REMOTELY INSTALLED MINE SEALS FOR MINE FIRE CONTROL

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Abstract

Mine fires constitute one of the greatest threats to the health and safety of those working in the underground environment and each event has the potential for disastrous consequences. Of the major mine fires and thermal events that have occurred in the United States in the last 6 years, it is estimated that remotely installed seals could have been used in 63% of the events to control fire growth or to aid in fire suppression work. The National Institute for Occupational Safety and Health (NIOSH) is conducting full-scale tests at the NIOSH Lake Lynn Experimental Mine to evaluate and improve remote mine seal construction technology. The main focus of this work is to develop reliable technology that will completely close the mine opening from floor-to-roof and rib-to-rib. This paper presents the results of remote seal installations using grout-based materials.

Introduction

Remotely installed mine seals have become an important component of the mine fire-fighting control and suppression arsenal. Of the mine major fires and thermal events that have occurred in the United States in last 6 years, it is estimated that remotely installed seals could have been used in 63% of the events to control the fire or to aid in fire suppression work.

Remotely installed mine seals are utilized when direct underground access to the mine fire area is impossible or too dangerous. The seals are typically used to isolate the fire area and limit the inflow of oxygen. Once an area is sealed, the fire can be more readily controlled or suppressed by flooding the area behind the seals with water, gas-enhanced foam, inert gas, silt or other material.

Underground observations of remotely installed mine seals suggest that currently available commercial technology often does not achieve the goal of fully closing the mine opening (figure 1). If the mine seals do not mostly close the opening, then oxygen inflow cannot be controlled which can lead to growth of the mine fire. The seals that mostly close the mine opening however may be used to restrict and control the amount of air and inert gas that passes in or out of a fire area.

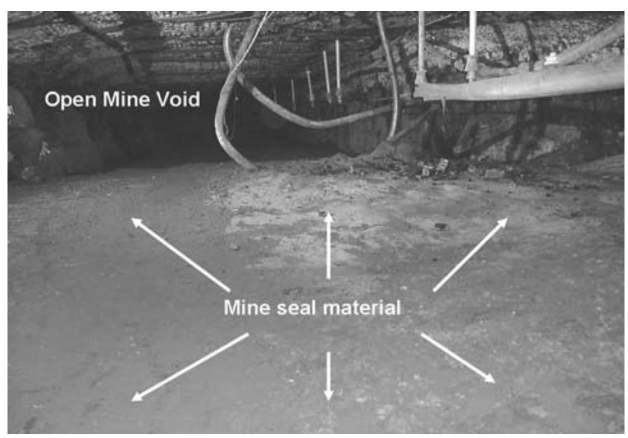

Figure 1. Remotely installed mine seal that did not close the mine void (Urosek, 2005).

The need to evaluate, improve and develop new technology to remotely construct mine seals was identified jointly by National Institute for Occupational Safety and Health (NIOSH) and the Mine Safety and Health Administration (MSHA) in 2001. This need resulted in a NIOSH research project (NIOSH, 2001). In addition, MSHA agreed to serve as a technical consultant in this effort. The first phase of the work involved the qualitative review of existing technology used to remotely construct mine seals. The review included materials used to construct mine seals, including cement and polyurethane foam, and an analysis of the available material mixing technologies (surface versus downhole mixing technologies) (Trevits and Urosek, 2002).

The second phase of the work involved the remote construction of mine seals. The research was conducted at the NIOSH Lake Lynn Experimental Mine (LLEM) located approximately 60 miles southeast of Pittsburgh, Pennsylvania. The LLEM is a world-class, highly sophisticated underground facility where large-scale explosion trials and mine fire research is conducted (NIOSH, 1999) (figure 2). As a part of a prior research study, a 6-in diameter cased borehole was drilled and completed in the first cross-cut between the B and C Drifts of LLEM. It was determined that this mine area and the accompanying borehole was suitable for the seal construction work (figure 3). The thickness of the overburden in the area of the borehole is 197 ft. The cross-cut in the mine measured 19 ft wide, 40 ft long and 7 ft high, with a mine floor slope gradient of 1.13 percent. A second borehole, located about 30 ft away, was available for viewing the mine seal installation using a downhole video camera.

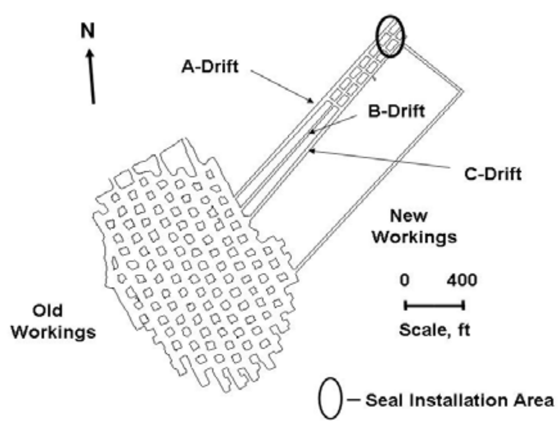

Figure 2. Layout map of the Lake Lynn Laboratory Experimental Mine.

