1:70. A frame was built out of 2" x 4" lumber to support a clear plastic box (6 ft. x 6 ft x 2.5 ft) to contain the surface mine model. The frame was constructed with legs to support the bottom of the model 2 ft. up from the floor. Holes were drilled 6 inches apart along a centerline normal to the last cut so that leachates, if any, could be collected. A fine screen covered the holes on the top side and small funnels were glued to the underside. Plastic tubing was then connected to the funnels with the other end inserted tightly into collection jars. Mortar sand two inches thick was first placed in the bottom of the clear plastic box. A layer of stripping bench material (fire clay) four to six inches thick was then placed on top of the sand. This material and the overburden material were both obtained from the AMAX Delta mine. A last cut was next formed, using overburden material, with the steep slope being 60° and the other slope being 35°. Wood partitions were placed at each end of the clear plastic box. Overburden was then placed in the void between the partitions and the box walls.

Electrokinetically Assisted Stability

As the particle size decreases in a slurry, the particles stay suspended for longer times. The reasons for long-term turbidity include: the slow gravitational settling velocities due to small size, electrostatic repulsion between particles, and liquid motion. A well-established method of forcing settling is electrophoresis. The theory of electrophoresis is well understood and easily accessible in textbooks on colloidal chemistry and physics. Almost all colloidal particles have a net electric charge when suspended in water. Thus, by applying a dc electric field across the suspension, a force which is proportional to the charge and the electric field moves the particle toward the electrode of polarity opposite that of the particle charge. This phenomenon, which is known as electrophoresis, promotes settling.

It was decided that mixture combinations of utility and coal processing wastes be slurried (50% water and 50% solids by weight) to simulate conditions of pipeline transport to the deposition site. Davis (1987) has done research on the pumping characteristics of similar slurries and found no problem with blockage when pumping them up to solids concentrations of approximately 70 wt. % with a regular centrifugal slurry pump. With a 50% water content, it was anticipated that decanting would be necessary following settling. Since it is desirable to limit suspended solids in decant water, an experimental test involving forced settling by electrophoresis was included in the laboratory work. The test was done as follows: A 250 ml graduated cylinder was filled with the 50/50 mixture of solids and water. The settling distance between the sediment/water boundary and the meniscus was then plotted as a function of time. The time constant, T_2, is the time it takes to settle to 63% of the final settling distance. The effects of electrophoresis are tested by applying a dc electric field between an electrode placed near the water surface and one placed below the anticipated sediment/water boundary surface.

Electroosmotically Assisted Compaction

Electroosmotically-assisted compaction has been used for decades to densify soils. In recent years, this method has been extended to various mined products (Sami, Smith and Davis, 1989) (Sprute and Kelsh, 1974, 1976, 1980, 1982, and Kelsh and Sprute, 1986). Because FGD sludge, fly ash, and coal processing wastes contain very fine particles, the situation in which electroosmosis is generally the most effective, electroosmosis compaction tests were included in this research.

Tests were conducted in the laboratory on 5 cm and 20 cm columns of various combinations of utilization and coal processing slurries. After settling the clear surface water was decanted and then dc currents were applied between the top and the bottom of the columns for one hour. Theoretically, the electroosmatic pressure forces water toward the electrode nearest the surface where it should tend to evaporate more rapidly. As the mixtures hardened at room temperatures and humidities, penetrometer readings were recorded as a function of time.

Natural Stability and Compaction

Natural stability refers to the settling rate of the slurry under gravity only. Each of the sample mixtures was mixed into a 50 wt. % solids concentration slurry then placed into a 250 cc graduated cylinder. The growth of the clear column of water on top was then observed as a function of time until there was no more settling. The clear water column was then decanted, after which the compressive strength was measured as a function of time to determine the compaction.

Proof-of-Concept Field Pit

A field study pit (10 ft. x 10 ft. by 5 ft. deep) was dug so that the bottom of the pit lies just beneath the water table (Figure 1). Wells for monitoring groundwater were constructed with one approximately 15 ft. to the north of the pit and the other approximately 5 ft. to the south. The wells are on the groundwater upstream and the downstream sides of the pit. Samples for leachate monitoring are collected from a horizontal PVC screen pipe placed across the bottom of the pit. This system is accessed through a vertical PVC pipe so that samples may be taken out with a bailer.

