TECHNICAL REPORT
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Project Title: **CARBONATION AS A BINDING MECHANISM FOR COAL/CALCIUM HYDROXIDE PELLETS**

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ABSTRACT

This research is an investigation of calcium hydroxide, a sulfur-capturing sorbent, as a binder for coal fines. The reaction of carbon dioxide with calcium hydroxide, referred to as carbonation, is being studied as a method of improving pellet quality. Carbonation forms a cementitious matrix of calcium carbonate.

The effect of particle size and compaction pressure on pellet strength was studied using a laboratory hydraulic press. Particle distributions with mean sizes of 200, 90 and 40 microns were tested. The results indicate that pellet strength increased with decreasing particle size and increasing compaction pressure when calcium hydroxide was used as a binder. Pellets containing 10 wt% calcium hydroxide increased in strength by approximately 40% when air dried for one day. This increase in strength is attributed to carbonation of the calcium hydroxide via atmospheric carbon dioxide.

Corn starch, an adhesive binder, was tested at the finest particle size. Pellet strength did not increase as a function of increasing compaction pressure. At the finest particle size and highest compaction pressure (18,750 psi), dried pellets formed with 2 wt% corn starch were equivalent in strength to pellets containing 5 wt% calcium hydroxide.

Extrusion tests were conducted using 2 wt% corn starch and 10 wt% calcium hydroxide as binders. In this application, corn starch produced extrudates of approximately 4 times the strength of extrudates containing 10 wt% calcium hydroxide (dry basis). The results for extrusion when correlated with results from the above particle size testing indicated that extrusion could be simulated with the hydraulic press when a compaction pressure of 12,500 psi was applied to a 1/2-inch diameter cylindrical mold.

EXECUTIVE SUMMARY

Each year in Illinois, 2-3 million tons of coal fines (approximately 5% of the State's annual production), are disposed of in tailings ponds. The fines, generated during the routine mining and processing of coal, are disposed of because it has been considered uneconomical to recover and process them into a form that could be marketed. Currently, the only option available to Illinois companies for selling coal fines is to blend and ship them along with the coarse cleaned coal. In many cases, this cannot be done because of product quality considerations such as total moisture content and the allowable percentage of fines.

Pelletizing with calcium hydroxide, a sulfur capturing sorbent, represents a method to improve the marketability of these fines. The objective is to produce a readily-transportable fuel which would burn with reduced emissions of sulfur dioxide. To improve pellet quality, the reaction of calcium hydroxide with carbon dioxide is being investigated. Referred to as carbonation, the reaction results in the formation of a cementitious matrix of calcium carbonate.

The effect of particle size and compaction pressure on pellet strength was studied using IBC-106 from the Illinois Basin Coal Sample Program. Pellets were prepared using a laboratory Carver hydraulic press from samples with mean particle sizes of 200, 90 and 40 microns. Compaction pressures ranged from 6,250 to 18,750 psi. Calcium hydroxide in the amount of 5, 10 and 15 wt% was tested as a binder at all particle size distributions; corn starch in the amount of 1 and 2 wt% was tested as a binder at the finest particle size distribution. For purposes of comparison, binderless pellets were prepared at all particle size distributions. Companion tests were conducted using a 40-ton Loomis piston extruder from the University of Illinois Center for Composite Materials using a sample of IBC-106 ground to a mean particle size of 150 microns.

All pellets were tested for compressive strength along the radial axis using a soil testing machine. Load at failure in lbf (pounds-force) was measured for each pellet. This value was converted to psi using the formula for diametral compression which is discussed in the body of this report. The formula accounts for differences in pellet length.

The results indicate that pellet strength increased with increasing compaction pressure and decreasing particle size when calcium hydroxide was used as a binder. Increases in pellet strength with calcium hydroxide binder were marginal at the coarsest particle size but increased as particle size was reduced to the 40 micron mean size. Pellets containing calcium hydroxide prepared using the 40 micron mean particle sized feed that were air dried for one day were approximately

40% stronger than pellets fully dried in a vacuum drier and tested for strength. This increase in pellet strength is attributed to carbonation of calcium hydroxide via atmospheric carbon dioxide.

For pellets bound with corn starch, pellet strength increased as compaction pressure was increased from 6,250 to 12,555 psi but the increase in pellet strength as compaction pressure increased to 18,750 psi was minimal. At the finest particle size and highest compaction pressure, pellets containing 2 wt% corn starch attained a compressive strength of 34.2 psi when vacuum dried and 38.2 psi when air dried. Pellets containing 5 wt% calcium hydroxide achieved a strength of 32.0 psi when vacuum dried and 48.3 psi when air dried for one day. For pellets containing 10 wt% calcium hydroxide, the vacuum dried and air dried strengths were 37.0 and 52.7 psi, respectively. For 3.76% sulfur IBC-106, 10 wt% calcium hydroxide represents a 1.6/1 Ca/S ratio.

Extrusion tests were conducted using 10 wt% calcium hydroxide and 2 wt% corn starch as binders. The results indicate that corn starch produced pellets with a strength of 84.7 psi (dry basis) while pellets with calcium hydroxide attained a strength of 17.6 psi.

The pellets from extrusion containing 2 wt% corn starch were significantly stronger than the pellets containing 2 wt% corn starch formed with the 40 micron mean sized feed (34.2 psi). As a follow up, pellets were prepared in the hydraulic press using 2 wt% corn starch and the 150 micron mean sized extrusion feed sample. Pellets with a strength of 69.5 psi were produced. The only difference between the two batches of hydraulic press pellets was the particle size of the feed. This is an indication that the effectiveness of corn starch as a binder increases with increased particle size, at least within the range of particle sizes tested. This finding is opposite to that determined for calcium hydroxide. Follow up work will be conducted to confirm this. Another finding of this work is that extrusion could be simulated using the hydraulic press when a compaction pressure of 12,500 psi was applied to a 1/2-inch diameter cylindrical mold. The correlation was good for corn starch and calcium hydroxide.