Howard Concrete Pumping Company (Howard)[1] of Cuddy, Pennsylvania and GAI Consultants, Inc., (GAI)[1] of Homestead, Pennsylvania served as research partners with NIOSH in this effort. This paper describes the development of novel grout-based technology, evaluation of the materials used, construction practices, and follow-up testing.

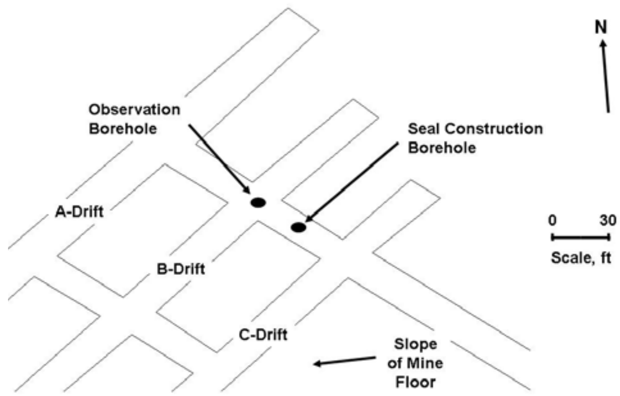

Figure 3. Underground layout of the seal construction site.

The objective of this research effort was to develop a specialty grout product and a method for placing the product through a borehole into a mine opening to build a mine seal. There were several additional factors that were included in the engineering design process. These factors are listed as follows:

- The methodology developed must be quickly deployable (within a few days).
- The mine seal must be rapidly installed (within a day or so).
- The mine seal material used must be locally available.
- The mine seal must be made of non-combustible material.
- The grout material used must allow placement in a free space without excessive flow if the mine is open and unobstructed and have flowable characteristics should the mine opening contain roof fall debris, cribbing, posts, and equipment and conveyor structures.
- The grout and the installation technology should facilitate full mine roof-to-floor and rib-to-rib closure.
- The seal must be strong and withstand the force of a methane gas explosion of about 20 psi.

[1] Mention of a specific product or company name does not imply endorsement by NIOSH.

Seal Material Placement Technology

A model mine opening was constructed at Howard's facility for testing and direct observation of the performance of the downhole and surface equipment. The model mine opening consisted of a small excavation in a hillside. The roof of the model mine was made using crane mats so a drill rig could be located over the mine void to hold the pipe for the downhole equipment (figure 4). Two series of tests were performed at the model mine along with an initial test at the LLEM before the final seal material delivery technology and seal grout mixture was developed. Changes were made to the cement content, admixtures and additive ratios to improve stickiness, time-of-set and application uniformity. Laboratory work was also conducted to improve the grout blends by modifying admixtures and additive ratios. After each test, modifications were made to the materials and equipment.

Figure 4. View of the model mine.

The final technique developed included a specialized directional elbow for directional placement of bulk fill material (figure 5) and a proprietary spray nozzle for material to address the remaining open areas in the mine void (figure 6). The spray nozzle required the use of two strings of pipe (one inside of the other) to convey two streams of material to the nozzle. The spray nozzle permitted the blending of the two-part grout accelerator mix with sufficient air velocity to transport the grout to the mine roof-and-rib areas. The bulk grout was pumped to the borehole using a positive displacement pump and compressed air. The sprayed grout was moved to the borehole using a conventional grout pump and compressed air. A detailed report on the development of this technology is presented by Gray et al (2004).

Figure 5. Elbow for bulk fill placement.

Figure 6. Spray nozzle.

Seal Material Development

During the initial work, it was decided that the first material to be placed into the mine would be a bulk fill material designed to occupy most of the open space in the mine void. The bulk fill material was comprised of a mixture of fly ash, Portland cement, and 2A (3/4-in minus) crushed limestone aggregate. A conventional concrete admixture was used to accelerate the set of the grout. The material was blended to achieve a pumpable mixture that had adequate strength and rapid setting properties. Fly ash was added to produce a mix that could be pumped to the borehole, travel down the borehole without segregation and provide a moderate degree of flowability. Once the material was in-place, the aggregate would provide sufficient shear resistance for the grout to be somewhat immobile until the mix set. Typical initial set time for this mixture could be achieved in 15 to 20 minutes and would support foot traffic in 30 to 45 minutes.

