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Testing Materials for Support-Wall Construction

By Kenneth E. Hay and Joanne L. Johnston

UNITED STATES DEPARTMENT OF THE INTERIOR

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

°C	degree Celsius	min	minute
°F	degree Fahrenheit	mm	millimeter
fl oz	fluid ounce	pct	percent
ft	foot	psi	pound per square inch
ft^3	cubic foot	psig	pound per square inch, gauge
in	inch	sp gr	specific gravity
lb	pound	yd^3	cubic yard

TESTING MATERIALS FOR SUPPORT-WALL CONSTRUCTION

By Kenneth E. Hay[1] and Joanne L. Johnston[2]

ABSTRACT

The Bureau of Mines collected coal and coal waste aggregate material from two different mine sites to determine their strength characteristics for use in concrete. The concrete would be placed underground as support walls for ground control in adverse conditions or unique mining applications. A standard mix design was established for a "wet" mix using a water-to-cement (w/c) ratio of 1.0 to facilitate pumping into place. Later, material was collected from four more mine sites and used to make 2- by 2- by 2-ft test blocks with the same w/c ratio. A pullout cone device and borehole shear tester were used to determine the in situ material strength of the test blocks. These techniques will provide a simple and quick way of determining support wall strength in an underground environment. Test results from the pullout cone device showed a good correlation of 0.98 to test cylinder compressive strengths of the same mix. Results of the borehole shear tester were inconclusive.

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INTRODUCTION

Mining of coal seams that are deeper and more irregular than those currently being mined, accompanied by adverse conditions for mining these seams, will require changes in support systems to increase production and miner safety. A variety of advancing or retreating longwall mining methods have been used and/or are being considered for mining under these difficult conditions. Typical roof bolting and the use of wood cribs or posts will not provide either adequate roof support for maintaining longwall panel entries or adequate barriers for the control of ventilation and methane accumulation.

Support walls constructed of cement and a coal-coal waste mixture can provide the support properties needed, as well as meet health and safety requirements. Currently, support walls are used in Europe with several variations of equipment, materials, and construction methods (1-3).[3] According to a Bureau-supported study (4) on support walls in Europe, such methods would not be economical for U.S. mines today. However, as energy resources diminish, the support wall technique will undoubtedly increase in importance, since it is the only known means that will permit mining of otherwise inaccessible coal seams. Reserves from deep seams, with their resulting high pressures, steep pitch, and other unfavorable geologic conditions, become viable candidates for this technique. When mining such coal becomes a national necessity, then monolithic support wall techniques will prove economically sound.

Typically, support walls use coal and/or coal waste from the mine as the only aggregate. The aggregate is prepared at the mine surface, then transported to a stationary hydraulic pumping station where the aggregate and water are mixed and pumped to the face. At this point, the cement and additives (if desired) are introduced, and the mixture is placed in the forms.

In order to develop an optimum mix design for support-wall construction and establish in situ testing criteria, various concrete mix designs were evaluated, using coal, coal waste, and various combinations for the aggregate. Extensive testing was conducted at the Bureau's Spokane Research Center (SRC) and the Bureau's former Boulder City Engineering Laboratory (BCEL) in Nevada. The work at SRC consisted of preparing and testing standard concrete cylinders and using the pullout cone and borehole shear test methods on in situ laboratory blocks. Various cements and additives were tested at BCEL to establish the optimum high-early-strength mix design required for underground support. Data derived on the physical and mechanical properties of these support walls will provide guidance to industry, the Mine Health and Safety Administration (MSHA), and other regulatory agencies.

MIX DESIGN AND TESTING

A standard support-wall mix design had to be established before testing could begin. The limiting requirements involved using coal or coal refuse as the bulk aggregate and using a high w/c ratio, which would allow pumping the mix into place up to 6,000 ft away.

Aggregate was obtained from different mining operations--two sources in West Virginia (Fairmont and Beckley) and two in Utah (Salina and Sunnyside). The aggregate consisted of coal waste out of the washing plant or from waste piles and coal as mined or from the cleaning plant. A gradation analysis was conducted on each batch of aggregate (fig. 1). The mix did not include any aggregate that passed the 200-mesh sieve, in order to limit water and cement requirements. Specific gravity, absorption, and moisture content were also determined (table 1).

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[3] Underlined numbers in parentheses refer to items in the list of references at the end of this report.