Results and Discussion

Specific Gravity and Particle Size Distribution

The specific gravity on a dry basis for each material (FGD sludges, fly ash and coal processing waste from the fine circuit) is given in Table 2. FGD (1) refers to a dual alkali scrubber sludge whereas FGD (2) is a sludge from a magnesium-enhanced lime process. FGD (2) was used in both the laboratory model and the field pit. The FGD (2) sludge had pH of 8.59 for the selected mixture. The FGD sludges are the most dense with a specific gravity of approximately 2.65. The fly ash is nearly as dense with a specific gravity of 2.35. The coal processing waste from the fine circuit has, as expected, approximately the same specific gravity as coal (1.28). These measurements were carried out according to ASTM procedure No. D-854.

The particle size distribution analyses for the four products were accomplished by means of a combination of two methods. The larger particles were sized with sieves (ASTM No. D-421) while the smaller ones were done by means of a hydrometer analysis (ASTM No. D- 422). The results are given in Table 2. Clearly the FGD sludge contains the smallest particles and the coal processing waste has the largest particles of the three products.

Chemical Analyses

FGD, fly ash and coal processing wastes were each tested for the following chemicals: Al, As, Ba, B, Cd, Ca, Cl, Cr(tri), Cr(hex), Cr(total), Cu, Fl, Fe, Pb, Mg, Mn, Hg, Ni, K, Ag, Na, Sr, Zn, Mo, sulfate, antimony, cyanide, and phenols. The same chemical analysis was done on the decant from a slurry using sample No. 8 (25 wt % FGD sludge, 15 wt. % fly ash, 10 wt. % coal processing waste and 50 wt.% water). The undiluted, unfiltered, and untreated decant sample shows only five parameters (boron, flouride, total iron, total lead, and sulfates) that exceeded Illinois EPA stream water quality standards (IEPA, 1979). The groundwater samples which will be taken from the monitoring wells of the field project during year two will be tested for these chemicals. However, since these tests will be mainly for dissolved chemicals, it is not anticipated that there will be a groundwater problem.

Sample Descriptions

Thirteen different mixtures were bench-top tested in an effort to determine a suitable mixture. The percentages of FGD sludge, fly ash and coal processing waste in each sample are given in Table 1. Sample No. 8a (50 wt. % FGD sludge, 30 wt. % fly ash and 20 wt. % coal processing waste) was selected to use to make a 50 wt. % solids concentration slurry (25 wt % FGD sludge, 15 wt. % fly ash, 10 wt. % coal processing waste and 50 wt. % water) to put into the laboratory model and the pit in the field project. However, the FGD sludge is different [FGD(2) in Table 1] in the slurry that was actually used in the model and the field project because the CIPS Newton Power Plant changed it's scrubbing process. It turned out however, that the sample 8a with the same proportions of solids as sample 8 is better in that the pH is better (8.59).

pH Measurements

The pH of a 50 wt. % solids concentration slurry for pure FGD(1) is 11.2, 8.4 for FGD(2), 10.6 for pure fly ash and 7.4 for pure coal processing waste. It had been expected that the processing slurry would be more acidic. However, since the FGD(2) sludge is less alkaline, the sample 8a mixture has a pH (8.59) within IEPA (1979) streamwater limits of 6.5-9.0. This is the mixture that was put into the mine model and into the field pit for further studies.

Natural Stability

Each sample was mixed into a 50 wt. % solids concentration slurry then placed into a 250 cc graduated cylinder. The growth of the clear column of water on top was then observed as a function of time. Figure 2 shows an example plot for Sample No. 7 and a diagram showing how the data were taken. The time constant T_0) in Table 2 is the time required for the sample slurry to reach 63% of the total amount of time that it takes to settle. T_i is the time that it takes to reach 98% of the time for the slurry to settle out completely. The time range for complete settling for all the mixtures was from approximately 36 to 154 minutes. These slurries are therefore, all fairly fast settling mixtures (rather unstable suspensions).