A second proprietary material was designed to fill any remaining open space above the bulk fill especially along the problematic roof-rib line areas. This material consisted of a two-part grout blend that was developed using a novel combination of materials procured from Master Builder's Concrete Products Laboratory[1] in Cleveland, Ohio. The grout was generally a mixture of ASTM Class-F fly ash and Portland cement. The initial testing of the grout indicated that a conventional shotcrete accelerator would not produce sufficient stiffening in the desired time frame. Additionally, it did not exhibit suitable rheological and hardening properties required for the grout application. Further testing determined that a specially modified proprietary mixture was more effective in providing the desired grout characteristics than the conventional admixtures. In general, the proprietary mixture is made up of two parts. Part A improves the pumping characteristics and provides a reaction platform for Part B and is mixed with the grout before it is pumped into the borehole. Part B creates an immediate stiffening of the grout. Part B is added to the grout mixture at the spray nozzle (positioned at the mine level) using the stream of air that also transports the grout to the mine roof-and-rib surface. Other additives accelerate the hydration process and facilitate rapid strength development. The water content of the mix was also adjusted to improve the stiffening properties of the grout and produce the required stickiness for the grout spray to adhere to the mine roof-and-rib areas.

As the work on the seal material development progressed, it became apparent that the uniform, consistent blending of the constituents in the sprayed grout was critical to the grout performance. The final portion of the grout mix design work focused on a sensitivity study that identified the grout's reaction to deviations in the blending process. It was concluded that it would be necessary to finely meter the ingredients in the grout mix to achieve the desired performance. After a series of field and laboratory tests, adjustments were made to the equipment used to control material feed and a significant improvement of the material mix was achieved by the Howard Concrete and GAI team. It was also believed that sufficient latitude for field adjustments existed in the material design to account for changing conditions that might be encountered in the field.

Mine Seal No. 1

The equipment used for this work included a volumetric mixer batch plant, cement storage silo, water tanks, pumps, air compressor, a drill rig, and miscellaneous support equipment such as trucks and loaders. Initial operations included calibrating the batch plant so that a uniform flow of bulk material could be mixed to produce a rate of approximately 30 yd^3 per hour. Placement of the bulk fill for seal No. 1 was initiated using a mixture composed of 2A crushed limestone aggregate, fly ash and cement. This mixture was pumped into the mine opening using a string of casing. Bulk fill was pumped over different time intervals with a pause between intervals to allow the in-place grout to stiffen and begin to set. This process was used to control the extent of lateral material flow out of the cross-cut areas. The pumping time and the pause intervals were determined by visual observation via a downhole video camera. The installation of this seal was not designed to be a "blind" operation so in-mine to surface communication was also facilitated through the use of a mine pager phone system. Pumping was terminated after approximately 112 yd^3 of material had been placed into the cross-cut (figure 7). Underground examination revealed that the mine opening had not been completely sealed (open spaces were observed at the mine roof-and-rib areas) and some of the bulk fill material had flowed into the adjacent mine areas.

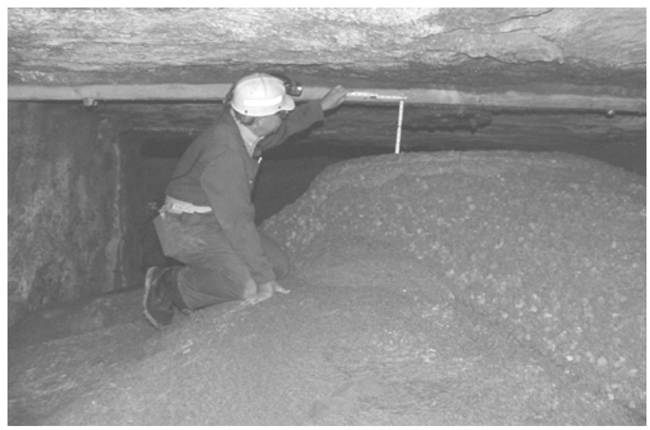

Figure 7. Underground view of bulk fill material for seal No. 1.

A dual string of drill pipe and casing affixed with the spray nozzle was then placed into the borehole in preparation for the second part of the mine seal construction. Unfortunately, after only a few minutes of pumping, a critical hose failed on the surface and the pumping operation was terminated. Underground examination of the sprayed areas indicated that the spray mixture did not stick to the mine rib areas and flowed away. Also, since minimal space (about 12 inches) between the bulk fill and the bottom of the borehole was available, it was decide to remove 18 inches of bulk fill material below the bottom of the borehole to provide sufficient space for follow-up backfilling work.