Findings from this work indicate that when calcium hydroxide is used as a binder, it will be more effective if a high compaction pressure method of pellet formation is used. A Roller-and-Die pellet mill produces a higher compaction pressure than extrusion and would be more applicable when calcium hydroxide is used as a binder. Also, the indication is that calcium hydroxide will be more effective at pelletizing a minus 100 mesh flotation concentrate rather than a 28x0 concentrate. That is assuming that the finer particle sized feed does not have an elevated moisture content which would reduce pellet strength.

OBJECTIVES

This research is a two-year effort with two complementary goals. The first goal was completed in year one. The second will be completed in year two.

1) Production of Compliance Stoker Fuel from Fine Illinois Coal - The first goal was to investigate factors relevant to producing a stoker fuel from Illinois coal fines with potential to burn at the year 2000 compliance sulfur dioxide emission limit of 1.2/lbs/10^6 Btu. An Illinois coal with 1.6% sulfur was selected for this goal. Approximately 50% sulfur capture is required for this coal to meet the compliance emission limit.

2) Determination of a General Approach to the Production of Carbonated Coal/Calcium Hydroxide Pellets - Previous results have indicated that effective binder levels and carbonation conditions vary as a function of particle size and moisture content. The equipment used for pelletization also may depend upon the particle size and moisture content of the coal fines due to materials handling considerations. Goal two is to determine a general approach for pelletizing and carbonating coal/calcium hydroxide pellets.

INTRODUCTION

Project Background

This research represents a continuation of two projects (1,2) co-funded by the Center for Research on Sulfur in Coal (CRSC),and the Army Construction Engineering Research Lab (CERL). The CRSC's interest in funding the previous work has been to develop a method for utilizing Illinois coal fines that, in many cases, are currently being disposed of in tailings ponds. CERL's interest has been to develop a fuel for their stoker boilers that would burn at the year 2000 compliance sulfur dioxide emission level.

The Carbonation Reaction

For calcium hydroxide, the carbonation reaction is:

$$Ca(OH)_2 + CO_2 + H_2O \rightarrow CaCO_3 + 2H_2O + 19.6 \text{ kcal.}$$

The reaction is an ionic reaction with water acting as a solvent for both the carbon dioxide and calcium hydroxide. The proposed mechanism involves the dissolution of the $Ca(OH)_2$ to produce Ca++ and OH- ions. The carbon dioxide dissolves to form HCO_3-, CO_3-- and H + ions. The Ca++ and CO_3-- ions react to form insoluble calcium carbonate (5). As shown, carbonation produces a net increase in water in the system.

Key factors influencing the rate of carbonation for pellets are the concentration of carbon dioxide in the carbonating gas and the moisture content of the pellet. If too much moisture is present in a pellet, the pore spaces are filled and the carbon dioxide must diffuse through the water to react with the calcium hydroxide. This can severely slow the reaction. The ideal situation for the reaction to proceed is when there is enough moisture to coat the calcium hydroxide but leaving an open pore structure for the rapid ingress of carbon dioxide.

EXPERIMENTAL PROCEDURES

Materials

Binder Study-Minus 28 Mesh Preparation Plant Fines

The fine coal used in the Binder Study was collected from a southern-Illinois preparation plant. The sample had been mined from the Springfield coal seam (Illinois No. 5) and was a concentrate from spiral concentrators and flotation circuitry. The concentrates from the spirals and flotation cells were joined and dewatered in a screen bowl centrifuge. The moisture content after dewatering was approximately 22%. After collection, the sample was stored in two, sealed, 55-gallon drums equipped with plastic liners.

The sample (Table 1) was quite low in sulfur for an Illinois coal at 1.6%. The mean particle size was 227 microns with a 90% passing size of 590 microns. The coal fines are referred to as minus 28 mesh as this is the cut the plant wished to send to their spirals and flotation cells.

Particle Size Study and Extrusion Testing

IBC-106 from the Illinois Basin Sample Program was used in these studies. The sample is a preparation plant product and was mined from the Indiana No.5 Seam (Illinois No. 5).

For all tests, the calcium hydroxide used was a commercial product prepared from the Burlington limestone. The corn starches tested were obtained from commercial grain processing facilities.

Procedures

Pellet Formation-Hydraulic Press - To prepare coal/binder mixtures, the desired wt% of binder was added to the coal sample and blended for two minutes using a variable speed hand-held mixer. Sample sizes were 125 grams in the Binder Study and 100 grams in the Particle Size and Extrusion Studies (dry basis).

Pellets were formed using 1/2 inch (inside diameter) stainless steel cylindrical mold and piston and a Carver hydraulic press. Pellets were approximately equal in height and diameter. The sample was placed in the mold, compacted for 10 seconds with the desired pressure, the pellet was then removed from the mold. Because pellet height was a function of the amount of sample placed in the mold, there were slight differences in pellet height.

For each mixture, a sample was removed to obtain a moisture content before pellet formation. Moisture content was determined by drying on a hot plate at 105 °C until no further weight loss due to evaporation was observed. Moisture content after pellet formation was also determined by removing three pellets and drying them on the hot plate.

Pellet Formation-Extrusion - Extrusion tests were conducted at the University of Illinois Ceramic Engineering Building. The extruder was a 40-ton Loomis piston extruder with a 4-inch diameter barrel. The extrusion pressure was in the range of 2000 to 2500 psi. A circular die of approximately 0.56" in diameter was used.

Pellet Carbonation - Pellets were carbonated for 15 minutes using 100 vol% carbon dioxide in 10 cm diameter Buchner funnel sealed with a No.15 rubber stopper.

Strength Testing - A Geotest model S2013 was used for strength testing. A pellet was positioned on its side, a force was then applied at 0.25 cm/minute and load at failure in lbf (pounds-force) was recorded.

All pellets referred to as dried pellets were dried prior to testing for one hour using a vacuum drier set at 70°C and with a vacuum of approximately 125 mm Hg pressure absolute. Thus, all cured pellets were tested on a "moisture free" basis. Pellets referred to as green were tested before drying.