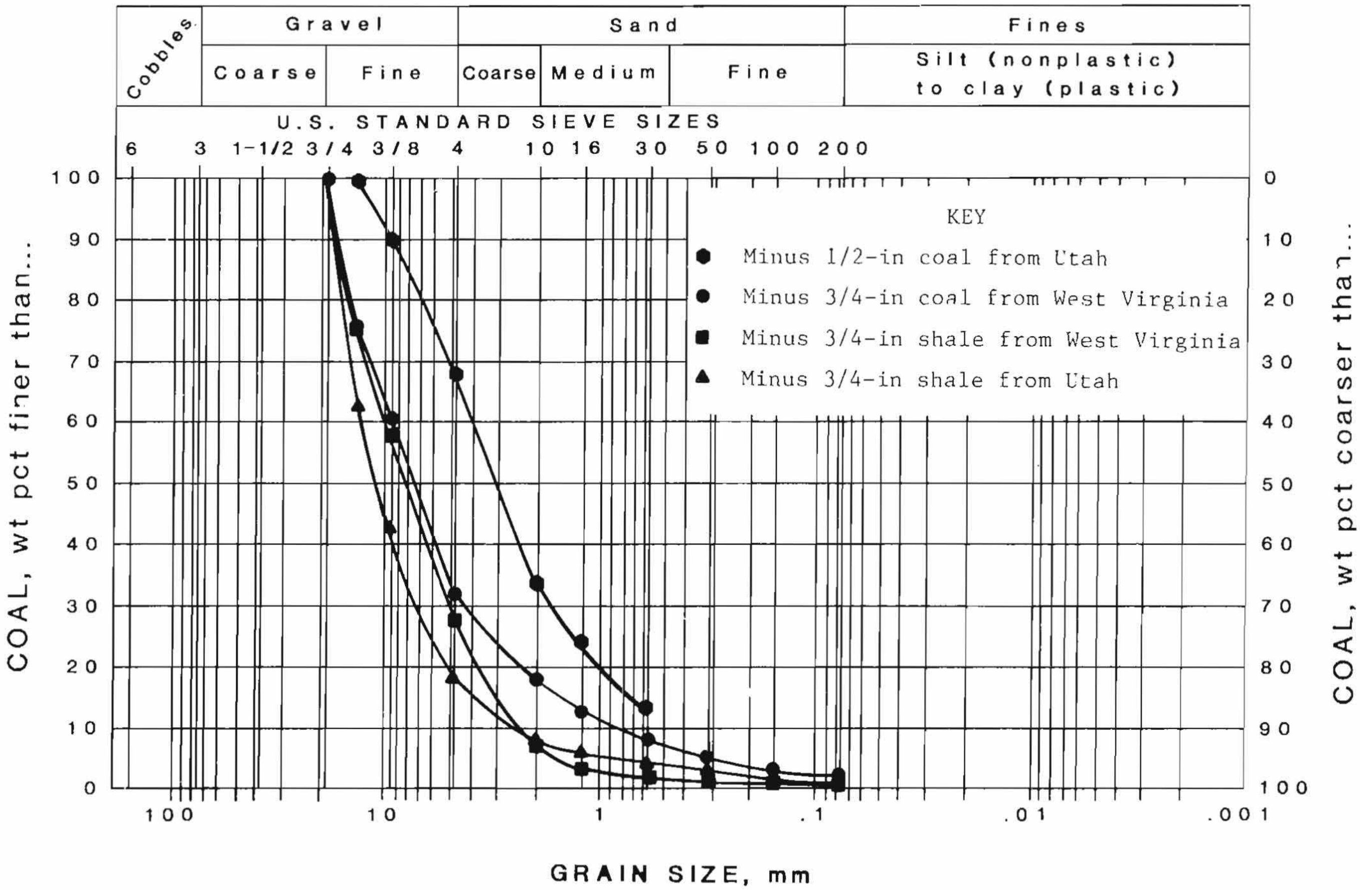

FIGURE 1.—Gradation analysis of aggregate materials.

TABLE 1. - Physical properties of aggregates used in the admixture and in situ study

Aggregate type	Specific gravity	Absorption, pct	Moisture, pct
Coal: Salina, UT	1.520	9.88	8.69
Coal waste:			
Beckley, WV....	2.256	2.98	1.40
Fairmont, WV...	2.289	2.45	1.30
Sunnyside, UT..	1.638	11.60	4.58

TABLE 2. - Typical mix design[1]

	Weight, lb/yd^3	Volume, ft^3/yd	Batch weight, lb
Water.........	587	9.41	21.74
Cement........	470	2.41	17.41
Aggregate.....	1,478	15.18	54.74
Total......	2,535	27.00	93.89

[1]Cement: Type III portland, 4 bags; w/c ratio = 1.25. Aggregate: Clean coal waste, 1/2-in; sp gr = 1.56.

A test batch consisted of 1 ft^3 of material, which was used to make twenty 3- by 6-in cylinders and four 4- by 8-in cylinders. A typical mix design is shown in table 2. A Cumflow[4] mixer with a 2-ft^3 bucket was used. The cylinders were filled on a vibrating table until problems were encountered with the aggregate settling and the method was abandoned. Subsequently, the tamping method described in ASTM C-192-76, "Making and Curing Concrete Test Specimens in the Laboratory," was used.

The cylinders were cured in a fog room at 100-pct humidity and 70° F during the entire curing time prior to testing.

[4]Reference to specific equipment, trade names, or manufacturers does not imply endorsement by the Bureau of Mines.

Upon removal, they were capped and prepared for compression testing on the Tinius Olsen universal testing machine. The compressive strength of three cylinders was determined after 3, 7, 28, and 90 days of curing. The tests were conducted as prescribed in ASTM C-39, "Compressive Strength of Cylindrical Concrete Specimens." The results of varying w/c ratios are shown in figure 2*A*. Each point represents the average of three test cylinders of Sunnyside material.