The disappointing results of the spray nozzle application indicated that additional work was needed to further refine the material mix components before the spray nozzle was used again. In the interim, after reviewing the progress made during the placement of the bulk fill, it was also decided to fit the end of the casing string of pipe with an elbow (refer to the section on Seal Material Placement Technology above) to provide a means of directionally controlling the placement of grout material (refer to figure 5). It was also thought that this elbow configuration could facilitate roof-rib closure with the bulk fill material.

After some additional laboratory and design work, the newly designed elbow was lowered into the mine opening from the surface borehole. It was thought that use of this design might achieve full mine void closure thus eliminating the need for the spray nozzle. Once the elbow was positioned in place, pumping of the seal material began using a 2A limestone aggregate, fly ash and cement mixture. Compressed air was added to the flow stream to facilitate movement of the material towards the mine rib areas. Seal material was pumped into select locations along the mine rib areas in an attempt to fill the mine opening. Pumping was terminated after approximately 100 yd^3 of material had been placed into the cross-cut and after the elbow became plugged.

Underground examination revealed that the mine opening had not been completely sealed, some of the material had flowed beyond the cross-cut and into the adjacent mine areas. The area directly below the borehole and in the immediate vicinity of the elbow had been completely sealed to the mine roof. Several unsuccessful attempts were made to dislodge the plug in the elbow and it was ultimately decided to terminate the construction of mine seal No. 1. In general, before the elbow became plugged, significant progress had been made towards filling the mine opening. A subsequent meeting with Howard/GAI team revealed that additional design work was necessary before installation of seal No. 2 could begin. Later, mine seal No. 1 was removed.

Mine Seal No. 2

Pumping of the first part of seal No. 2 (bulk material) began using a sand, fly ash and cement mixture. This material was pumped into the mine opening using the directional elbow. The bulk material was pumped in a series of lifts to fill most of the mine opening. Pumping was terminated after approximately 55 yd^3 of material had been placed into the cross-cut. It should be noted that that communication with underground personnel was allowed to orient the directional elbow and complete the construction of the first part of the seal. Underground examination revealed that seal material was placed to within 1.5 ft of the mine roof below the borehole and within 2.5 to 3 ft of the mine roof near the rib areas (figure 8).

Figure 8. View of bulk fill placement for seal No. 2.

It was decided to remove 6 in of material at the top of the seal to allow sufficient room to test the capability of the spray nozzle. For this part of the seal installation, the raw material was brought to the site using “Redi-Mix” trucks. This equipment worked well with the small volume batch plant used for this work. After conducting a 10 yd^3 surface test of the seal mixture (fly ash, cement and accelerators), a dual string of drill pipe and casing affixed with the spray nozzle was then placed into the borehole in preparation for the second part of the seal construction. Once the nozzle penetrated the mine opening, seal material was sprayed in a back-and-forth motion along the mine rib areas to fill in the gaps. Interaction between observers underground and engineers on the surface ensured that the nozzle was aimed in the proper direction. Good mine roof-and-rib contact was made with the sprayed material. The problematic corner areas at the mine roof-rib intersection were filled before the grout began to build up and migrate towards the spray nozzle (figure 9).

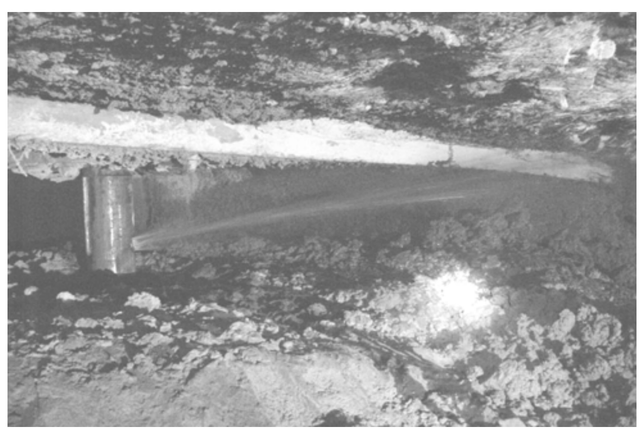

Figure 9. Underground view of spray nozzle during seal No. 2 construction.

Filling of the remaining area near the borehole was accomplished by lowering the spray nozzle into the wet material and then rotating the operating spray nozzle through a 360 degree arc. Eventually, the material built-up around the nozzle and closed the mine opening (figure 10). In all, a total of 22.5 yd^3 of sprayed material was used to close the mine opening. An underground examination showed that the mine seal material (both bulk and sprayed material) was sprayed about 12 ft from the borehole towards the B-Drift and only about 9 ft from the borehole towards the C-Drift (this reduced distance was due to the slope of the mine floor). The final shape of the seal approximated a truncated pyramid whose base measured 19 ft wide (the width of the cross cut) by 21 ft deep and whose top measured 19 ft wide (the width of the cross cut) by 3 to 5 ft deep. Later, mine seal No. 2 was removed.