The results for pellet strength are reported in psi (pounds per square inch) to failure. For pellets tested in the above mentioned manner, conversion from lbf to psi is accomplished by use of the formula below. The measurement is referred to as diametral compression.

$$\text{Strength (psi)} = \frac{2\ (\text{Load})}{3.14\ (\text{Diameter})\ (\text{Length})}$$

The diameter of each pellet was 1/2-inch (unless noted otherwise). The length of each pellet was measured by use of a digital micrometer. Because the extruded pellets had irregular ends, the ends of each extrudate were sanded to produce planer surfaces.

RESULTS AND DISCUSSION

Binder Study

Several binders were tested for effectiveness using the No. 5 seam preparation plant coal fines. Two corn starches were tested; one a lower quality, lower priced starch, the other a higher quality, higher priced starch. Also tested were calcium lignosulfonate and a petroleum water emulsion-SHUR BOND. These binders were tested to evaluate the relative effectiveness of calcium hydroxide and the carbonate binding system under the conditions tested.

The binders were tested using the fines at the "as received" moisture content which was approximately 22 wt%. Pellets were tested for the green strength, or, the strength immediately after formation, and the dried strength, which was the strength after the pellets were dried in a vacuum drier for approximately 1 hour. Pellets were formed at three compaction pressures.

The results (Table 2) show that higher priced corn starch (corn starch 1) produced pellets of the highest strength per the amount of binder added. The pellets bound using corn starch 1 showed no improvement in pellet quality with increased compaction pressure as did the pellets bound using calcium lignosulfonate. The lower priced starch did not impart any binding action at the compaction pressures tested showing results similar to those for no binder. The green strengths for these binders were insignificant.

The binder SHUR BOND did not impart significant pellet strength under the conditions tested. Pellet strength did not increase with addition of increased amounts of binder, in fact it decreased as the amount of SHUR BOND was increased above 2.5 wt%. For SHUR BOND, even 2.5 wt% may have been more binder than was necessary to get the most strength for the least cost. Although the pellets containing SHUR BOND exhibit strengths similar to those for pellets without binder, the pellets by inspection were better than pellets without binder with regards to fines production and weatherability. For this test series though, these characteristics were not quantified.

For the pellets bound with calcium hydroxide, strength increased with compaction pressure and carbonation increased the strength of pellets by approximately a factor of 4. In another test shown in Table 3, pellets containing 10 wt% calcium hydroxide, formed with 18,750 psi, were air cured to determine how much strength developed due to exposure to atmospheric carbon dioxide. The pellets in this example did not achieve a strength equivalent to those pellets carbonated with 100% carbon dioxide. Previously, pellets prepared with

10 wt% calcium hydroxide have been shown to achieve strengths due to reaction with atmospheric carbon dioxide equal to pellets carbonated with 100 vol% carbon dioxide. These results were reported in the first and second quarterly report for this research. The pellets did increase in strength though and attained a strength in one day of the same order of magnitude as did pellets formed with 1 wt% corn starch 1 and 2.5 wt % calcium lignosulfonate.

IBC-106 Particle Size Study

The following test matrix has been completed on IBC-106. The coarsest particle size distribution approximates a 28x0 preparation plant clean coal concentrate such as would be produced by blending a 28x100 gravity concentrate with a minus 100 mesh flotation concentrate. The finest particle size approximates a flotation concentrate.

Mean Particle Size (um)	Wt% Calcium Hydroxide	Compaction Pressure (psi)
200,90,40	0,5,10,15	6,250;12,500;18,750

The results are listed in Tables 4-7. In addition to the above matrix, tests were run at the finest particle size using 1 and 2 wt% corn starch. Pellets were tested for compressive strength immediately after formation (green), after drying in a vacuum drier for one hour at 70 °C with a vacuum of approximately 125 mm Hg absolute and after air curing for one day.

Significant findings of the study are:

1. For binderless pellets and pellets formed with calcium hydroxide, pellet strength increased as particle size was decreased (Figure 1) and compaction pressure was increased (Figures 2 and 3).

2. Calcium hydroxide improved pellet strength (Figures 4 and 5). Pellets containing calcium hydroxide formed at the finest particle distribution (mean size of 40 microns) when air cured for one day were approximately 40% stronger than pellets that were vacuum dried (Figure 6). The increased strength is attributed to the calcium hydroxide in the pellets reacting with atmospheric carbon dioxide to form a cementitious matrix of calcium carbonate which further hardened the pellets. The increase in strength with air curing was less pronounced at the coarser particle size distributions.

3. The effectiveness of corn starch increased only marginally with increased compaction pressure (Table 8). This relationship between compaction pressure was also exhibited in the Binder Study.

Extrusion

Extrusion tests were conducted using an extruder located at the University of Illinois Ceramic Engineering Building. Used as binders were corn starch (number 1 in the Binder Study) in the amount of 2 wt%, and 10 wt% calcium hydroxide. The results (Table 9) indicate that, for extrusion, corn starch is significantly better as a binder than calcium hydroxide. The strength attained using corn starch was 84.7 psi. The strength for the pellets formed with calcium hydroxide was 15.7 psi.

The strength of 84.7 psi for the extrudates containing 2 wt% corn starch was significantly higher than the value of 32.4 psi achieved with 2 wt% corn starch binder (12,500 psi) in the Particle Size Study (See Table 8). In the Particle Size Study, the compressive strength of pellets containing 2 wt% corn starch (mean particle size-40 microns) was not highly dependent on compaction pressure, an indication that other factors were responsible for the difference in pellet strength.

To determine if particle size fully or partially accounted for this difference, pellets were prepared with the hydraulic press using the extrusion feed sample (mean particle size 150 microns) and 2 wt% corn starch as a binder. The procedures followed were the same as used in the Particle Size Study. The moisture content of all batches tested were similar. The feed to the extrusion tests was 25.7 wt% moisture and the extrudate moisture was essentially unchanged at 25.2 wt% moisture. For the pellets prepared with the hydraulic press using the extrusion feed, the feed moisture content was 25.6 wt%; the pellets contained 22.6 wt% moisture (For the Particle Size Study, the feed moisture content was 27.5 wt% and the pellet moisture was 20.6 wt%).