Without admixtures, strengths of 200 to 1,200 psi were obtained by using

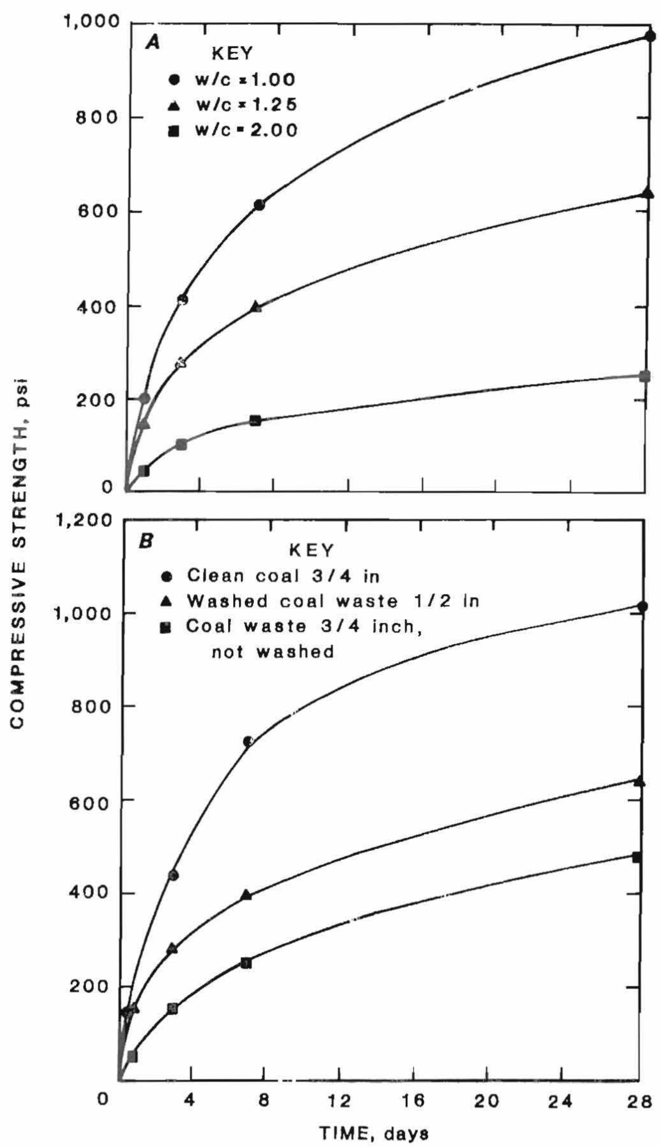

FIGURE 2.—Compressive strengths (*A*) with varying w/c ratios and (*B*) with varying aggregate characteristics.

4-bag/yd^3 mix and w/c ratios from 1.0 to 2.0. Naturally, a higher w/c ratio gives a lower compressive strength. Addition of fly ash to some mixes resulted in changes in compressive strength. The higher strength mixes (>500 psi) increased up to 20 pct in strength with fly ash, and the lower strength mixes (<200 psi) decreased a maximum of 15 pct in strength with fly ash.

Several of the cylinders were tested until initial failure was observed and then removed for retesting at a later date. Between the time they were first tested and tested again, they were left to cure at an uncontrolled room temperature and humidity. These cylinders continued to strengthen and reached strengths higher than their original failure value.

Aggregate can vary greatly in strength, size, specific gravity, and absorption capacity. The grading and maximum size of the aggregate in the concrete have a definite effect on the strength. As the size of aggregate particles become smaller, the total surface area of the aggregate increases; therefore, as the surface area of the aggregate increases, the amount of cement and water required to coat the aggregate increases. It was found that mixes using unwashed coal waste produced the lowest strengths. This is due primarily to the presence of clay and fines. The highest strength mixes were those using cleaned coal. Waste material from the cleaning plant was better than uncleaned waste, but some clay material was still present, which caused lower strengths than for cleaned coal. Effects of various aggregates with similar w/c ratios are shown in figure 2*B*. All data points represent the average of three test results using Sunnyside material.

The following summarizes the preliminary mix design work:

1. Concrete strengths between 200 and 1,200 psi can be obtained using coal and/or waste with w/c ratios from 1.0 to 2.0. Greater strengths can be obtained by reducing the w/c ratio.

2. The use of fly ash in the mix will affect the strengths. Strength increased

in higher strength (>500 psi) concrete but decreased in lower strength (<200 psi) concrete when fly ash was added.

3. After the 28-day tests, the concrete continued to gain strength when left outside the controlled environment.

4. Aggregate conditions have a definite effect on the concrete strength. Size and cleanliness are the most important factors. The fewer fines contained in the mix and the cleaner the aggregate, the higher the strengths.

ADMIXTURE STUDY

As part of the support-wall study, BCEL personnel conducted tests with several admixtures and studied the creep properties of support-wall material. The admixtures considered were accelerators with high-early-strength characteristics and superplasticizers that make it possible to maintain a soupy mix with less water. A Bureau report describing their work with admixtures (5) was prepared by BCEL.

The results of the BCEL study can be summarized as follows:

1. Strengths of coal and coal waste aggregate-formulated concrete increased with higher portland cement contents or lower w/c ratios.

2. Concrete with coal waste aggregate containing 10- to 20-pct total coal content gave higher strength than concrete formulated with all-coal aggregate.

3. Twenty-eight-day coal aggregate concrete increased 20 pct in compressive strength when high-early-strength accelerator was added.

4. Twenty-eight-day coal waste aggregate concrete increased 30 pct in compressive strength when high early-strength accelerator was added.

IN SITU STRENGTH TESTING

Stability and safety of support walls cannot be assumed, but rather require some means of testing or verification. The following section describes tests performed at SRC with two types of devices that may be used to determine the in situ strength of a support wall. The devices used were the pullout cone device and the borehole shear tester. The results of these tests, when compared with results of compression test cylinders of the same material, will indicate if these devices may be used to accurately measure in situ strength of support walls.