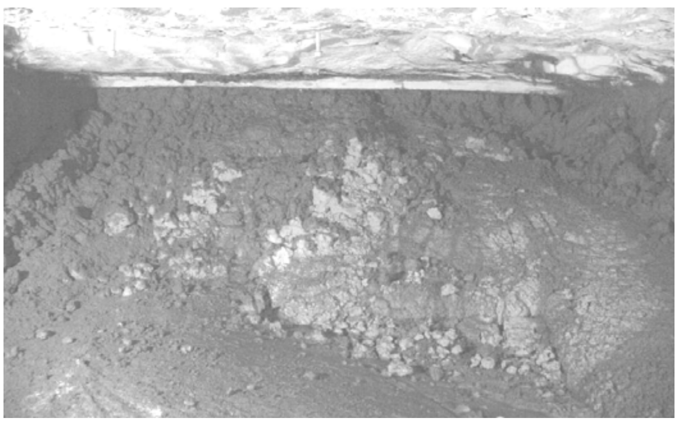

Figure 10. Underground view of mine seal No. 2 from the B-Drift.

Mine Seal No. 3

The design concept for seal No. 3 called for using only the spray nozzle and eliminating the bulk component of the fill. Furthermore, this seal installation was to be conducted without direct communication with observers in the underground mine. The only means of observing the progress of the work was through the nearby observation borehole using a downhole camera. The material mix was also altered somewhat from that used for seal No. 2 as the water component was slightly reduced. This change would facilitate an increase in the amount of Part B in the mix and would increase the stiffness of the material.

As discussed earlier, underground information showing the orientation of the spray nozzle and extent of the seal construction was limited to observations made with a borehole video camera that was installed in the second borehole located about 30 ft away. All material used was brought to the site in "Redi-Mix" trucks and the various components were added to the mix using a small batch plant. Installation of the seal was initiated using the spray nozzle rotating through a 360 degree arc. Installation progressed smoothly and the material throw distance was about 20 ft on the B-Drift side and about 15 to 18 ft on the C-Drift Side. The difference in throw distance is attributed spray pressure and the slope of the mine floor. Spraying of the seal material continued along the 360 degree arc until it was decided by the engineers on the surface to only spray the C-Drift side. It was later disclosed that this approach was used to limit the size of the seal to approximately one-half the area of the cross-cut area yet still allow for a sufficiently sized seal. Work was terminated for the day due to closure of the local cement plant after only 35 yd^3 had been placed into the mine opening.

Spraying of seal material resumed the next day and seal material was sprayed along a 70 degree arc across the upslope, C-drift side of the cross-cut. Pumping continued until about 40 yd^3 of material had been placed into the mine void. Pumping was terminated when it was determined that seal material had rolled back onto and enveloped the spray nozzle and this material could not be removed or moved away using the nozzle. In addition, it was thought by engineers on the surface that underground visibility had diminished significantly (due to water vapor and fog accumulation in the mine) as observed through the downhole camera. Later it was determined that a gasket in the downhole camera had failed, causing a build-up of water that obscured the lens and ultimately caused the camera to become unusable.

An underground examination of the seal void showed that the mine void appeared closed on one side of the borehole along the cross-cut, but a significant hole remained on the other side of the borehole (figure 11). The Howard/GAI team later concluded that the full capability of the spray nozzle had yet to be tested. Therefore, it was thought that another attempt should be made to build a seal (called seal No. 3-A) using the spray nozzle in the down slope area of the cross-cut towards the B-Drift and that viewing of the progress of construction might be easier because this operation would take place about 20 ft closer to the observation borehole. Some of the material from Seal No. 3 was removed from the area of the borehole and along the ribs to allow the spray nozzle unobstructed movement and to permit seal material to be sprayed the maximum distance from the borehole.

A fixed-position video camera was located below the second borehole because the downhole camera was damaged as noted previously. This camera would provide the same function as the downhole camera without compromising the in-mine communication restriction placed on this experiment. This camera was not moved or rotated during construction work and was positioned to provide a view across the total width of the cross-cut.

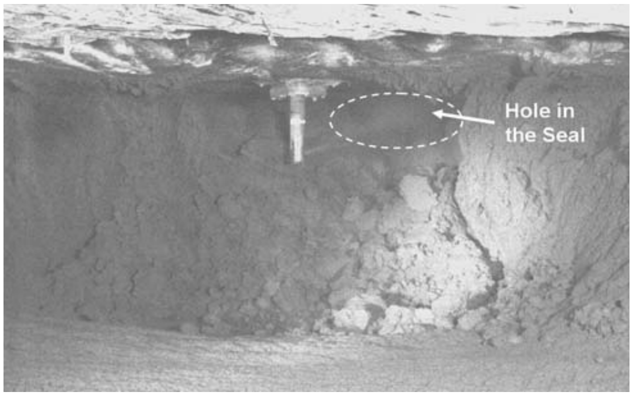

Figure 11. Underground view of mine seal No. 3 from the B-Drift.

