U.S. Department of Labor

Mine Safety and Health Administration
Pittsburgh Safety & Health Technology Center
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Mine Waste and Geotechnical Engineering Division

April 13, 2007

MEMORANDUM FOR RICHARD A. GATES
District Manager, District 11
Coal Mine Safety and Health

THROUGH: M. TERRY HOCH
Chief, Pittsburgh Safety and Health Technology Center

STANLEY J. MICHALEK
Acting Chief, Mine Waste and Geotechnical Engineering Division

FROM: TERENCE M. TAYLOR
Senior Civil Engineer, Mine Waste and Geotechnical Engineering Division

SUBJECT: Sampling and Testing of Mortar Bed Cores Taken From Failed Ventilation Seals at Wolf Run Coal Company's Sago Mine, Mine ID No. 46-08791, Buckhannon, West Virginia

On January 2, 2006, a fatal explosion occurred at the Sago Mine, owned by the International Coal Group and operated by Wolf Run Coal Company. Ten 40-inch-thick Omega block ventilation seals failed as a result of the explosion. During the course of the initial investigation, the Sago Investigation Team raised concerns about the quality of the mortar beds located beneath the seals as the remnant mortar on the mine floor appeared to be discolored and friable. On March 26, 2006, I was contacted and asked to travel to the mine and determine how samples could be removed from the mine floor using coring or other methods to determine the depth of the remaining Blocbond and to establish the competency of this material. The setting bed beneath the seals had reportedly been constructed by placing a dry mixture of Blocbond powder on the moist to wet mine floor at each seal location. A 40-inch-thick Omega block seal was then constructed on top of the setting bed.

Following a site visit on March 29, 2006, this office arranged a contract with Professional Service Industries, Incorporated (PSI) to sample the remnant Blocbond setting beds and mine floor at each seal location so that further examination and testing could be conducted in a laboratory. On June 13 and 14, 2006, Paul Sanchez from PSI conducted the mine floor coring using a portable drill unit with a 3-inch-diameter drill bit. The following individuals observed the sampling:

Terence M. Taylor – MSHA, Technical Support
Russell Dresch – MSHA, Sago Investigation Team
Johnny Stemple – International Coal Group, Inc.
Chuck Dunbar – International Coal Group, Inc.
Brian Curtis – Miners' Representative, International Coal Group, Inc.
Ron Bowersox- United Mine Workers of America
John Cruse – West Virginia MHST

The cores were taken up to a depth of 6 inches using a dry drilling method. Wet drilling was not used as it was felt that the use of water could lead to further hydration of the cementitious materials in the Blocbond samples. The samples were placed in sealed plastic bags and wrapped in bubble wrap to prevent sample disturbance during transport. A log was kept to describe details of each of the sample locations. Also, a chain of custody was maintained for all the samples.

The samples were designated as follows: S1 refers to a sample taken from Seal 1, S2 refers to a sample taken from Seal 2, etc. The number following the dash refers to the number of the sample taken at a given seal location. The first three samples taken at each seal location were consistently 5, 10, and 15 feet, respectively, from the left rib (as designated looking inby). As the mine entries were between 18 and 21 feet wide, this represented taking samples at the middle and quarter points along the seals. The fourth, fifth, or any additional samples are followed by an "R" designation. This indicates that the sample location within the footprint of the seal was random, rather than one of the first three pre-selected locations at each seal. For example, S6-4R refers to the fourth sample taken from the mine floor at Seal 6 and that the sample was at a random location on the floor beneath the seal. Note that the contents at a few of the core locations were further designated as being either the top or bottom of the core. As the cores were generally friable and in multiple pieces, the upper portion of the core typically contained the Blocbond. All samples are listed in Table 1.