Electrokinetically Assisted Stability

While some variations occur between samples in reaching stability, most of the combinations settled very quickly. Furthermore, the positive effects of applying direct current to speed settling were not detectable. In fact, electrophoresis appeared to somewhat inhibit the final stability level. A part of this discrepancy can be attributed to the volume of the electrodes. However, none of the errors that might be present are large enough to alter the conclusion that electrophoresis would not be necessary or of any value in stabilizing the combinations examined in this research.

Electroosmotically Assisted Compaction

The effects of applying a current density, J, of 500 $\mu A/cm^2$ for one hour to the settled slurry after decanting the clear water are shown in Table 1. The time in days required for the mixture to reach a compressive strength of 120 psi is called T_4. This time is shown in the first column under the heading "Electroosmotically Assisted Compaction". The ambient air conditions were those of an indoor laboratory.

It was found that a one hour application of either 500 $\mu A/cm^2$ just after settling and decanting and no appreciable effect upon the compressive strength while it was in the process of hardening.

The upper measurement limit of the laboratory penetrometer was 140 psi. Since the compressive strengths always exceeded this value, if left to dry at ambient room conditions long enough, the final compressive strengths were not determined.

We found electroosmotically-assisted compaction was of little value in the mixtures tried. As was the case for electrophoretic-assisted stability, the observations appear to be at odds with previous research. Part of the explanation for our negative results may be gleaned from the data in the column with the heading "Electroosmotically Assisted Compaction" in Table 1. The constant K_0), the electroosmotic transfer coefficient, measures the number of uncharged water molecules which are pulled to the upper electrode for each ionic charge (1.6×10^{-19} coulomb) collected by that same electrode. Although the numbers range from 23 to 109, these values represent a rather weak electroosmotic pressure. Unless compacted molecules approach one another close enough to fall within Van der Waal and structural attraction force distances, the materials may not compact due to Helmholtz repulsive electrostatic forces.

Model Study

The model was filled with 84 gal. of sample No. 8a slurry. It was not necessary to pump out the decant water since the stripping bench material (fire clay) and overburden quickly absorbed the water. The model is designed to collect leachates from the bottom. However, since the moisture was all absorbed by the soil, no leachates were collected. Future research will involve simulating rainfall by flooding a portion of the surface and thus forcing water through the fill material into the collection system.

The compressive strength of the fill material was measured as a function of time and location. Figure 3, shows the compressive strength data. This material hardens much more slowly than had been anticipated from the results of the bench-top studies. In the bench-top studies the compressive strengths ranged from 50 to 85 psi after 83 days.

Proof-Of-Concept Field Study

A field study pit was dug and the same slurry mix as was used for the model study was input to a depth of approximately three feet. The pit was constructed so that the bottom lies several inches below the water table. Wells for monitoring groundwater were constructed with one located approximately fifteen ft. to the north of the pit and the other approximately five ft. to the south. The wells are on the groundwater upstream and downstream sides of the pit. The water table data indicate that the groundwater flows from north to south toward an adjacent pond.

The pH of the slurry mix was originally 8.59. During the first three months of monitoring, at two-week intervals, the pH of the groundwater varied between 6.2 and 7.2. No chemical analyses have been carried out thus far, but these are scheduled to begin soon. On arrival at the proof-of-concept field site, the watertable elevation will be determined first. The monitoring wells will then be purged for at least three well volumes. Water samples will then be collected, preserved and analyzed according to USEPA (1979, revised 1983) guidelines. Chemical analysis will be performed approximately every three months.

The compressive strength of the fill material is continually being monitored. As in the case of the model, it was not necessary to pump off the decant water. The compressive strength varies as a result of rainfall, the maximum strength measured thus far is approximately 3.5 psi, significantly less than was anticipated. This indicates that the introduction of a hardening agent may be needed if this mixture is to be used as a suitable fill material where heavy equipment must run on it.

