TESTS OF FIBER-REINFORCED SHOTCRETE AT THE CHIEF JOSEPH MINE, BUTTE, MONTANA

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Abstract

Researchers from the Spokane Research Laboratory, National Institute for Occupational Safety and Health, in cooperation with engineers from the Department of Mining and Geological Engineering, Montana Tech, Butte, MT, conducted tests to evaluate the tensile strength, fiber count, and adhesion of shotcrete applied to panels at the Chief Joseph Mine, a research and training facility operated by Montana Tech. The tests were conducted in the mine ramp 45 m (150 ft) inward from the access portal at a 15.25-m- (50-ft) long test area divided into five 3-m- (10-ft) long sections. The shotcrete was applied with an Aliva 240.5 machine fitted with a predampener. Different amounts of fiber were entrained for each panel. Background data for the tests were obtained from earlier tests in Nevada, where the typical amount of fiber in the shotcrete is 6.54 kg/m^3 (11 lb/yd^3). All shotcrete was applied to a minimum thickness of 76 mm (3 in). Cylindrical cores were drilled at the wall-rock interface, and adhesion was tested after 28 days of curing. The goal of this research is to reduce the need to install multiple supports at the advancing face by creating a safer mining system that limits the time miners are exposed to unprotected roof.

Introduction

Researchers from the Spokane Research Laboratory, National Institute for Occupational Safety and Health (NIOSH), in cooperation with engineers from the Department of Mining and Geological Engineering, Montana Tech of the University of Montana, Butte, MT, conducted tests to evaluate the tensile strength, fiber count, and adhesion of shotcrete applied to panels at the Chief Joseph Mine, Butte, MT, a research and training facility operated by Montana Tech. The goal of the research study was to determine the effectiveness of the primary support, which consists of synthetic-fiber-reinforced shotcrete. Previous studies conducted at an underground mine in Nevada showed that fiber-reinforced shotcrete could be used instead of unreinforced shotcrete and wire mesh mats as ground support in rocks with a low rock mass rating (RMR) (1). By conducting round-panel tests to determine compressive strength, adhesion, and modulus, engineering data were collected that will allow rock mechanics engineers to improve mine design.

Prior to the tests, the mine site was thoroughly mapped to establish the orientation and number of joints, fractures, and faults; RMR; and rock quality (Q) values to establish the best conditions for applying the shotcrete. Samples were collected and tested to determine the unconfined compressive strength of the rock, which was found to range from 12 to 234 MPa (1740 to 34,000 psi) (2). Representative cell mapping rather than scan line mapping was used to collect the data because this method generates a better data set, particularly at sites of limited size such as in this mine.

RMR values resulted in grouping the rock into five categories (very good, good, fair, poor, and very poor) on the basis of scores of 68, 62, 57, 80, and 82, respectively (2). Cell 3, which was rated as fair, would correlate with RMR's found in Nevada underground mines. This section also contained three dominate joint sets.

The tests were conducted in the mine ramp 45 m (150 ft) inward from the access portal at a 15.25-m- (50-ft) long test area divided into five 3-m- (10-ft) long sections. The shotcrete was applied wall to wall by a certified nozzle man at a thickness of 76 mm (3 in). In addition, fiber count and adhesion tests were conducted at each section and then correlated to the rock mass.

The shotcrete was mixed at a plant in Big Timber MT, using a mixture (SUPERSTICK[1]) developed by Thiessen Team USA for Nevada and Montana mines and applied with a dry system. The shotcrete mix consisted of portland cement, microsilica, coarse aggregate, fine aggregate, sand, water reducer, and bar-chip fiber (4).