The material mix was altered somewhat from that used for seal No. 3 as the water component was again slightly reduced. This change would increase the stiffness of the material to minimize material flow away from the borehole on the down slope side of the cross-cut. The construction of seal No. 3-A began by rotating the spray nozzle back and forth through a 70 to 80 degree arc. The spray material was thrown a maximum distance from 20 to 22 ft from the borehole although most of the material seemed to be fall along an arc from 8 to 10 ft from the borehole. Pumping continued until about 37 yd^3 had been placed in the mine void when it was determined from the video camera image that the material had been placed to within a few inches of the mine roof (figure 12). The resulting mine seal was a large bowl-shaped structure extending about 8 to 10 ft from the borehole. The addition of accelerator (Part B) to the spray was then stopped and grout was permitted to flow from the spray nozzle to help infill any remaining voids in the mass of the seal. Pumping was terminated after about 3 yd^3 of this material had been pumped and a total of 40 yd^3 was pumped to construct this seal.

Figure 12. Underground view of mine seal No. 3-A from the B-Drift.

Unfortunately the observations made using the video camera did not agree with the actual conditions in the mine void. The mine roof near the area of the borehole had been broken upward on the B-Drift side and this irregularity was obscured by the general slope of the mine roof towards the video camera location. Although the video images showed the front top (from the B-Drift side) of the seal to be at or near the mine roof, in fact, the seal was nearly 18 inches from the mine roof along an arc about 8 to 10 ft from the borehole (figure 13). However, upon closer inspection inside the bowl-shaped structure, it was observed that seal material was placed to within 4 to 6 ft, radially, from the borehole and was at the mine roof level completely across the mine opening (figure 14).

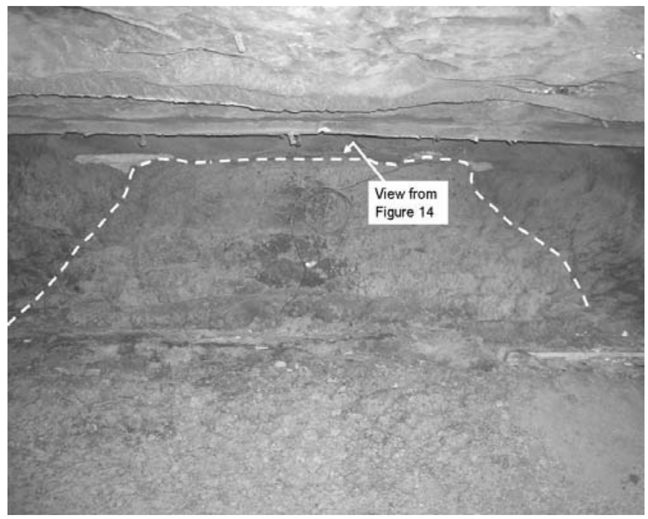

Figure 13. Underground view of mine seal No. 3-A from the B-Drift (note dotted line shows outline of the seal).

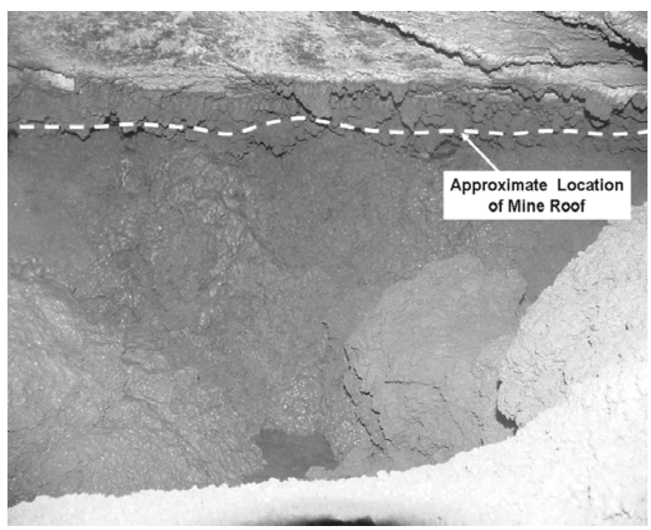

Figure 14. View of mine seal material inside of the bowl-shaped structure of Mine seal No. 3-A (close to injection borehole).