Conclusions

1. The processing waste (from the fine circuit) and the utilization wastes used in this research were all from Illinois No. 6 coal mined at the AMAX Delta mine near Marion, Illinois. The characterization of the individual products (FGD sludge, fly ash and coal processing wastes) and 13 different mixture combinations are given in Tables 1 and 2. A brief summary is: (a) the FGD sludge and fly ash are roughly twice as dense as the coal processing waste, (b) the particle size range of the coal processing waste is -2000 microns, -1000 microns for the fly ash and -850 microns for the FGD sludge, (c) all slurries tested were fast settling (<150 min) and (d) all mixtures reached a compressive strength of 120 psi in less than 24 days in a dry laboratory environment after they had settled and were decanted.

2. We found no evidence to indicate that electroosmotically-assisted compaction or electrophoresis-assisted settling were of any significant benefit.

3. The waste mixture selected for use in the laboratory model and proof-of-concept field pit is sample 8a in Table 1 (50 wt. % FGD (2), 30 wt. % fly ash and 20 wt. % coal processing waste). This is approximately the same proportion that the wastes are generated. The

dry solids were then mixed with an equal weight of water to form a 50 wt. % solids concentration slurry. The chemical analysis report for the unfiltered and untreated decant from this slurry shows that only five parameters (boron, flouride, total iron, total lead, and sulfates) out of the 29 tested exceeded Illinois EPA stream water quality standards. This does not mean that there will be a problem with groundwater contamination since we will be checking mainly for dissolved chemicals.

4. Observations from the model study thus far are: there was no need for decanting since the over-burden quickly absorbed the excess water; no leachates made it through the stripping bench material; and the slurry dried and compacted significantly slower than was observed in the bench top studies (see Figure 4).

5. Observations from the proof-of-concept field study thus far are: there was no need for decanting since the pit walls quickly absorbed the excess water; the surrounding groundwater pH has not been lower than 6.2 nor has it exceeded 7.2. (groundwater chemical analyses are not available at the time of submission of this manuscript); the compressive strength is significantly lower than was anticipated; and rain retards the hardening process.

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TABLE 1

WASTE MIXTURE CHARACTRIZATION

	SAMPLE DESCRIPTION			PH and NATURAL STABILITY			ELECTROKINETICALLY ASSISTED STABILITY			ELECTRO-OSMOTICALLY ASSISTED COMPACTION				
Sample number	FGD % dry wt.	Flyash % dry wt.	Coal wst. % dry wt.	pH	T0 Time constant min.	T1 equil. time min.	T2 time const. min.	T3 time const. min.	KW-Hr cost to T3 per ton	T4 time tgt. pntromtr.	KW-Hr per ton	K0 electo-os transfer coeff.	J current density µA/cm2	Time cycle regime hrs
1	60	40	0	10.71	30	47	66	81	0.138	17.4	0.248	48	500	1
2	50	50	0	10.52	33	50	30	50	0.096	23.4	—	45	500	1
3	33	17	50	9.32	50	148	65	88	0.231	9.6	0.211	109	500	1
4	60	30	10	10.27	26	40	54	88	0.140	21.1	0.117	45	500	1
5	50	40	10	10.17	34	47	44	87	0.130	19.0	0.120	61	500	1
6	40	50	10	10.03	36	49	33	65	0.131	12.4	0.142	73	500	1
7	30	60	10	9.81	49	71	32	73	0.159	7.7	0.149	76	500	1
8	50	30	20	10.40	24	35	22	34	0.036	12.9	0.136	76	500	1
8a	50	30	20	8.59	68	135	50	77	0.089	12.1	0.192	23	500	1
9	40	40	20	10.88	56	151	22	63	0.134	9.8	0.150	76	500	1
10	30	50	20	10.03	38	64	32	57	0.146	9.3	0.165	102	500	1
11	40	30	30	9.82	29	52	28	85	0.203	10.8	0.260	94	500	1
12	30	40	30	9.95	27	49	27	40	0.108	9.0	0.306	109	500	1