A gradation analysis of the aggregate used for the tests is given in figure 3. The portland cement used was type 1. A w/c ratio of 1 with a 4-bag/yd^3 mix was used to represent a "wet" mix. This would be a typical w/c ratio required for pumping. In order to test the two devices, concrete test blocks were cast with support-wall material. The mix material was cast in 2- by 2- by 2-ft forms. Sixteen 3- by 6-in and four 4- by 8-in test cylinders from each of the mixes were also cast to compare the strengths tested by the two devices with the cylinder compression tests at 3, 7, 28, and 90 days. The support-wall mix for this testing included aggregate, portland cement, and water only.

TESTING WITH PULLOUT CONE DEVICE

The pullout cone concept was obtained from a study done by Malhorta and Carette (6). Their study compared pullout strength in concrete with compressive strength of test cylinders and cores, pulse velocity, and rebound number. The relatively new pullout technique measures with a tension ram the force required to pull out a specially shaped steel rod whose enlarged end (fig. 4) has been cast into the concrete. This concept was chosen for determining in situ strength of support-wall material.

Analysis of the test data acquired by Malhorta and Carette shows that a significant correlation of 0.91, at 28 days, exists between the compressive strength of cylinders cured under standard conditions and the pullout strength of concrete. The intent is to achieve the same success with pullout cones on

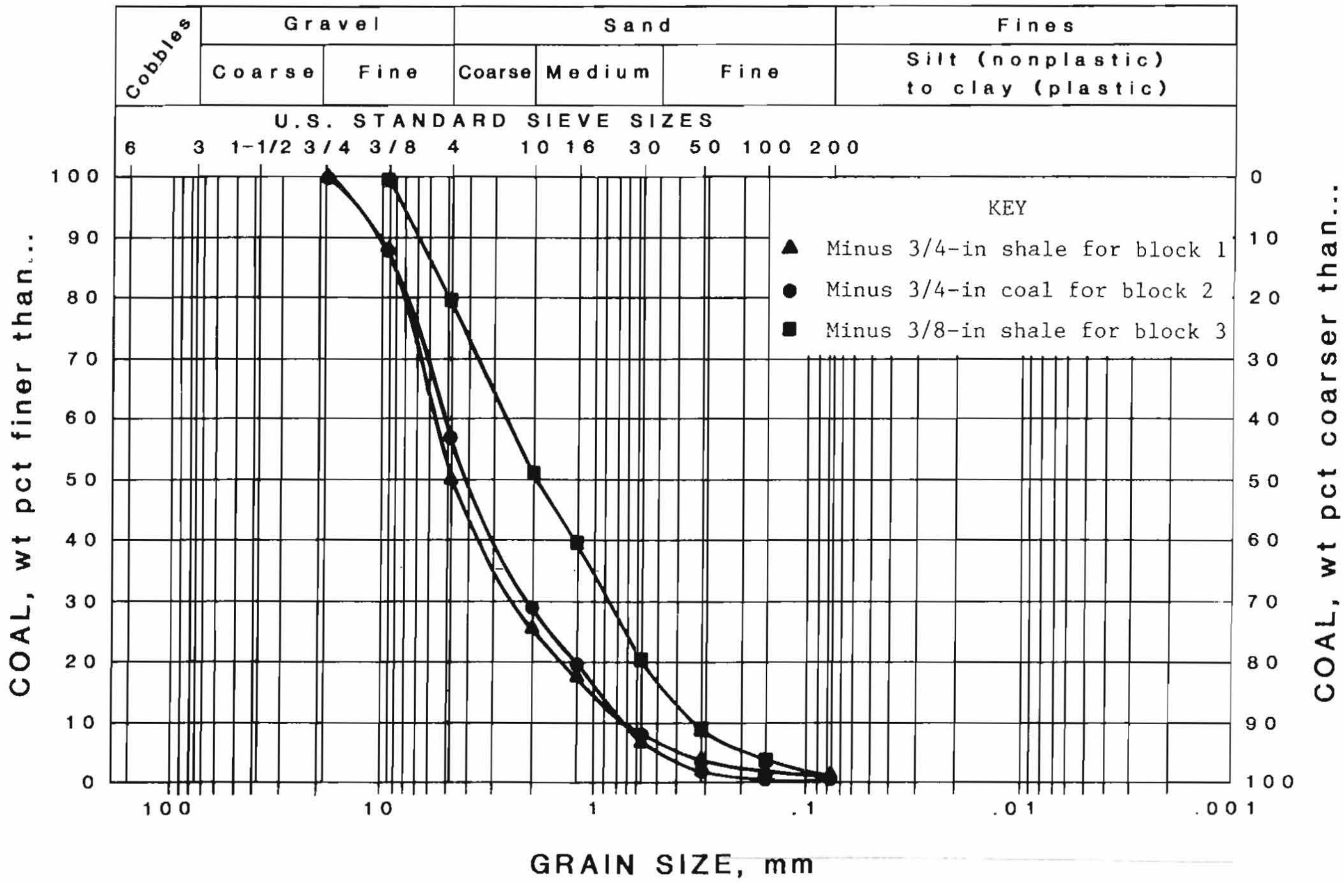

FIGURE 3.—Gradation analysis of test block aggregates.

support-wall material so that a quick, easy, and reliable method of determining in situ strengths of support walls can be made.

The pullout test has been suggested as an alternative to drilling cores from concrete and testing them in compression. A disadvantage is that the pullout tests have to be planned in advance of placing, whereas the cores can be drilled at any time after the concrete has sufficiently hardened.