Australian Round Panel Flexure Test

Shotcrete round panels were constructed according to American Society for Testing and Materials (ASTM) standard c1550 and were mounted on pallets for ease of handling. The shotcrete was applied to the panels following a sequence in which fiber densities were increased in 0.3-kg/m^3 (0.5-lb/ft^3) increments, beginning with 5.9 kg/m^3 (10 lb/ft^3) through 7.13 kg/m^3 (12 lb/ft^3). The panels were washed down and degreased before the shotcrete was applied; following application, the panels were covered with plastic and wet burlap for 3 days and then taken to cure in the mine haulageway for 28 days.

Fifteen panels (three for each quantity of fiber added) were tested with a portable round-panel test frame and a 10-ton ram fitted with an electronic pressure transducer and pressure gauge to duplicate readings (figure 1). Displacement data were gathered by a string potentiometer attached to the frame and ram pedestal. All data were stored on a Campbell Scientific 21 datalogger. Scan rates were taken at 1-sec intervals. Typically, each panel was loaded to failure (or just 75 mm [3 in] of deformation) in about 15 min. The graphs in figure 2 (next page) show each test sequence.

Analysis of the graphs shows a repeatable loading trend in the data that supports the use of this field test frame. This finding encourages researchers to think that similar tests could easily be conducted at other mine sites. An analysis of the data shows that the initial breaking strength of the samples tends to deteriorate as fiber count increases. This result was not unexpected because the fiber is designed to absorb energy after initial failure of the shotcrete. Also, as the amount of fiber dosage increases, the ultimate carrying capacity of the panel also increases. Graph *C* in figure 2 shows that there may be a point of diminishing return on adding more fiber. Published articles mention that dosage rates between 9 to 18 kg/m^3 (15 to 30 lb/yd^3) are used in mining applications (5). In these and other tests conducted in Nevada mines, a dosage of 6.5 kg/m^3 (11 lb/yd^3) of the bar-chip fiber appears to be optimal in maintaining residual strength of the round panels.

[1] Mention of specific products and manufacturers does not constitute endorsement by the National Institute for Occupational Safety and Health.

In figure 3, the initial dose of 6.5 kg/m^3 (11 lb/yd^3) provides a residual strength of 12 kN (2700 lb). The shotcrete panel shows higher load-carrying capacities, which indicates that cost savings could be achieved by using less fiber and still provide ultimate safety. The peak strength of the panels is lower with higher fiber counts than the strength of the panel with the lower fiber counts; however, a residual load over 76 mm (3 in) of deformation has greater energy absorption with increased fiber dosages up to the optimal amount of 6.5 kg/m^3 (11 lb/yd^3).