TABLE 2

PARTICLE DENSITY AND SIZE ANALYSIS

	SG	SIZE	
FGD (1)	2.65	100% < 297 Micron	(50 mesh)
		50% < 74 Micron	(200 mesh)
		20% < 31 Micron	(500 mesh)
FGD (2)	2.54	100% < 850 Micron	(20 mesh)
		50% < 7 Micron	
		20% < 3.5 Micron	
Fly Ash	2.35	100% <1000 Micron	(18 mesh)
		50% < 62 Micron	(230 mesh)
		20% < 31 Micron	(500 mesh)
Coal Proc. Waste	1.28	100% <2000 Micron	(10 mesh)
		50% < 210 Micron	(70 mesh)
		20% < 74 Micron	(200 mesh)

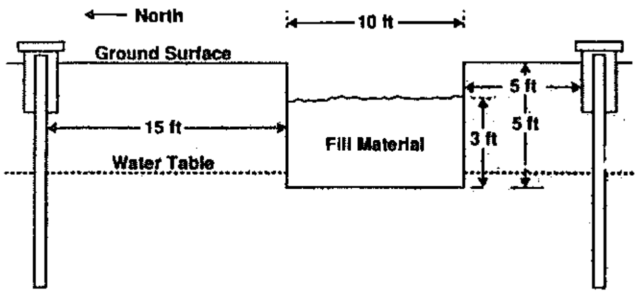

Figure 1. Proof-of-Concept Field Pit

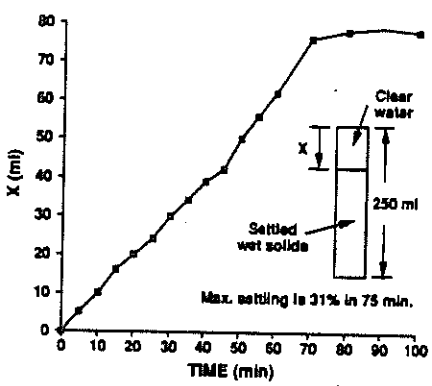

Figure 2. Settling Data for Sample No. 7 (15% FGD, 30% Fly Ash, 5% Coal Processing Waste and 50% Water)

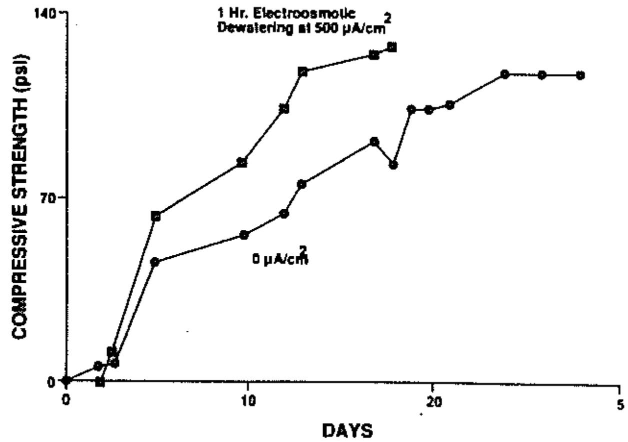

Figure 3. Compressive Strength of 50:30:20 Mixture

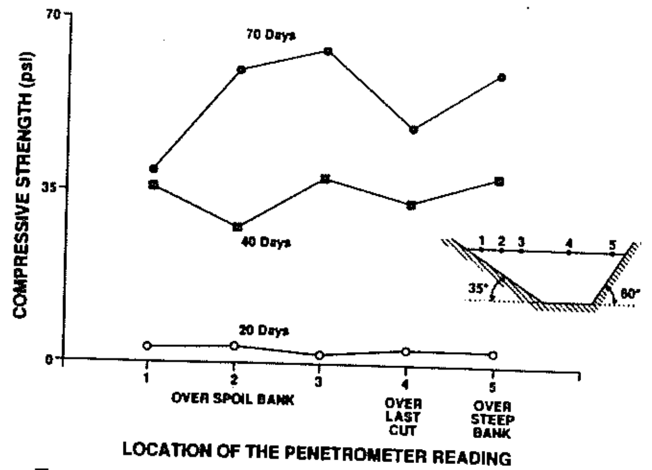

Figure 4. Compressive Strength of the Fill Material in the Mine Model