The pullout test, however, cost considerably less than drilling cores, primarily because of the equipment needed and time required to drill, transport, prepare, and test the cores. Another advantage is that the pullout strength results are available within minutes of the testing.

The individual test blocks contained 20 cones cast into the four sides (five per side) and were spaced like five dots on a die. For identification purposes they were labeled, as stated below, for each side:

UL-Upper left,

UR-Upper right,

M-middle,

LL-Lower left,

LR-Lower right.

Both the blocks and the test cylinders were placed in the fog room at 100-pct humidity, 70° F for curing. On 3, 7, 28, and 90 days, five cones were pulled from each block, and four 3- by 6-in test cylinders were tested for strength in compression. The conversion formula (equation shown in figure 5) was used to compute the surface area of the cone pulled out of the block. The hydraulic jack apparatus was also calibrated to standardize the gauge reading to actual

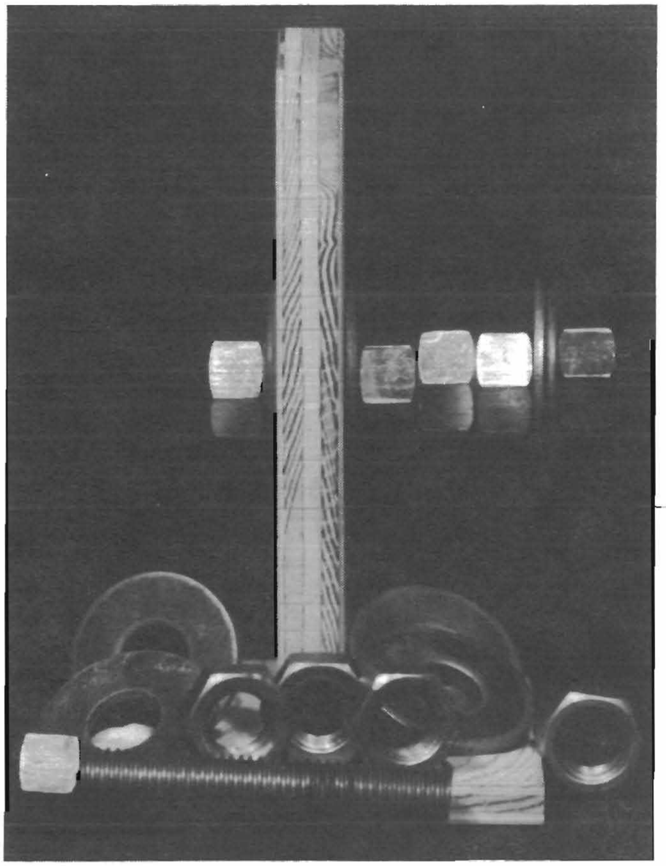

FIGURE 4.—Pullout components and assembly.

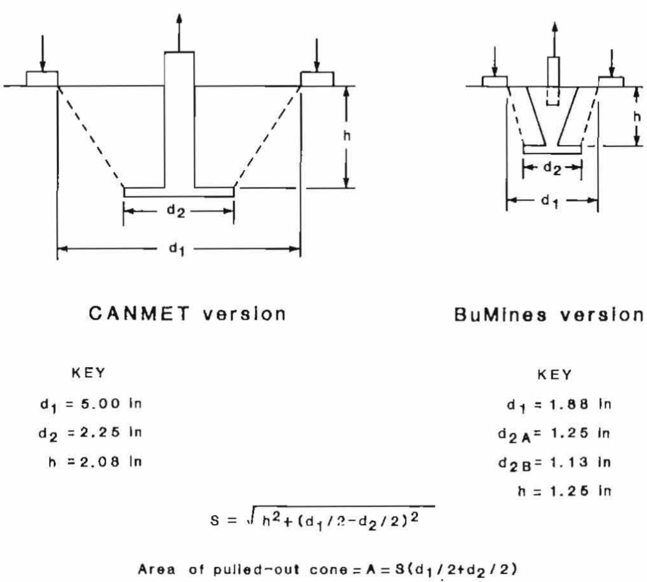

FIGURE 5.—Calculated area of pulled-out cones.

TABLE 3. - Summary of results from pullout tests

At hole position	Pullout strength, psi		
	Block 1	Block 2	Block 3
3 days:			
Upper right (UR)	97	125	129
Lower right (LR)	101	138	120
Middle (M)......	87	146	124
Upper left (UL).	75	121	145
Lower left (LL).	110	146	135
Average strength:			
Total......	94	135	131
Upper......	86	123	137
Lower......	106	142	128
7 days:			
Upper right (UR)	108	159	145
Lower right (LR)	150	159	103
Middle (M)......	125	159	124
Upper left (UL).	129	144	181
Lower left (LL).	146	182	128
Average strength:			
Total......	132	161	136
Upper......	119	152	163
Lower......	148	171	116
28 days:			
Upper right (UR)	210	224	223
Lower right (LR)	184	183	219
Middle (M)......	227	170	243
Upper left (UL).	286	186	232
Lower left (LL).	242	145	215
Average strength:			
Total......	230	182	226
Upper......	248	205	228
Lower......	213	164	217
90 days:			
Upper right (UR)	278	219	236
Lower right (LR)	327	241	214
Middle (M)......	289	249	205
Upper left (UL).	281	205	219
Lower left (LL).	342	201	219
Average strength:			
Total......	303	223	219
Upper......	280	212	228
Lower......	335	221	217