The results showed that the pellets prepared using the hydraulic press attained a strength of 69.5 psi (12,500 psi compaction pressure), almost double that of the 32.4 psi attained with the 40 micron sized feed in the Particle Size Study and comparable to that attained with the extruder. This is an indication that corn starch increases in effectiveness with increasing particle size. This potential trend will be investigated next quarter by testing corn starch at the 200 and 90 mean particle sizes tested in the Binder Study.

Although the values for pellet strength attained with the hydraulic press (69.5 psi) and the extruder (84.7 psi) are similar, the extrudates are still about 20% stronger. Another factor which could influence pellet strength is mixing intensity. In our laboratory, samples are mixed for two minutes using a hand mixer such as would be commonly used in a kitchen. The sample used for the extrusion test was mixed in a high torque Hobart planetary mixer. The sample was mixed and the moisture content adjusted until the sample attained a degree of plasticity which was noticeable by observation. This plasticity is desired for extruding high strength ceramic materials. To attain this state at a given binder content, the moisture content must be in a narrow range and the sample mixed with sufficient intensity. This implies that to reduce binder requirements for extrusion of coal fines, moisture content and mixing are important factors.

The results for the extrusion testing corresponded well with the results in the Particle Size Study for both calcium hydroxide and corn starch. For calcium hydroxide, the average strength of the extrudates was 15.7 psi. This value is intermediate to the value achieved at the 12,500 psi compaction pressure for the 200 mean particle size sample with 10 wt% calcium hydroxide (11.6 psi) and the 90 micron mean particle size sample (19.1 psi). As mentioned, the mean particle size of the extrusion feed was 150 microns. This information, along with the information determined for the pellets containing corn starch, indicate that the extruder can be roughly simulated in our lab using a 12,500 psi compaction pressure on a 1/2-inch diameter cylindrical mold.

SUMMARY

This research is an investigation of calcium hydroxide as a binder/sorbent for coal fines. To give the Principal Investigator and reviewers of the work a feel for the success of the approach, alternate binders have been tested; these binders have been selected based on recommendations in the literature. Additionally, it has always been desired to generate data with as much industrial application as possible. With this in mind, industrial methods of pellet production and related unit operations such as filtration and flotation have been an utmost consideration when designing and executing test programs. There were several findings in this quarter's research that have potential application toward determining a method of pellet production on a commercial scale.

For application of calcium hydroxide as a binder for coal fines, the finding that pellet strength increased with increasing compaction pressure and decreasing particle size indicate that calcium hydroxide has the most application to a finer particle sized feed. An example of such a feed would be

a column flotation concentrate. The method of pellet production would also need to generate a significant compaction pressure. Extrusion is a relatively low compaction pressure method of pellet production so calcium hydroxide would have less application to this approach. A Roller-and-Die pelletizer though produces a significant compaction pressure and would be recommended when calcium hydroxide is used as a binder. Indeed, quality pellets have been produced with a California Pellet Mill (CPM), a Roller-and-Die mill, using as little as 5% calcium hydroxide, albeit a relatively coarse feed was used (mean particle size-227 microns) (4). Still to be investigated is the quality of pellet that can be produced with a CPM using a finer sized feed.

Corn starch is a binder that has been recommended for coal fines (5,6). Two corn starches varying in price were tested this quarter. The results indicate that all corn starches are not created equal and that cheaper is not always better, at least within the conditions tested in this work. The lower priced starch did little to improve pellet quality; the higher priced starch was actually cheaper on a cost per pellet strength basis. A caveat is that this finding does not apply to all starches of varying price, only the two tested in this work and under the conditions tested.

For corn starch, it was shown that pellet quality does not necessarily improve with increased compaction pressure and that very strong pellets can be produced (on a dry basis) by extrusion when corn starch is used as a binder. There was also indication, which requires further testing for verification, that the effectiveness of corn starch as a binder increased with increasing particle size, within the range of particle sizes tested. This indicates that corn starch will be more effective as a binder on 28x0 feeds rather than with minus 100 mesh feeds. A significant drawback to using corn starch is that the pellet green strength is quite low, for both an extruder and CPM. When using a CPM, pellets bound with calcium hydroxide are significantly stronger.

This research has progressed to the point where recovery and pelletization of coal fines needs to be considered on a comprehensive basis involving the flotation, filtration and pelletization unit operations, rather than a series of uncoordinated efforts. The pelletization testing need be performed with an industrially practical method of pellet production. This approach yields the best method of evaluating the feasibility of the overall process and determining potential cost savings by optimally integrating the unit operations. Also, required is an investigation of the potential markets for the pellets, both near and longer term, for pellets bound with either calcium hydroxide or corn starch, to determine what prices the pellets could command.

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REFERENCES

1. Rapp, D. M., J. M. Lytle, K. C. Hackley, L. B.Kohlenberger, D. L. Moran, R. L. Berger, and K. Griggs. 1990. A Method for Improving Sulfur Capture Using Coal/Sorbent Pellets, Final Report to the Center for Research on Sulfur in Coal.

2. Rapp, D. M., J. M. Lytle, K. C. Hackley, D. L. Moran, R. L. Berger, and K. Griggs. 1992. Process Development for the Production of Coal/Sorbent Agglomerates, Final Report to the Center for Research on Sulfur in Coal.

3. Moorehead, D. R., and P. J. Morand. 1975. Some Observations of the Carbonation of Portlandite ($Ca(OH)_2$ and Its Relationship to the Carbonation Hardening of Lime Products, 3rd Symposium on Science and Research in Silicate Chemistry, Bras, Czechoslovakia.