Table 1: Floor Core Samples from Sago Mine Ventilation Seals

Sample I.D.	Location	Evaluated by Consultant
SEAL 1		
S1-1	5′ from left rib	X
S1-2	10′ from left rib	
S1-3	15′ from left rib	
S1-4R	1′ from right rib	
S1-5R	1′ 4″ from left rib	
S1-6R	9′ 4″ from left rib	X
S1-7R	7′ from left rib	
S1-8R	4′ 8″ from left rib	
SEAL 2		
S2-1	5′ from left rib	X
S2-2	10′ from left rib	
S2-3	15′ from left rib	X
S2-4R	2′ 6″ from left rib	
SEAL 3		
S3-1	5′ from left rib	X
S3-2	10′ from left rib	
S3-3	15′ from left rib	X
S3-4R	1′ 6″ from left rib	
SEAL 4		
S4-1	5′ from left rib	
S4-2	10′ from left rib	
S4-3	15′ from left rib	
S4-4R	1′ 6″ from left rib	X
SEAL 5		
S5-1	5′ from left rib	X
S5-2	10′ from left rib	
S5-3	15′ from left rib	
S5-4R	1′ from left rib	
SEAL 6		
S6-1	5′ from left rib	X
S6-2	10′ from left rib	X
S6-3	15′ from left rib	
S6-4R	15′ from left rib (grab sample next to S6-3)	X
S6-5R	1′ 1″ from right rib	
SEAL 7		
S7-1	5′ from left rib	X
S7-2	10′ from left rib	
S7-3	15′ from left rib	
S7-4R	3′ 6″ from right rib	

S7-5R	10″ from left rib	
S7-6R	3′ 8″ from right rib	X
SEAL 8		
S8-1	5′ from left rib	
S8-2	10′ from left rib	
S8-3	15′ from left rib	X
S8-4R	16″ from right rib	X
SEAL 9		
S9-1	5′ from left rib	
S9-2	10′ from left rib	
S9-3	15′ from left rib	X
S9-4R	1′ 3″ from right rib	
SEAL 10		
S10-1	5′ from left rib	X
S10-2	10′ from left rib	
S10-3	15′ from left rib	
S10-4R	16″ from right rib	X

Petrographic Evaluation

A contract was entered into with Mark E. Patton, LTD, a materials consultant, to evaluate the quality and composition of the Blocbond setting bed samples. Mr. Patton was charged with conducting petrographic examinations, visual examinations, and compression strength testing of select samples from the ten seal locations. The samples given for evaluation were representative of the better quality samples collected and therefore represent an upper bound on the quality of the setting beds. The lower quality samples did not contain intact pieces large enough to conduct testing or examination. A bag of Blocbond was given to the consultant to prepare control samples that were used for comparison in both the examination and testing phases of the study.

A full copy of the petrographic study report has been forwarded to your office. Attached to this memorandum is a copy of the executive summary from that report. Based on the findings of the consultant's study, the Blocbond setting beds beneath the ten failed ventilation seals were not properly mixed, placed, and cured, which resulted in a generally weak, friable material.

If there are any questions, please contact this office.

Attachment

cc: M. Skiles - Director, TS
M. Kalich - Acting Chief, Safety Div., CMS&H

Mark E. Patton Ltd
Materials Consultant
105 Pfeffer Road, Suite 1
Phone: 724 325 1915 Export, PA 15632 Facsimile: 724 325 1917

EXECUTIVE SUMMARY

MSHA personnel from the Pittsburgh Technical Support, Mine Waste and Geotechnical Engineering Division, Pittsburgh, Pennsylvania submitted eighteen samples and requested an assessment of the composition, quality and strength of the mortar in the setting beds from ten ventilation seals at the Sago Mine. In addition to a laboratory prepared sample of mortar, laboratory studies were done on 17 core samples and one grab sample of setting bed mortar taken through mortar beds under ten ventilation seals from the Sago Mine. The laboratory studies include: (1) petrographic examinations of one laboratory prepared sample of mortar, the grab sample and two cores from the mortar beds at ventilation seals; (2) visual examinations of 15 core samples through the mortar beds, and (3) compressive strength testing of laboratory prepared mortar cubes and mortar cubes saw cut from the core samples from the ventilation seals.