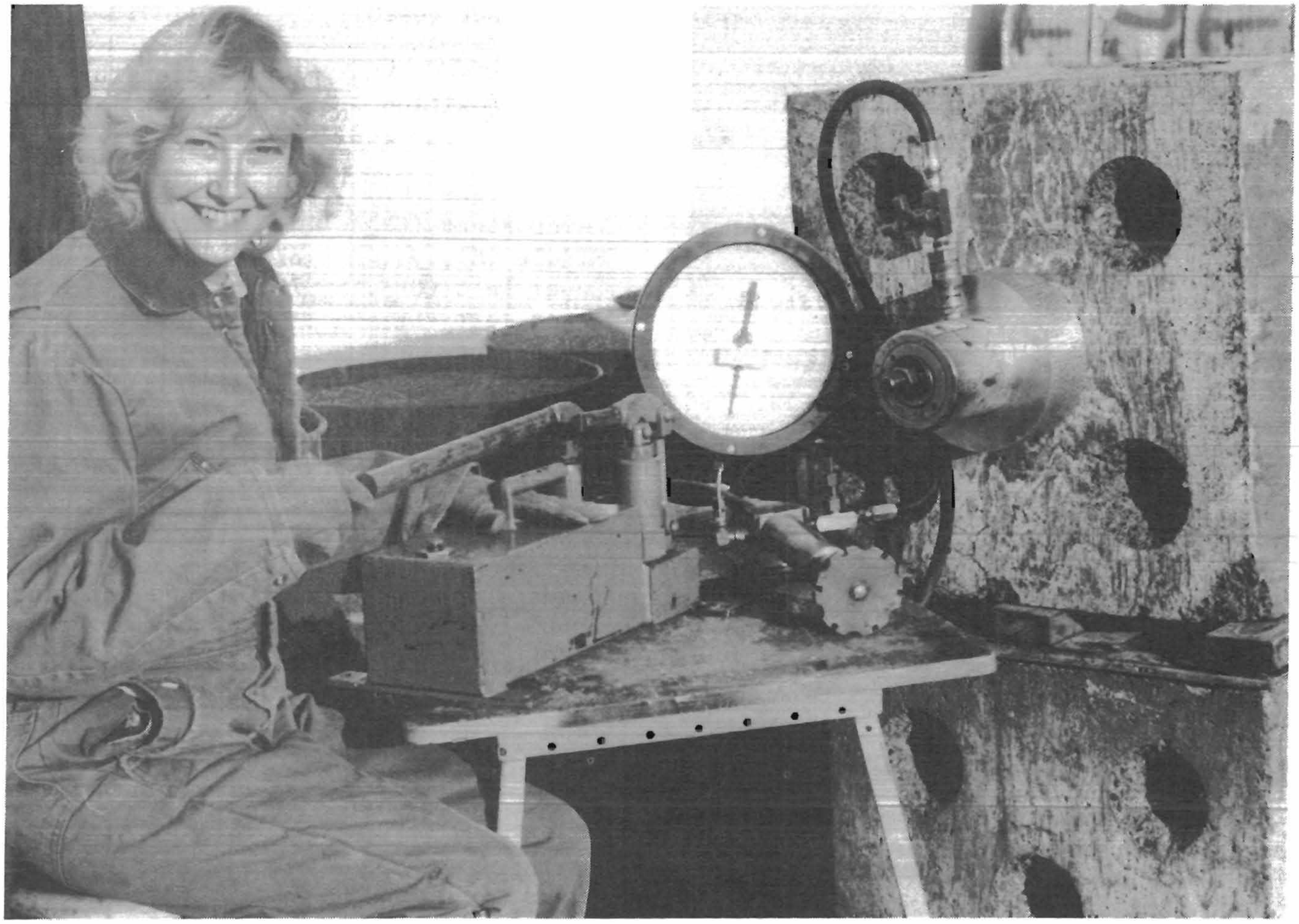

FIGURE 6.—Pullout cones apparatus in place for testing.

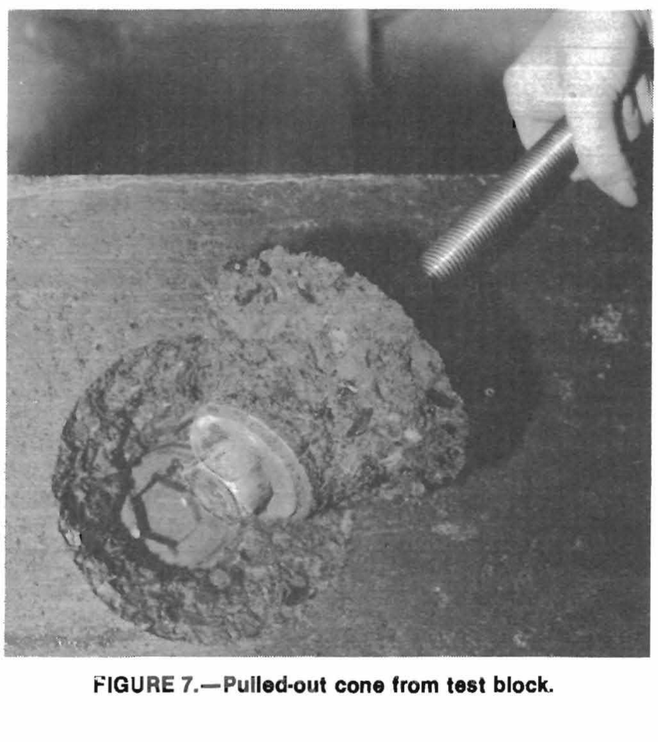

FIGURE 7.—Pulled-out cone from test block.

pounds of force. Thus, by standardizing the actual gauge reading and dividing it by the computed surface area of the pulled-out core, a strength value for the pullout cones was acquired for comparison with the average strength value of the compression tests. Figure 6 shows the pullout cone apparatus set up on a test block, and figure 7 shows a pulled-out cone. Results of the pullout tests conducted are listed in table 3.