4. Rapp, D. M., J. M. Lytle, K. C. Hackley, R. L. Berger, and G. Schanche. December, 1992. Carbonation as a Binding Mechanism for Coal/Calcium Hydroxide Pellets. First Quarterly Report to the Illinois Clean Coal Institute.

5. Pelletizing/Reslurrying as a Means of Distributing and Firing Clean Coal, Final Report to the U.S. D.O.E., Contract No. DE-AC22-90PC90166, 1992.

6. Wasson, G. E.,(1991) Extrusion Agglomeration of Fine Coal, Presented at 1991 Annual Meeting of the AIME/SME.

DISCLAIMER

Table 1 - Chemical analysis of Springfield fine coal concentrate (% on a dry basis).

	Wt%
Ash	9.7
Total Sulfur	1.6
Pyritic Sulfur	0.75
Organic Sulfur	0.74
Sulfatic Sulfur	0.11
Total Chlorine	0.4
Hydrogen	4.7
Carbon	74.9
Nitrogen	1.5
Oxygen	7.2
Heating Value (Btu/lb)	13141

Table 2 - Results from binder study on 28x0 mesh Illinois No. 5 seam coal fines.

Binder		Compaction Pressure (psi) 3,125	6,250	12,500	18,750
No Binder	green	0	0	0.6	1.2
	dried	6.0	8.0	7.1	5.7
1% corn starch 1 (13.5 cents/lb.)	green	0	0	0.3	0.8
	dried	26.0	31.9	26.8	27.8
2% corn starch 1	green	0	0	0	0
	dried	60.3	68.0	62.8	60.2
2% corn starch 2 (7.5 cents/lb.)	green	0	0.1	0.1	1.1
	dried	1.4	3.8	5.1	5.8
5% corn starch 2	green	0	0	0.3	0
	dried	2.7	4.4	6.8	6.0
1% calcium lignosulfonate (4 cents/lb.)	green	0	0	0.4	1.0
	dried	6.0	7.0	7.3	8.0
2.5 calcium lignosulfonate	green	0	0	0.6	1.2
	dried	28.9	29.1	29.5	29.1
2.5% SHUR BOND (25 cents/lb.)	green	0	0	0.7	0.6
	dried	3.5	3.4	3.6	4.5
5.0% SHUR BOND	green	0	0.1	1.4	1.9
	dried	0	0	0.7	1.6
10% SHUR BOND	green	0	0	0	0
	dried	0.1	0	0.3	0.3
10% calcium hydroxide ($48.5/ton)	green	0	.8	3.4	4.9
	dried	4.3	7.2	10.7	11.4
10% calcium hydroxide, carbonated	green	7.1	12.8	23.5	21.7
	dried	23.6	30.9	44.3	47.8

Table 3 - Comparison of compressive strength for pellets dried in a vacuum drier to pellets air dried. Pellets formed with 18,750 psi using 28 x0 Illinois No. 5 seam coal fines.

10% calcium hydroxide	green	dried	1 day	1 month
	4.5	16.6	23.9	26.0

Table 4 - Results from Particle Size Study for pellets formed without binder.

Compaction Pressure	Mean Particle Size (microns)	Binderless Pellets	
		Green	Dried
6,250 psi	200	9.0	2.4
	90	2.6	3.7
	40	7.8	5.6
12,500 psi	200	6.0	10.3
	90	9.0	10.8
	40	12.3	13.9
18,750 psi vacuum dried	200	1.7	19.2
	90	13.4	19.9
	40	18.9	25.4
18,750 psi air dried	200	18.2	
	90	18.4	
	40	27.2	

Table 5 - Results from Particle Size Study for pellets formed with 5% calcium hydroxide.

Compaction Pressure	Mean Particle Size (microns)	5% Calcium Hydroxide	
		Green	Dried
6,250 psi	200	1.4	7.4
	90	4.9	9.5
	40	6.3	10.1
12,500 psi	200	3.8	11.9
	90	8.6	19.1
	40	13.3	16.8
18,750 psi vacuum dried	200	5.8	16.2
	90	11.7	22.0
	40	20.8	34.1
18,750 psi carbonated, vacuum dried	200	11.7	16.4
	90	20.7	26.5
	40	27.4	32.0
18,750 psi air dried	200	18.7	
	90	28.6	
	40	48.3	

Table 6 - Results from Particle Size Study for pellets formed with 10% calcium hydroxide.

Compaction Pressure	Mean Particle Size (Microns)	10% Calcium Hydroxide	
		Green	Dried
6,250 psi	200	3.7	6.5
	90	3.7	11.7
	40	7.2	12.5
12,500 psi	200	6.0	11.6
	90	5.4	19.1
	40	13.4	26.7
18,750 psi vacuum dried	200	7.0	15.2
	90	10.3	23.2
	40	20.2	37.0
18,750 psi carbonated, vacuum dried	200	24.2	56.4
	90	29.2	45.9
	40	43.4	51.8
18,750 psi air dried	200	20.8	
	90	23.6	
	40	52.7	

Table 7 - Results from Particle Size Study for pellets formed with 15% calcium hydroxide.

Compaction Pressure	Mean Particle Size (microns)	15% Calcium Hydroxide	
		Green	Dried
6,250 psi	200	3.3	13.7
	90	3.2	11.4
	40	5.9	14
12,500 psi	200	5.1	17.6
	90	6.5	17.6
	40	13.3	21.7
18,750 psi vacuum dried	200	7.8	21.3
	90	10.6	26.7
	40	19.1	39.5
18,750 psi carbonated, vacuum dried	200	46.0	87.3
	90	57.5	96.9
	40	74.3	74.3
18,750 psi air dried	200	28.5	
	90	30.8	
	40	55.8	

Table 8 - Results from Particle Size Study for pellets formed with corn starch.

		Compaction Pressure			
Wt% Binder		6,250	12,500	18,750	18,750*
1% corn starch	green	3.7	10.6	15.0	
	dried	10.3	24.3	26.1	27.8
2% corn starch	green	4.4	7.6	8.1	
	dried	20.9	32.4	34.2	38.2

* air dried for one day

Table 9 - Results from extrusion testing using feed with 150 micron mean particle size. Result from test using the hydraulic press included for purposes of comparison.