Seal Strength Tests

Unconfined uniaxial compressive strength tests were conducted on 3-in diameter cylinder samples that were collected during seal construction. Samples were collected underground as the material was being placed in the mine void. The results of the tests are shown in figures 15 and 16. The marked difference between the uniaxial compressive strength of the bulk material used for seal No. 1 as compared to seal No. 2 is most likely the sand component used in seal No. 2. With respect to the sprayed material, the uniaxial compressive strength of the bulk fill material is substantially higher than that of the sprayed fill material. The reason for the lower uniaxial compressive strength of the sprayed material is that the sprayed material does not contain sand or aggregate and most likely had air bubbles trapped in the mixture from the mine seal material placement process.

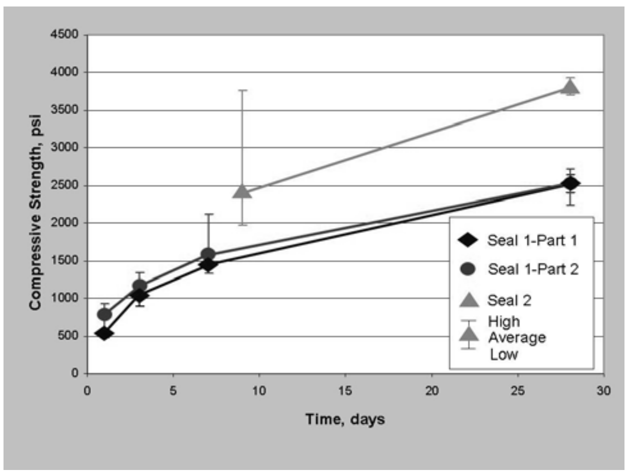

Figure 15. Results of unconfined uniaxial compression tests on bulk seal material samples.

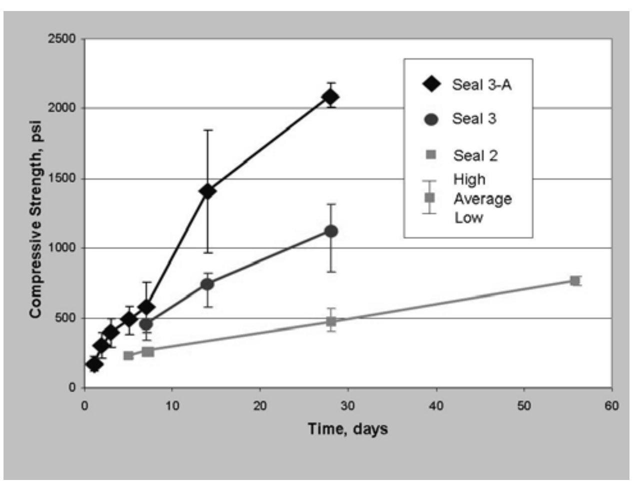

Figure 16. Results of unconfined uniaxial compression tests on spray seal material samples.

Unconfined compressive tests were conducted after 1, 2, 3, 5, 7, 14 and 28 days on samples collected from the sprayed material used to construct seal No. 3-A. The results of these tests showed that the material achieves significant strength quickly and given sufficient seal thickness could, in all likelihood, withstand the force of a mine explosion shortly after installation. Also, note that in figure 16, that there is an overall increase in compressive strength from one seal to another. This is a result of alteration of the grout mix components as discussed earlier.

Although the major thrust of this research effort was aimed at development of material mixes and mine seal construction techniques, the benefits of constructing the seal at the LLEM included the option of testing the seal's ability to confine mine air and also to withstand the forces of a mine explosion. Air leakage tests were conducted on seal Nos. 2 and 3-A by building a frame on one side of the mine seal and covering the frame with brattice cloth. Next an opening was made in the brattice cloth the size of an anemometer to facilitate air velocity measurements. Once this work was completed, air flow in the mine was adjusted to produce a desired differential pressure and the air leakage through the seal was measured. The results of the air leakage tests are shown in Table 1.

Table 1. Results of air leakage tests.

Parameter	Seal No. 2			Seal No. 3-A[1]		Seal No. 3-A[2]		
Differential Pressure, inches of water gage	0.52	1.05	1.52	0.8	1.5	0.85	1.5	2.25
Air Leakage Rate, ft^3/min	252	322	426	296	409	221	305	365

[1]Several holes were observed in rib-roof areas remaining from seal No. 3.
[2]Test performed after polyurethane foam was used to fill holes observed during initial test.