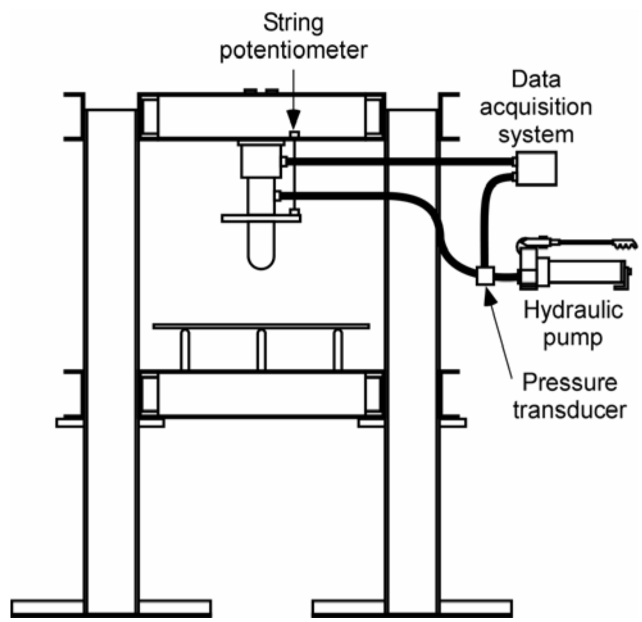

Figure 1.—Portable shotcrete round panel tester

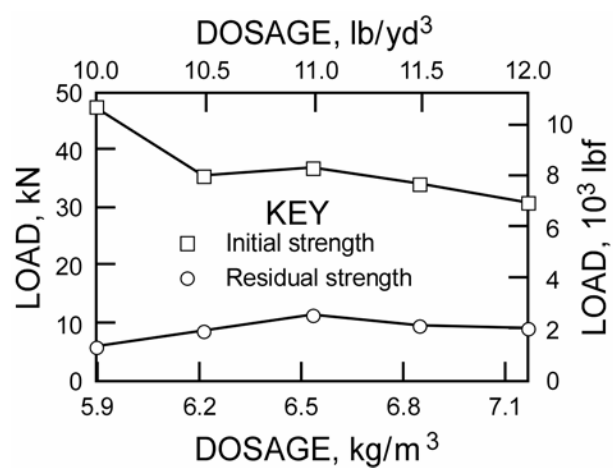

Figure 3.—Averaged peak load versus displacement for initial and residual strengths of round panel tests