PULLOUT TEST RESULTS

Preliminary testing was done using a scaled-down version of the pullout cone, as shown in figure 5. The results of this testing showed a poor correlation between the compressive strength and the pullout strength. This was thought to be due to either the low strengths of the mix or to the scaled-down size of the pullout cones. A decision was made to use the recommended-size pullout cone to eliminate this variable.

Table 4 shows the pullout cone and standard test cylinder strength results at 3, 7, 28, and 90 days' age. The results show that the ratio of the pullout strength to compressive strength (P/C) decreases with the increase in the strength of concrete. For example, for block 1, the P/C ratio varies from 0.2994 for 314-psi concrete to 0.2286 for 1,006-psi concrete (table 4).

With only one exception, the pullout strengths increased with the increasing age of concrete. For example, the average pullout strength for block 1 increased from 94 psi at 3 days to 230 psi at 28 days. As stated previously, the samples were in an uncontrolled environment after the 28-day tests.

The three-batch average coefficient of variation (C.V.) for the pullout tests at 28 days is 12.6 pct. The corresponding values for the compressive strength of the cylinders is 12.2 pct.

The data from table 4 are plotted in figure 8, which shows the relationship between the pullout and compressive strengths. The correlation coefficient is 0.98.

TABLE 4. - Summary of results (averages) from all pullout (P) and compression (C) tests

	Block 1	Block 2	Block 3
3-day:			
Pullout......psi..	94	135	131
Compression..psi..	314	469	489
Ratio (P/C).......	0.2994	0.2878	0.2679
7-day:			
Pullout......psi..	132	161	136
Compression..psi..	481	697	613
Ratio (P/C).......	0.2744	0.2310	0.2219
28-day:			
Pullout......psi..	230	182	226
Compression..psi..	1,006	991	1,009
Ratio (P/C).......	0.2286	0.1837	0.2240
90-day:			
Pullout......psi..	303	223	219
Compression..psi..	1,624	1,191	1,038
Ratio (P/C).......	0.1866	0.1872	0.2110

Before mine personnel use the pullout device, it will be necessary to calibrate the system and to determine the correlation between the pullout and compressive strengths. It is also important to take the average of several readings because of the difficulty in maintaining good quality in such large pours. Because of the behavior of a very wet mix, it may be necessary to use an admixture that prevents the material from segregating.

To conclude, the pullout cone device is a relatively quick and easy method of determining the in situ strength of support walls. Although a correlation to test cylinder strengths can be achieved, more work must be done to improve this method or device so that it will more accurately assist mine personnel and MSHA with a quick, easy method for determining in situ support-wall strength.

TESTING WITH BOREHOLE SHEAR TESTER

After all the cones were pulled from the four test blocks, three 76-mm-diam (NX-size) holes were cored through the top of each block. These holes were made in preparation for the use of the borehole shear test device (BSTD). The BSTD is a portable, self-contained permissible device used for determining in situ strength of mine rock. Because support-wall material is basically similar to mine rock, the BSTD may be a viable device for determining the in situ strength of support walls.

The BSTD was developed under a Bureau grant to Iowa State University. The apparatus consists of a hydraulic console, which connects to a probe with expandable shoes, and a hydraulic jack assembly. The data obtained from BSTD tests support well-known theories such as Mohr's theory of failure. This theory is based on a relationship between shearing stresses and normal stress at every point within the specimen body. Results of laboratory tests at Iowa State University on cores obtained from holes tested by the BSTD show excellent agreement with the data obtained from in situ tests (7-8). For these tests, the probe was inserted to the bottom of the block. The console was