	Compressive Strength in psi, (wt% moisture)		
Binder	green	dried	air cured 1 day
2% corn starch	6.6, (25.2)	94.9	80.6, (11.6)
10% calcium hydroxide	0.6, (27.0)	17.6	20.1, (9.13)
2% corn starch, hydraulic press		69.5	61.7, (5.2)

Figure 1-Effect of particle size on pellet strength with varied amounts of Ca(OH)2.

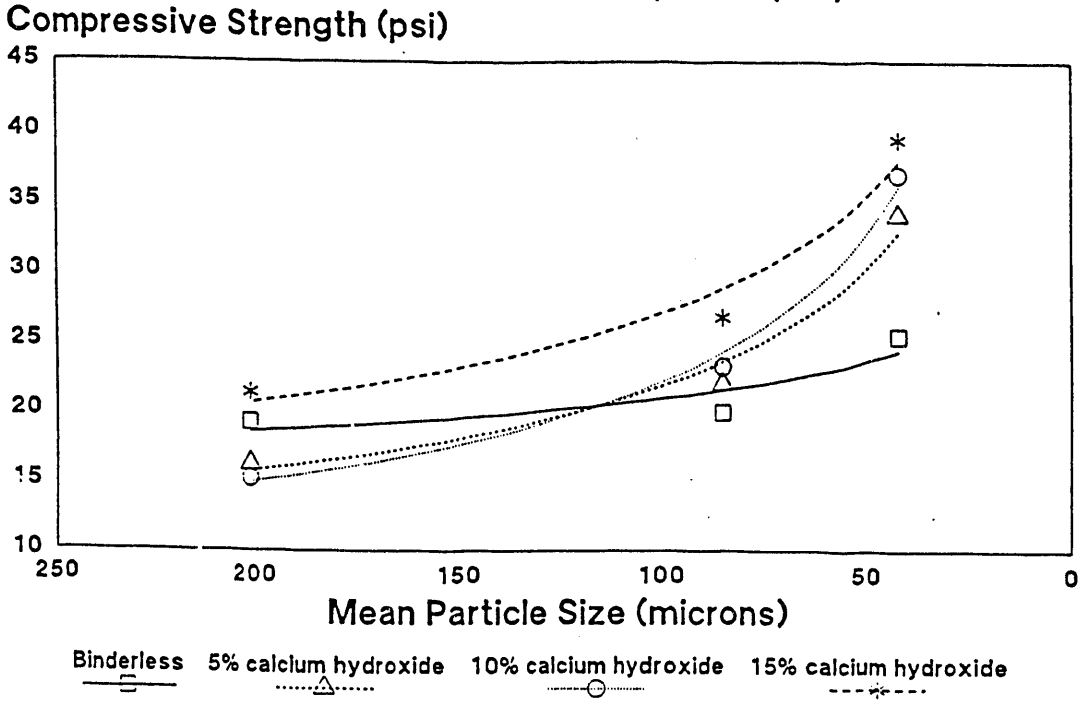


Figure 2-Effect of Compaction Pressure on Pellet Strength for Pellets Containing 10% Ca(OH)2

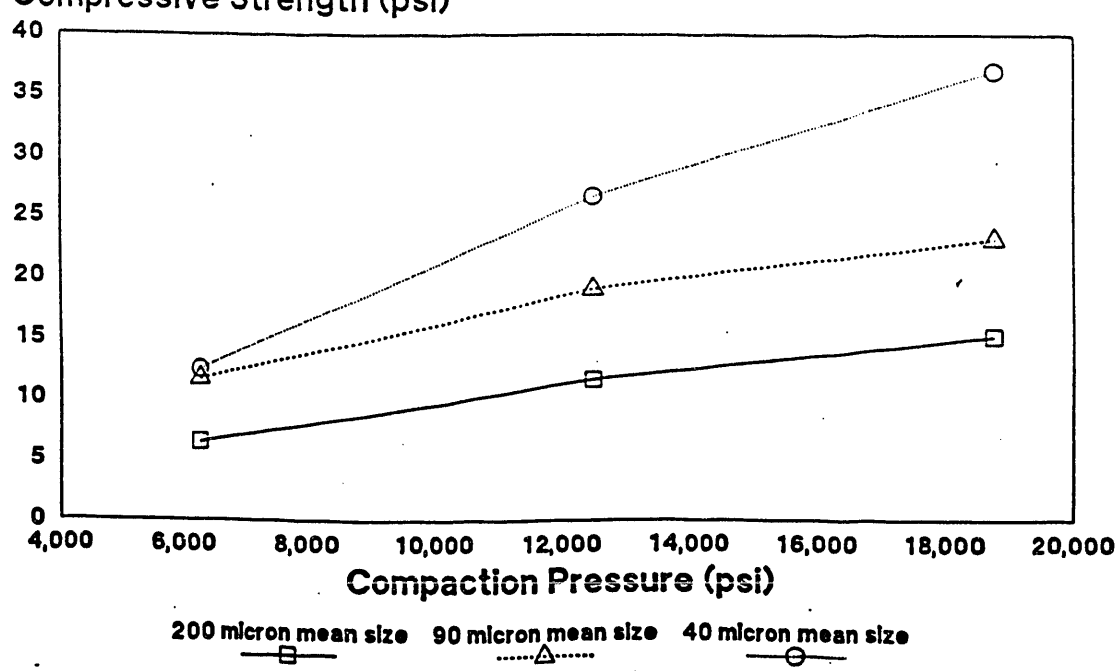


Figure 3-Effect of Compaction Pressure on Pellet Strength for Pellets Formed Without Binder.