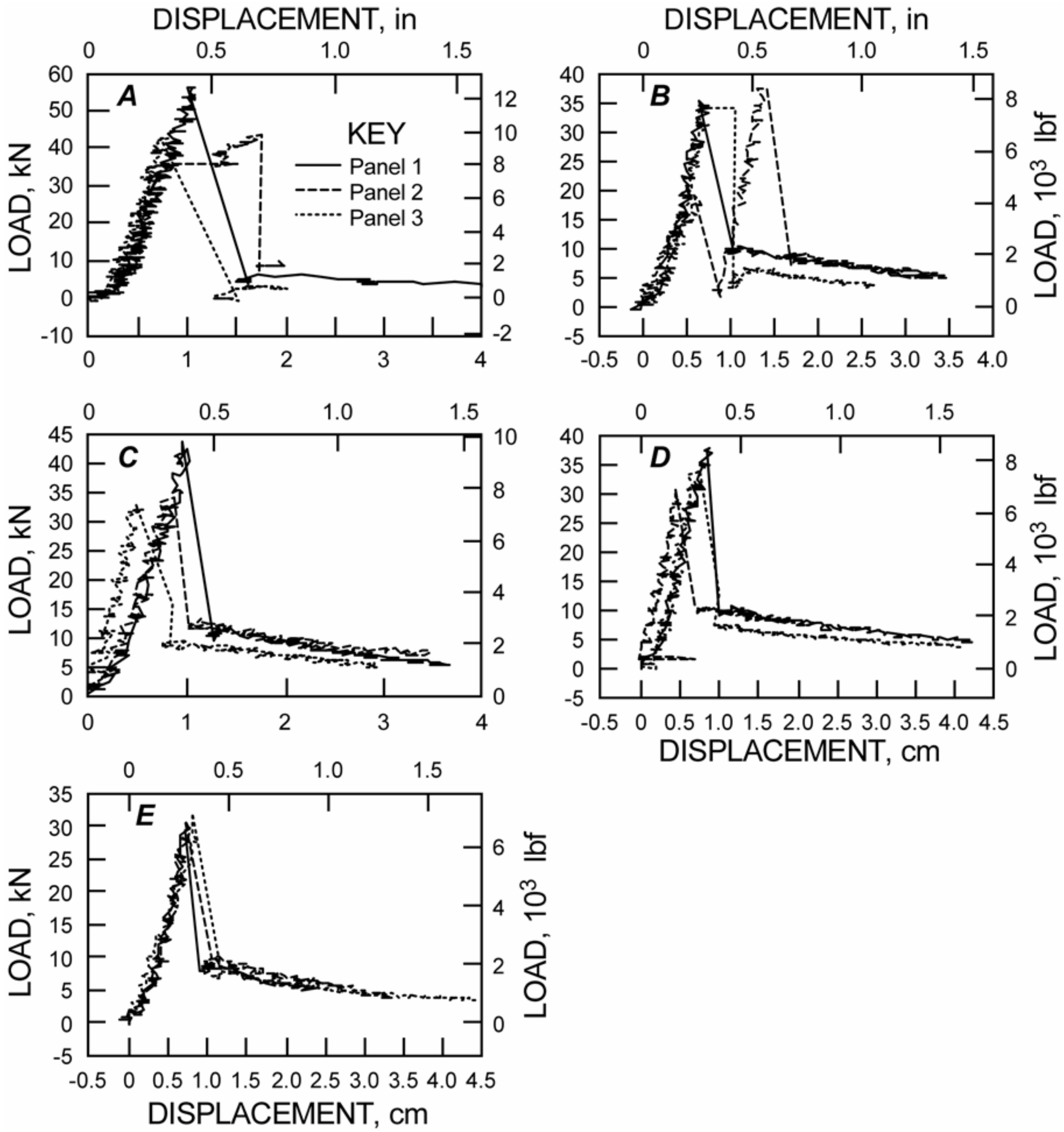

Figure 2.—Load versus displacement in round panel tests. *A*, Test 1 at fiber dosage of 5.9 kg/m^3 (10 lb/yd^3); *B,* test 2 at fiber dosage of 6.2 kg/m^3 (10.5 lb/yd^3); *C*, test 3 at fiber dosage of 6.5 kg/m^3 (11 lb/yd^3); *D*, test 4 at fiber dosage of 6.8 kg/m^3 (11.5 lb/yd^3); *E,* test 5 at fiber dosage of 7.1 kg/m^3 (12 lb/yd^3).

Table 1.—Fiber count information in five test cells

Cell A		Cell B		Cell C		Cell D		Cell E	
West	East	West	East	West	East	West	East	West	East
12	5	3	5	10	5	7	8	7	6
7	7	3	9	6	9	7	8	7	6
5	8	3	2	5	12	7	7	8	5
5	9	4	7	5	7	6	6	9	13
6	3	6	6	3	6	6	10	4	8
Average fibers									
7	6.4	3.8	5.8	5.8	7.8	6.6	7.8	7	7.6
Accumulative average									
6.7		4.8		6.8		7.2		7.3	

Table 2.—Fiber count information with outliers removed

Cell A		Cell B		Cell C		Cell D		Cell E	
West	East	West	East	West	East	West	East	West	East
7	8	4	5	6	9	7	8	7	6
6	7	3	6	5	7	7	8	7	6
5	5	3	7	5	6	6	7	8	8
Average number of fibers									
6	6.7	3.3	6	5.3	7.3	7.6	7.6	7.3	6.7
Accumulative average									
6.3		4.7		6.3	7.2			7	

Fiber Count Analysis for In-Place Shotcrete at Chief Joseph Mine

The analysis of fiber density was trying. An engineer working in the Nevada mines brought up the need to count fiber in place to determine if the mixing rate was what the design engineer specified. It would be desirable to have a nondestructive method to determine fiber count and thus establish a relationship to the overall physical properties. The method tried in this study was to mark an array of five 10.2-cm (4-in) squares on both sides of the entry in each section where the amount of fiber in the shotcrete changed. The squares were inspected visually, and the fibers within each marked square counted. They were then were logged for statistical analysis.

As can be seen in table 1, a visual relationship between the amount of fiber added to the mix and the number of fibers counted was not apparent. However, outlier numbers were seen in some sets. Another comparison was made by throwing out the high and low counts in each set (table 2). Again these data sets do not define a pattern that can be used to determine the amount of fiber visually.

Another count was done using a 25-cm (10-in) square in a five-set array (table 3). These data sets showed an increasing trend in fiber count with simple averaging.