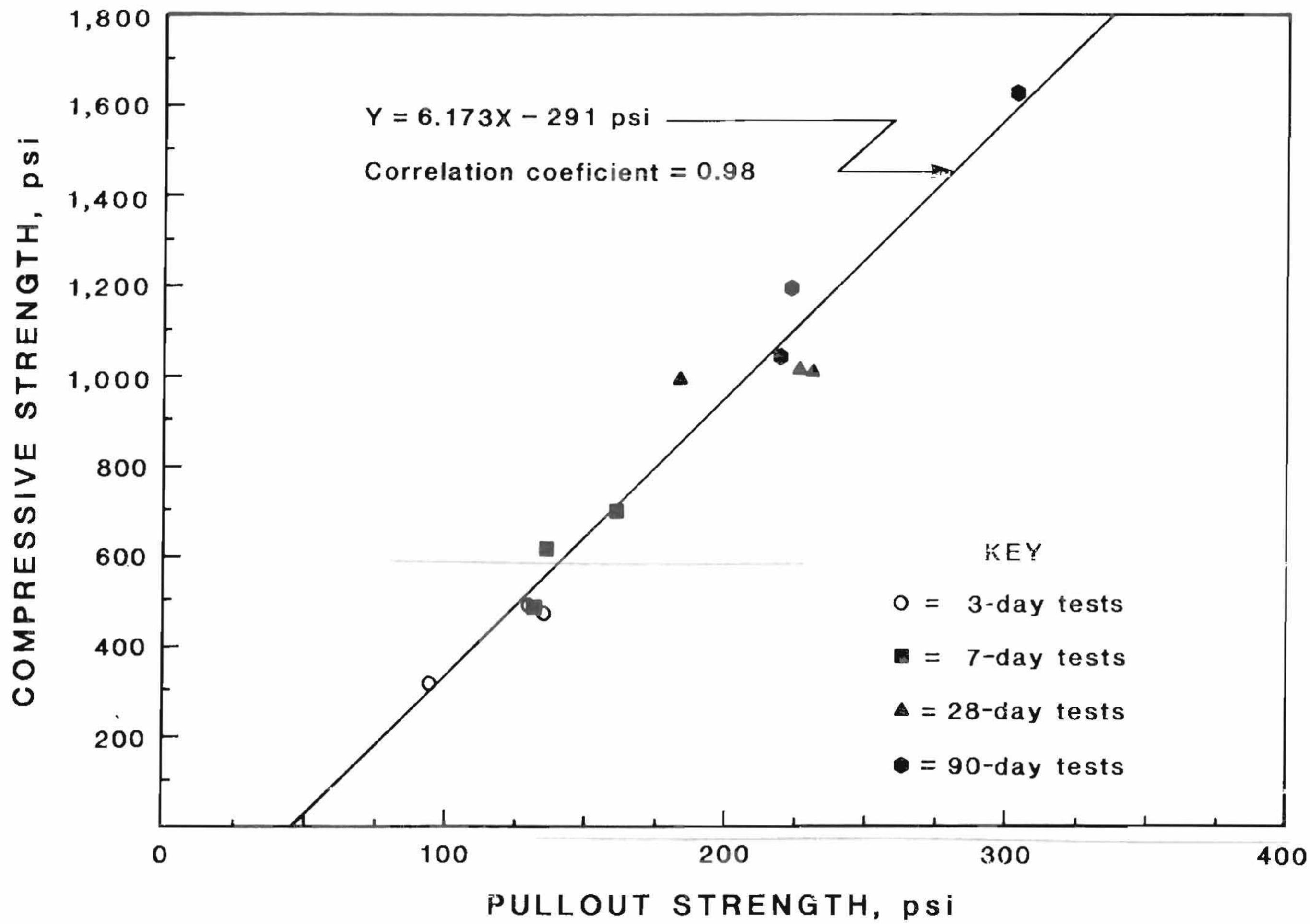

FIGURE 8.—Relationship between the pullout and compressive strengths.

operated as suggested by the Bureau's Denver Research Center (DRC) Procedures Manual (9).

The test involved placing the probe at a specified depth, performing the test, and then rotating it 90°. Once the two tests at this depth were complete, the probe was raised in 2-in increments, and the same procedure was followed until the probe reached a height of 6 in from the top of the block. At this point, another sequence of tests was started in another cored hole.

A series of tests was run using normal pressure, ranging between 400 and 1,800 psi, to determine the optimum pressure. Too low a pressure did not give a strong enough "bite," and too high a pressure caused unacceptable failure of material around the shoes, which possibly produced poor results.

BOREHOLE SHEAR TEST RESULTS

All blocks were tested using the BSTD. One block was discarded because it split when normal pressure was applied. The results obtained from the BSTD tests on the other blocks were then evaluated.

It was discovered after much of the testing was completed that the half-nut clamp had been slipping during some of the tests. The data were reevaluated, and all data that showed irregular displacement due to slippage were discarded. The computer regression analysis of the data gave a very low correlation coefficient (0.5). These data should have produced a Mohr envelope, as Ts = cohesion + σn tan ϕ (ϕ being the angle of internal friction). The data using a normal stress greater than 3,000 psi produced very poor shear stress results. This could have been due to the clamp slipping at the higher shear values. More likely in these cases, though, the normal stress caused prefailure of material around the shoes; thus, it gave poor results.

The preparation and use of the BSTD indicated it might be used to test strength of an in situ support wall. Although prior studies by the Iowa State University and DRC show excellent agreement between test cores and BSTD data obtained from in situ tests, SRC supportwall material tests were not as good. A large portion of the failure could have been due to inexperience in operating the BSTD. It is also possible that the inconsistent results were due to the low strength characteristics of the material.

CONCLUSIONS AND RECOMMENDATIONS

Preliminary testing identified typical mix proportions of aggregate, cement, and water needed to acquire a cured concrete compressive strength ranging from 200 to 1,200 psi, while also maintaining a high water content. In addition, the study showed that both the w/c ratio and aggregate characteristics (type, size, and cleanliness) affect the compressive strength of concrete. In this study, a 4-bag/yd^3 mix was used with aggregates obtained from different mines. Various w/c ratios ranging from 1.0 to 2.0 were used to maintain a "wet" mix.

In situ tests on support-wall concrete compared compressive strengths of test cylinders with data acquired with the pullout cones and the BSTD. The pullout cone data showed a direct correlation between the pullout strength and the compressive strength of concrete. Thus, the pullout technique is a viable alternative to drilling and testing in situ cores to determine in situ strength. This technique is simple, effective, and inexpensive.

The BSTD tests at SRC were erratic, even though prior tests by Iowa State University showed excellent agreement with concrete test cylinders. The poor results may be attributed to lack of experience with operating the BSTD or possibly to the low material strengths encountered. However, the results were encouraging enough to recommend additional testing of the BSTD technique as a means of determining in situ strengths.

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