Prior to conducting the air leakage tests, several holes (on the order of about 1-in diameter) were observed in seal No. 2 near the mine roof area. Therefore, the air leakage values shown in the table were not totally unexpected. During the initial test of seal No. 3-A several holes were observed in the rib-roof areas. The holes were created during the installation of seal No. 3 and the material left in place from the remnants of seal No. 3. The holes were filled with polyurethane foam and the test was conducted again. The results of the second test on Seal No. 3-A showed the air leakage rates were reduced after the polyurethane foam was applied. To determine where the seal leaked air, a fog machine was used to create smoke and was placed on the upwind side of the seal. Air pressure on that upwind side of the seal was increased to force the smoke through the seal. The smoke was observed at the mine roof areas on the downwind side of the seal. This observation was significant because it suggests that the seal material may not have been sprayed long enough to completely close the mine void or that the method used to complete the seal (as described earlier) eroded some of the sprayed seal material and created the holes. Also, it is important to note that leaks were not detected in the body of the seal, along the floor or rib areas.

An explosion test was conducted on mine seal No. 2. The mine seal withstood a pressure of 18 psi with no visible signs of damage. To conduct the explosion test, a known quantity of methane gas was injected in the end of the C-Drift near the cross-cut where the seal No. 2 was installed. This area was temporarily closed with a frame and brattice cloth to confine the gas. The gas was diluted with air to achieve an explosive concentration. The gas was then ignited producing an explosion. An explosion test on seal No. 3 was not conducted because it was assumed that the seal was of significant thickness and strength and would withstand the force of a methane gas explosion (of about 20 psi).

Conclusions and Recommendations

The overall objective of the work was to determine if an underground mine seal could be constructed remotely from the ground surface. This objective was achieved as two seals were successfully built through a borehole and the seals were confined to the cross-cut of the mine opening. The technology used to build the seal was tested and an appropriate material mix design was developed for both bulk and sprayed seal material. The results of follow-up testing (including compressive strength tests on seal samples, air leakage and explosion tests) showed that strong and robust seals were constructed as required in the design process. The issue of air-leakage may not be significant because the leakage rates were considered to be relatively small. In some cases, a certain amount of air leakage can be acceptable if the exchange of mine air and fire suppression agents (water, gas, foam, etc) into or out of the mine fire zone is manageable from the surface. However, if significant quantities of mine air can freely move across the area where mine seals have been remotely installed and where fire suppression agents cannot be contained as desired, the remotely installed seal most likely contains large holes and the installation is a failure. It is thought that air leakage may be further minimized by spraying the face of the seal with grout material using the spray nozzle from the observation borehole after completion of the downhole seal installation. This application should be tested in the future.

Results of the work to date suggest that this remote seal construction system may have merit for isolating a mine fire. This technique however does require additional trials to increase operator experience and overall familiarity with the technology.

One of the fundamental keys to successful in-mine seal construction using this technology is the ability to directly observe the progress of the work and that a blind seal installation (installation without an observation borehole) is most likely impossible. The only means of observing the in-mine construction may be via a nearby borehole that is equipped with a downhole video camera unless a camera can be directly affixed to the spray nozzle. Our experience suggests that conventional downhole camera lighting systems have a limited horizontal range of penetration (about 30 to 40 ft). Also, fog is created in the mine void as the seal material begins to set-up and this fog can significantly obscure the mine seal and limit the ability observe the work from a nearby borehole. This problem may become even more acute should the mine void be filled with smoke. It is suggested that future research be conducted using a downhole laser or a radar imaging device that offers real-time imaging and data processing with the capability of penetrating smoke, dust or fog.

A 6-in diameter, 197 ft deep, cased borehole was used during the trials at LLEM and the downhole equipment was designed to meet this need. The issue of working with this equipment at deeper depths should be evaluated as these conditions will be most likely encountered in the field.

Finally, it is suggested that this technology should be further tested with the construction of a mine seal in an entry that contains debris (roof fall material) and mine structures (possibly cribbing, track, or conveyor structures). This approach will test the ability of the seal material to flow around obstructions and still form a seal while closely matching the conditions most likely found in an underground mine.

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References

Gray, T.A., M.A. Trevits, L.M. Crayne, and P. Gloglowski. 2004. Demonstration of Remote Mine Seal Construction. 2004 SME Annual Meeting Denver, CO February 23-25 Preprint No. 04-194, 8 p.

National Institute for Occupational Safety and Health, 2001, "A Compendium of NIOSH Mining Research 2002," Washington, DC: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH), Publication No. 2002-110, p. 73.

National Institute for Occupational Safety and Health, 1999, "Lake Lynn Laboratory (flyer)," Pittsburgh, PA: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 99-149, 1 p.

Trevits, M.A. and Urosek, J.E., 2002, "Technology for Remote Mine Seal Construction," 2002 SME Annual Meeting, Phoenix, AZ, February 25-27, Preprint No. 02-185, 4 p.

Urosek, J.E., 2005, Chief, Ventilation Division, Pittsburgh Safety and Health Technology Center, MSHA, Personal Communication, March 22.