Table 3—Fibers counted in five-set array in 25-cm (10-in) square

Cell A		Cell B		Cell C		Cell D		Cell E	
West	East	West	East	West	East	West	East	West	East
22	13	7	10	34	19	18	28	36	17
13	15	11	23	20	12	22	19	28	17
1	5	11	13	22	29	18	10	23	13
8	10	13	17	15	23	27	25	32	120
2	13	27	9	12	11	31	29	26	15
Average fibers									
13	11.2	13.8	14.4	20.6	18.8	22.2	22.2	29	16.4
Accumulative average									
12.1		14.1		19.7				22.7	

Further analysis was conducted in which the high and low fiber counts were thrown out (table 4).

Table 4—Fibers counted in five-set array in 25-cm (10-in) square with high and low values eliminated

	Cell A		Cell B		Cell C		Cell D		Cell E	
	West	East	West	East	West	East	West	East	West	East
	13	13	11	10	20	12	18	19	26	17
	8	10	11	13	22	19	22	25	32	17
	21	13	13	17	15	123	27	28	28	15
Average fibers										
	14	12	11.7	13.3	19	18	22.3	17.6	28.6	16.3
Accumulative average										
	13		12.		18.5		19.9		22.3	

Based on just the core number of fibers, the upper dosage was more defined, but the lower dosages started to map each other. A larger population should be analyzed so that the outliers would become less significant and fiber readings could give a rough example of the dosage used. Continued research in this area is needed.

Adhesion Pull Tests

A portable drill with a thin-walled coring bit was used to develop a simple, portable method to obtain information on in-mine shotcrete adhesion. Adhesion of the shotcrete to the mine roof and walls was determined by conducting pull tests with a disk-type puller glued to the shotcrete surface of the wall with epoxy. A diamond core drill was then used to overcore the shotcrete until a full kerf of mine wall had been drilled. The apparatus was applied, and tests commenced. The RMR for each section, along with location and sample condition, are shown in table 5.

Table 5—Panel information

	Panel location in mine				
	0-2.5 m	2.5-5 m	5-7.5 m	7.5-10 m	10-12.5 m
RMR	69	34	61	74	69
Status	Broke sample	NA	Broke sample	NA	Broke sample

NA = Not applicable.

Upon running the tests at the mine, it was determined that another drill support platform needed to be developed, as the current drill does not generate enough axial force to penetrate the mine rock without jeopardizing the integrity of the shotcrete sample.

With an RMR less than a critical value, which appears to be approximately 50 at the Chief Joseph Mine, the rock itself is deteriorating, not the bond of the shotcrete to the wall and roof. Further research is necessary to understand fully this apparent critical RMR value with respect to rock versus bond deterioration and its influence on support systems in underground mines.

Dynamic Modulus of Shotcrete

Tests were conducted on cores taken from the round panels using an apparatus called the Hopkinson bar. The Hopkinson bar is a device that shoots projectiles at a test specimen. Velocity and strain readings are taken from the reactive bar. From these data and the calculations, a dynamic modulus can be determined. For shotcrete in which the amount of fiber equaled 6.5 kg/m^3 (11 lb/yd^3), the dynamic modulus E was 41 GPa (6×10^6 psi).

Conclusions

The panel tests conducted at the Chief Joseph Mine showed consistent results for initial round panel failure and energy absorption. With this test program, the characteristics of the shotcete being used at a specific site could be determined for various curing times without transporting the specimens to an independent lab. The data suggest that the 6.5-kg/m^3 (11-lb/yd^3) dosage is optimal with respect to ultimate load capacity. Fewer fibers result in less reinforcement of the shotcrete, and a greater number of fibers interferes with the strength of the shotcrete.

Counting the fibers shows promise if a 25-cm (10-in) square is used and enough samples are taken. The 10 sample areas used in these tests showed delineation, but 15 would be more statistically significant. The man-hour requirement is small (less than a minute a square), so quality control could be obtained through an inexpensive test.

Adhesion pull testing is a slow and arduous process that is not to be taken lightly. Development or use of proper drill equipment is imperative to make sure that the drilling is done without creating vibrations as the drill bit passes through the interface.

References

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