The petrographic examinations were done using applicable methods outlined in ASTM C856, "Petrographic Examination of Hardened Concrete." Scanning electron microscopy (SEM) and energy dispersive x-ray analysis (EDS) were used in addition to the optical microscopes. Visual examinations of the samples were limited to viewing the samples with the unaided eye; no microscopy was performed on the samples visually examined.

Based on the petrographic examinations, Samples S2-3 Top, S4-4R, and S6-4R were all made using the BlocBond material and contain similar amounts of fly ash, portland cement and glass fibers as the Control Sample made with the BlocBond in the laboratory. Except for Sample S1-1, all of the samples visually examined appear similar to the samples made with BlocBond and contain glass fiber bundles. Sample S1-1 is not made from BlocBond, but is similar to a prepackaged concrete mix.

The petrographic examination of the Control Sample demonstrates that when mixed for the recommended two minutes, the BlocBond material produces a mortar that is consistent, well-hydrated, dense, medium gray and hard. The mixing of the BlocBond entrains some amount of air that occurs mainly as small, fine and microscopic spherical voids characteristic of entrained air and minor amounts of coarse spherical and non-spherical voids. All portland cement products will contain some small amount of air that will occur as spherical or rounded voids from the mixing operations. The other feature that results from adequate mixing is the distribution of the glass fiber bundles. The glass fiber bundles are not only distributed throughout the Control Samples, many of the bundles are broken up and there are numerous smaller bundles and individual fibers present throughout the samples.

The compressive strength tests of the Control Samples confirmed that adequately mixed and cured BlocBond will attain compressive strengths in excess of 8,000 psi at ages beyond 28-days. The features of the hardened BlocBond Control Samples and the compressive strength results were used to assess the adequacy of the mixing of the samples taken from the mine.

The petrographic examinations show that all three samples, S2-3 Top, S4-4R and S6-4R, have some amount of entrained air that occurs as small, fine and microscopic spherical voids that are characteristic of entrained air voids. The presence of spherical void indicates that the samples were mixed either by hand or mechanically.

The Control Sample was made using the entire 50-pound bag of BlocBond with the prescribed $1^3/4$ gallons of water, which correlates to a water cementitious materials ratio of 0.29. Paste in Sample S4-4R is hard, firm and slightly darker than paste in the Control Sample. Compositional and textural features of the paste in S4-4R indicate that S4-4R is made using a water cementitious materials ratio that is lower than the Control Sample and is well mixed. A few fiber bundles are present but most of the original fiber bundles are distributed into smaller bundles and individual fibers dispersed throughout the sample. The distribution of fibers in S4-4R is similar to the distribution obtained in the Control Sample. Based on the known water cementitious materials ratio of the Control Sample, the water cementitious materials ratio of S4-4R is estimated to be 0.25 to 0.26. The compressive strength of S4-4R is similar to that of the Control Samples, 8,370 psi.

The paste in Sample S6-4R is variable in quality, with small areas of dense paste distributed throughout a matrix of soft paste. The water to cementitious materials ratio in the sample varies on a microscale and is estimated to vary from 0.25 to 0.26 in the dense areas to 0.29 to 0.34 in the remainder of the paste. The variation is due to incomplete intermixing of the components. Overall, the water content used to make the sample is estimated to be the same or slightly higher than the Control Sample, but incomplete intermixing resulted in the variable water cementitious ratios. Incomplete mixing does not completely and intimately intermix the water and cementitious materials into a consistent mass. The incomplete intermixing of water with the cementitious material results in small areas of dense paste distributed throughout, while the remainder of the paste is soft and has a higher water cement ratio.