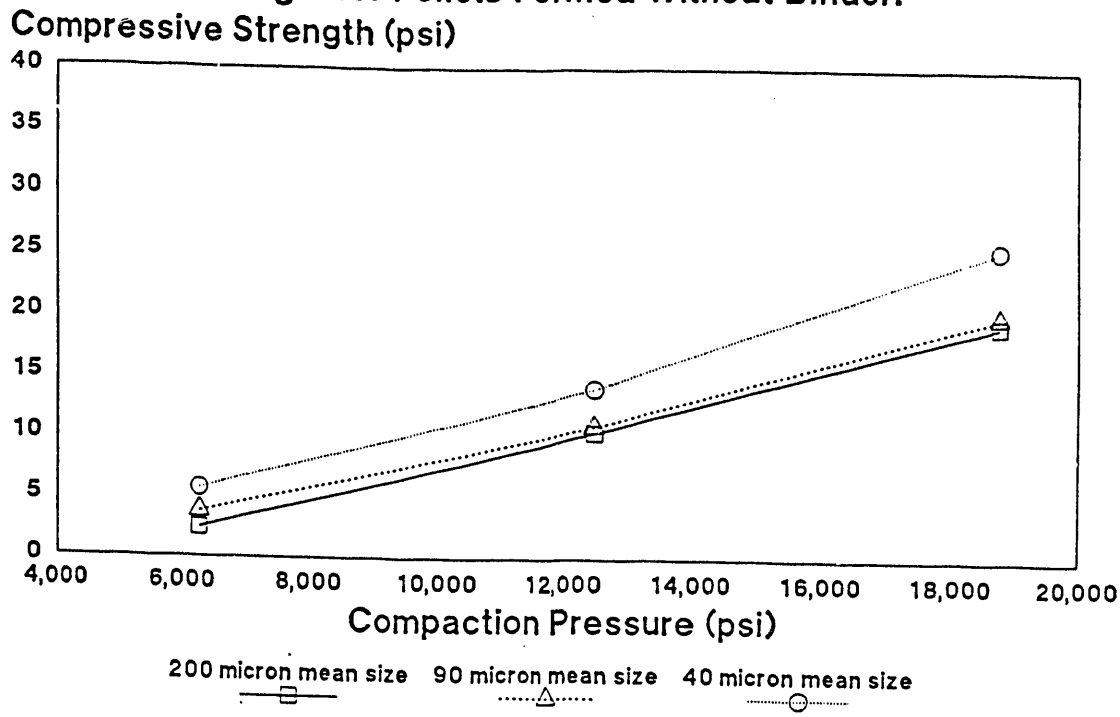


Figure 4-Effect of Calcium Hydroxide on Pellet Strength at Three Particle Size Distributions

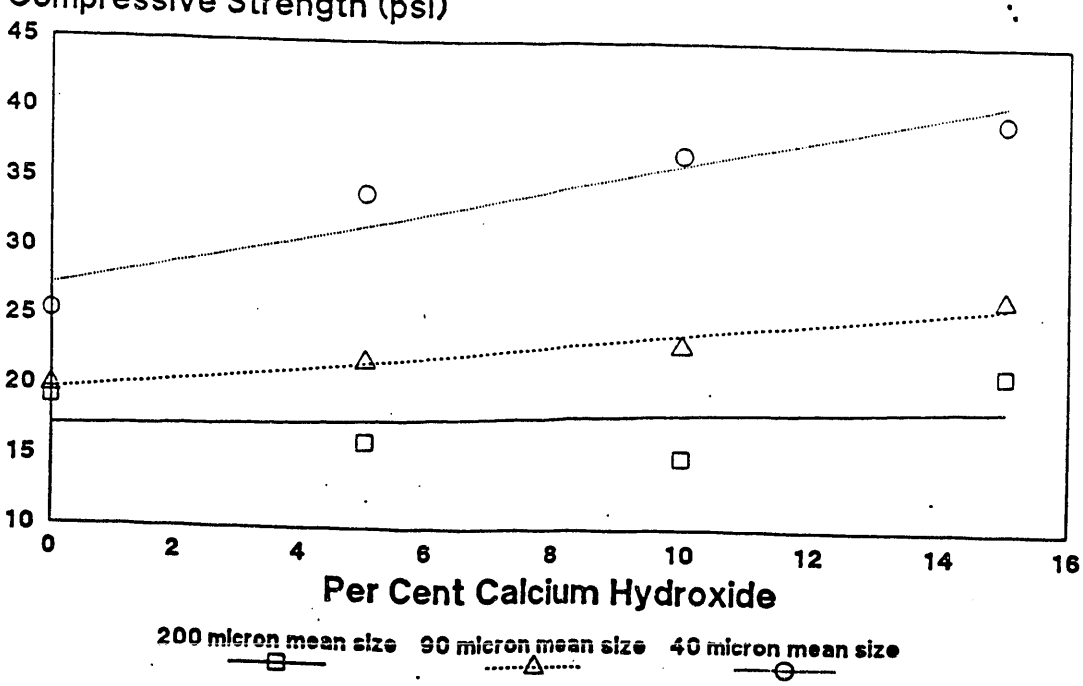


Figure 5-Effect of Calcium Hydroxide on Pellet Strength at Three Compaction Pressures