Sample S2-3 Top is mainly crumbly, friable and weak with few small inclusions of dark hard paste. Most of the paste can be scratched easily with a fingernail and fresh fracture surfaces have textures that are dull and earthy. Some carbonation of the porous paste is present throughout the sample. Numerous fine and coarse residual portland cement particles are present and indicate that hydration of the cement was restricted. Weak friable paste that is carbonated can be explained by a high water content and rapid drying of the paste that results in restricted hydration and carbonation, or the presence of a contaminant that restricts hydration. The water cementitious materials ratio of the sample is not easily estimated, but based on the friable nature of the paste, the water cementitious materials ratio is estimated to be moderate, e.g. 0.40, based on the known water cementitious materials ratio of the Control Sample.

The average compressive strength of the mortar cast in the laboratory exceeds 8,000 psi. The mortar from sample S4-4R has a compressive strength of 8,370 psi. The mortars from the remaining six mine samples tested have strengths from 830 to 2,810 psi.

Of the 17 core samples and one grab sample of mortar submitted for the studies, cubes could only be recovered from 7 of the samples or less than 40 percent. Fractures in the samples or inclusions that caused fracturing of the sample during saw cutting were the reasons that cube samples as small as 1 inch could not be recovered in 11 of the samples. Except for the cube sample from S4-4R, all of the cube samples remained moist and did not dry during the 1 hour drying period after preparation. This is due to either a porous microstructure or the presence of fine contaminants in the mortar that would retain moisture. The petrographic examination demonstrated that S2-3 Top has a porous microstructure. The cause of the lower strengths in all of the compressive strength cubes from the mine sample, except for S4-4R, include: (1) sometime higher than desired water cementitious materials ratios; (2) the presence of fractures, fissures or inclusions of coal and multiple layers of mortar, and (3) incomplete intermixing that resulted in variations in mortar quality within a sample.

Of the 17 core samples visually examined, evidence of inadequate mixing (large fiber bundles) is present in Samples S1-6R, S2-1 Top, S3-3 Top, S6-2 and S10-1. Variations in paste quality (hard and soft paste) are present in Samples S6-2, S7-6R, S8-4R and S10-4R. Overall soft paste is present in Samples S1-6R, S2-1 Top, S3-3 Top, S5-1 an S7-6R. Inclusions of coal or cementitious foam block are present in the mortar of Samples S3-1, S8-3, S8-4R, S9-3 and S10-4R. Finally fractures are present in Samples S7-1 and S9-3.

The visual and petrographic examinations show that, except for the mortar from S4-4R, the mortars from the ventilation seals do not have the same characteristics as the mortar produced in the laboratory. Sample S4-4R demonstrates that it is possible to construct a mortar bed for the ventilation seals that has strength similar to that of samples made in the laboratory. Based on the results of the testing and examinations, the mortar beds beneath the ventilation seals were significantly weaker than the mortar bed represented in S4-4R due to issues related to mixing, placement and curing of the BlocBond material. Strength of the mortar from the ventilation seals is affected by factors that include: (1) inadequate mixing that is characterized in some samples as numerous intact fiber bundles and/or variable paste quality such as inclusions of dense hard paste in softer paste; (2) higher than desired water contents and in the case of S2-3 rapid drying and carbonation of a mortar with a higher than desired water content; (3) inclusions of coal, and (4) fissures or tears that occurred in the mortar after it had stiffened. These tears or fissures are characteristic of plastic cracks that can occur if the mortar is manipulated for a prolonged time period. The randomly oriented fine cracks that are sometimes interconnected (for example as in Samples S6-4R and S7-1) are characteristic of drying shrinkage cracks, but the coring operations and stress related phenomena can not be ruled out as having contributed to these cracks.

Table– Summary of information from the laboratory studies.

Sample I.D.	Remarks	Compressive Strength, psi
S2-3 Top	Dark, hard inclusions of good quality paste distributed throughout a weak matrix. Weak matrix porous with numerous residual portland cement particles. Much higher w/cm ratio than Control Sample or S4-4R. Rapid drying and carbonation also probable contributors to weak matrix. Mixing is variable, fibers are distributed in some areas, but not in others. Spherical air voids are present.	1,064
S4-4R	Well mixed, low water to cement ratio estimated to be lower than the control sample. Fibers well distributed and spherical air voids are present.	8,340
S6-4R	Paste varies from soft to moderately hard. Paste with a slightly higher w/cm ratio than the Control Sample distributed throughout with channels of friable, soft porous paste running through the sample, indicative of incomplete intermixing of the mixing water. Spherical air voids present indicating some mixing, but fibers are mainly present in large intact bundles.	--
	Visual Examinations	
S1-1	Loose material that contains fine and coarse aggregate and trace amount of fly ash, not BlocBond. Non-spherical moderately hard agglomerations of cementitious material and aggregate are indicative of exposure to moisture resulting in hydration of some material. Agglomerations are indicative of exposure to water but no mechanical intermixing of the water and cement has occurred.	--
S1-6R	Extensively fractured moderately soft paste that can be scratched with a fingernail. Inclusions of hard paste indicative of incomplete intermixing of water. Fibers occur mainly in large intact bundles also indicate incomplete mixing.	--
S2-1 Top	Paste is medium gray and hard at the top and grades to soft, light gray paste at bottom. Paste at bottom can be scratched with fingernail. Placing and intermixing mixed mortar in standing water can explain soft mortar on bottom. Fibers are distributed but there are many large intact bundles of fibers present, which is an indication of incomplete mixing.	--
S3-1	Mortar is firm and hard with fiber well dispersed indicating adequate mixing. Numerous inclusions of coal throughout sample and one inclusion of a fragment of a foam block.	1,050
S3-3 Top	Mortar can be scratched with a fingernail. Fibers occur mainly as intact large bundles, one indication of incomplete intermixing.	--
S3-1	Mortar is firm and hard with fiber well dispersed indicating adequate mixing. Numerous inclusions of coal throughout sample and one inclusion of a fragment of a foam block.	1,050

Table (cont'd) – Summary of information from laboratory studies.

Sample I.D.	Remarks	Compressive Strength, psi
S3-3 Top	Mortar is soft and can be scratched with a fingernail. Fibers occur mainly as intact large bundles, one indication of incomplete intermixing.	--
S5-1	Mortar is mainly soft, friable and can be crushed with firm finger pressure. Fibers are distributed and occur mainly as small bundles and individual fibers, indicative of adequate mixing.	--
S6-1	Mortar is hard and firm. Fibers are well distributed indicating adequate mixing.	--
S6-2	Mortar is soft and can be scratched with a fingernail. There are a few small inclusions of dark hard and firm paste. Fibers are distributed in large intact bundles, which is one indication of incomplete mixing.	--
S7-1	Mortar is hard and firm. Fibers are well distributed with some larger bundles present indicating adequate mixing. Small, fine randomly oriented fractures that are sometimes interconnected are present in the sample.	1,960
S7-6R	Mortar is variable from light to medium gray, and is moderately hard and moderately firm. Some portions are soft enough to be scratched with a fingernail. Fibers are well distributed with a few intact bundles present indicating adequate mixing.	--
S8-3	Mortar is moderately hard and firm and cannot be scratched with a fingernail. Fibers are well distributed with a few intact large bundles visible indicating adequate mixing. Inclusions of coal are visible in the mortar.	830
S8-4R	Mortar is moderately hard and firm with a few small areas that are soft and can be scratched with a fingernail. Inclusions of coal are visible in the mortar and the fibers are well dispersed indicating adequate mixing.	1,690
S9-3	Two distinct mortars are present, a moderately hard and firm light gray and mainly a dark gray hard and firm mortar. Numerous fissures and plastic settlement cracks are present as are inclusions of coal. Good fiber distribution in dark mortar is an indication of adequate mixing.	2,810
S10-1	Mortar is hard and firm. Thin layers of separated mortar are present on the bottom surface. Intact bundles of fiber are present on the bottom surface, one indication of incomplete intermixing.	--
S10-4R	Mortar is mainly hard and firm with a few small areas of moderately soft mortar. Rock and coal inclusions are present and fibers are well distributed. Well-distributed fibers are one indication of adequate mixing.	--