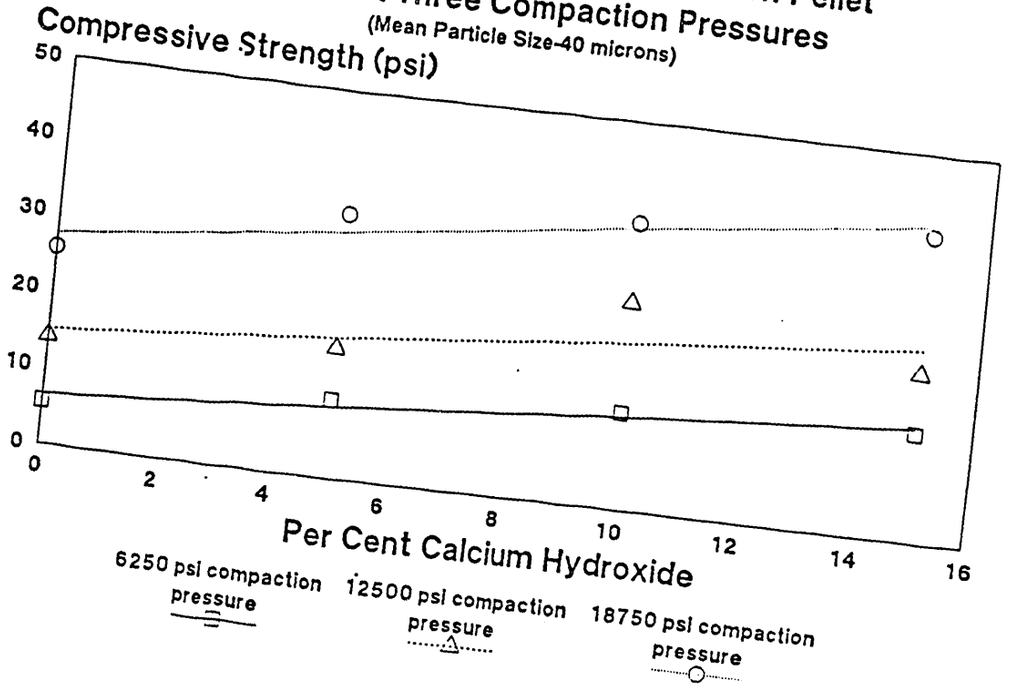
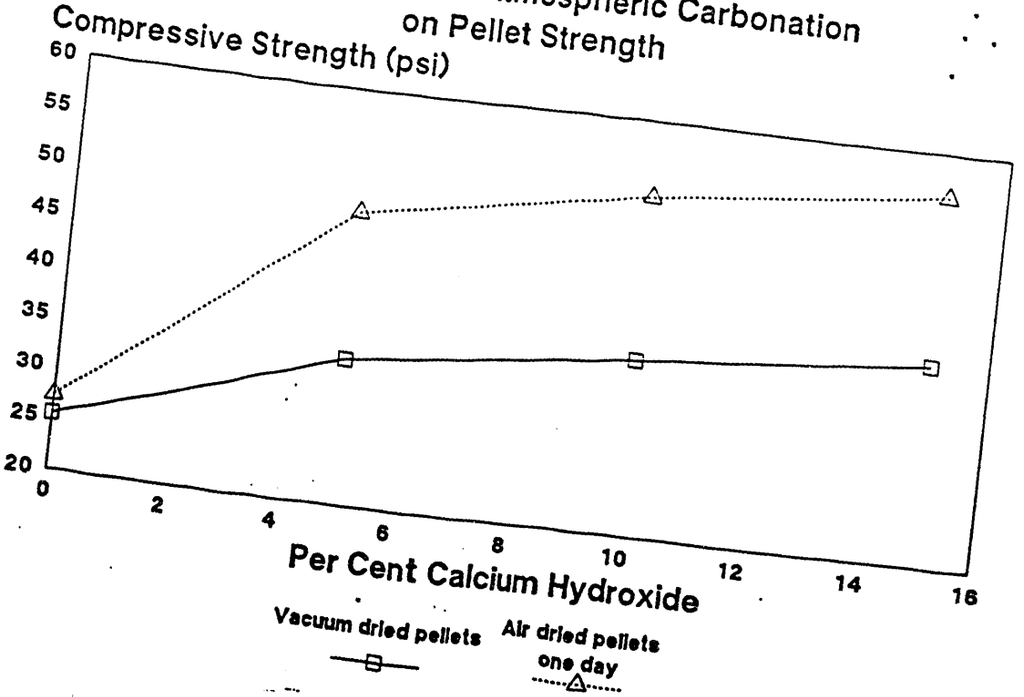


Figure 6-Effect of Atmospheric Carbonation on Pellet Strength



PROJECT MANAGEMENT REPORT
March 1, 1993 through May 31, 1993

Project Title: **CARBONATION AS A BINDING MECHANISM FOR COAL/CALCIUM HYDROXIDE PELLETS**

Principal Investigator: David Rapp, ISGS

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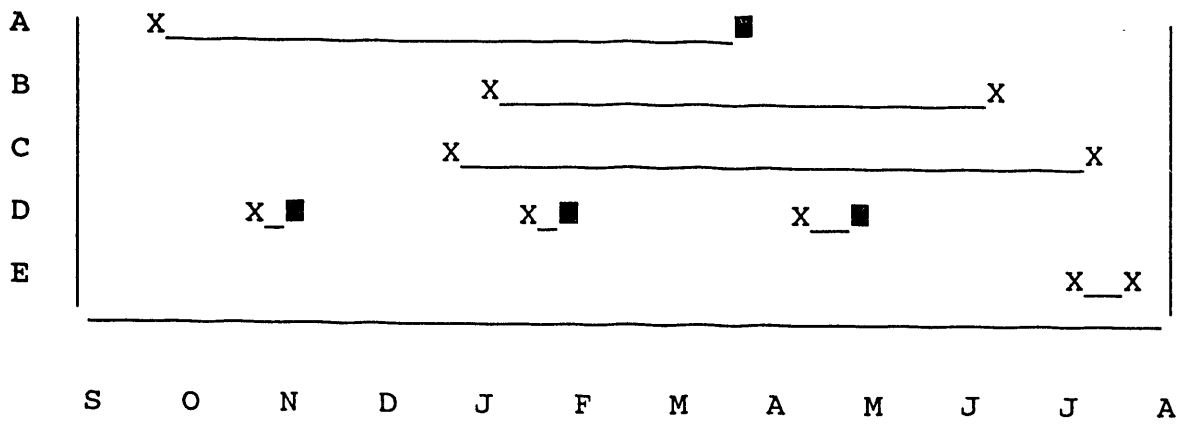
COMMENTS

SCHEDULE OF PROJECT MILESTONES



Milestone

A. Particle Size, Moisture, Binder Study
B. Extrusion
C. Drying/Carbonating Study
D. Quarterly Reports
E. Final Report

END

DATE
FILMED
10/5/93