Longwall Shield Recovery, Using Phenolic Foam Injection for Gob Control As An Alternative to Recovery Mesh

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INTRODUCTION

Following a methane ignition in the active panel of a longwall coal mine, the affected panel was successfully isolated from the rest of the mine. This allowed for the remainder of the mine to return to regular operation, and the conventional practice of having to seal the portals for a defined period of time was avoided. After the affected panel had remained isolated for a regulatorily mandated period of time, it was reopened in preparation for longwall face recovery. As it was not possible to move the shields from their existing positions to facilitate the installation of recovery mesh prior to shield recovery, alternative methods had to be considered to stabilise the gob and minimise flushing, thereby improving operator safety.

The objective of the paper is to show how stabilisation of the gob was achieved during shield recovery, thereby minimising flushing, and improving operator safety.

Phenolic foam was chosen and injected from between the shields into the gob behind them. This is a technique that has been used to great effect in Germany, to a lesser extent in Australia, but not knowingly to date in the United States. To ensure nothing was left to chance and thereby guarantee the project's success, the procedure used in Germany was employed, down to the application of equivalent hardware, which was sourced through the North American supplier.

PANEL SEALED OFF FROM SURFACE

Immediately after the ignition the mine was successfully evacuated in a safe and timely manner, without incident or injury. Within four hours of the occurrence, nitrogen was being injected directly into the area of the ignition, in quantity and from the surface (Figure 1). Full control of the situation was established within 48 hours of the incident, at which point the mine was faced with an exciting and stimulating technical possibility: if the affected longwall panel could be successfully isolated from the rest of the mine, then the remainder of the workings could be returned to regular operation and the conventional practice of having to seal the portals for a defined period of time could be avoided.

Figure 1. Nitrogen injection on gob vent borehole.

Cementitious and foam products were tested to determine their ability, and suitability, to seal the active longwall panel remotely from the surface (Figures 2 through 6).

Phenolic foam was chosen, and the longwall panel was successfully sealed with five in-mine ventilation control structures, remotely placed from the surface at depths of approximately 750 to 900 ft (230 to 275 m). The first two structures were placed using two injection boreholes and two video camera boreholes each (Figures 7 and 8). The last three structures were each placed with a single injection borehole and a single video camera borehole.

Initial evidence of the effectiveness of the sealing came from video footage and differential pressure gauge readings. This was corroborated with direct observation and measurements underground by the mine rescue teams when the mine was reentered.

After the in-mine ventilation control structures had been emplaced, they were backed up with stoppings and approved 50 psi (0.34 MPa) seals.

Figure 2. Test trench.

Figure 3. Test trench with nitrogen inertisation.

Figure 4. Start of phenolic foam testing.

Figure 5. Finish of phenolic foam testing.

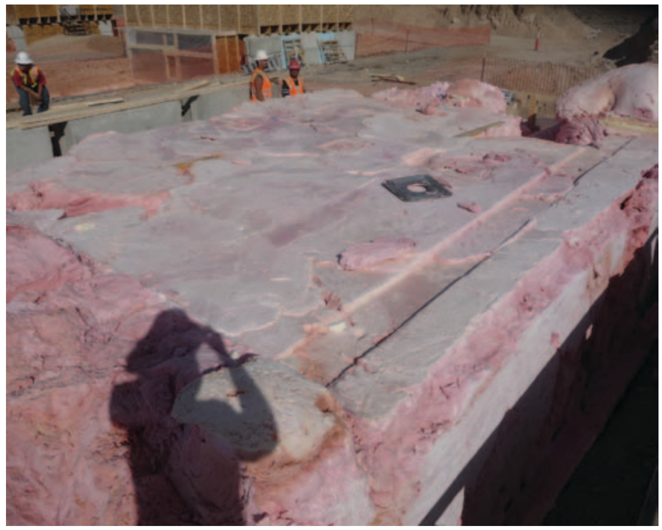

Figure 6. End result of phenolic foam testing.

Figure 7. Lowering hoses from surface.

Figure 8. Pumping from surface.

Success was achieved in the face of both technical and historically driven adversity. In spite of repeated assertions that there was little chance of success, perseverance and demonstration of proof of concept prevailed and delivered a product and technique that not only worked, but did so better than expected.

PANEL REOPENED UNDERGROUND

After the regulatorily mandated period of time had elapsed, access and ventilation were reestablished to the affected longwall face in readiness for gob consolidation. At the time of the ignition, the longwall face was approximately 3,100 ft (945 m) short of its planned recovery line, and the headgate drive and crawler-mounted tailpiece were partway along a chain pillar between crosscuts. A new set of recovery chutes were driven, and the pillar was split. The 50 psi (0.34 MPa) seals, stoppings and in-mine ventilation control structures were breached (Figures 9 through 12).

Figure 9. Test breaching 50 psi (0.34 MPa) seal.

Figure 10. Test breaching 50 psi (0.34 MPa) seal.

Figure 11. Phenolic foam underground.

Figure 12. Admiring our handiwork!

GOB STABILISATION

Once access and ventilation were reestablished to the affected longwall face, the process of gob consolidation commenced. Under conventional recovery conditions, recovery mesh would have been used. However, as this was not an option in this case, because it was not possible to move the shields from their existing positions to facilitate the installation of recovery mesh prior to shield recovery, alternatives methods were considered to stabilise the gob and minimise flushing, thereby improving operator safety.

Building on the success already achieved with phenolic foam for panel isolation, it was decided to use it again for another of its designated purposes: gob stabilisation (Figure 13). The technique has been used to great effect in Germany, to a lesser extent in Australia, but not knowingly to date in the United States. Additionally, it already had a proven track record at the San Juan Mine for void filling (Panel 202 tailgate fault (August and September 2007), the Panel 201 headgate fall (November and December 2008) and the Panel 301 headgate fall (November and December 2010)), and had just been tested again and approved for use under the federal 103(k) order outstanding from the ignition.

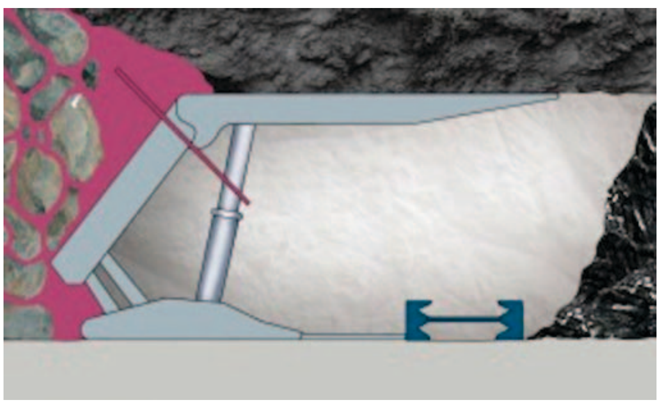

Figure 13. Concept of gob stabilisation using Rocsil foam (A. Weber SA, 2013).

Accordingly, phenolic foam was injected from between the shields, into the gob behind them. To ensure that nothing was left to chance, and thereby guarantee the continuing success of the project, the procedure used in Germany was used, down to the use of equivalent injection hardware.

PHENOLIC FOAM AND INJECTION HARDWARE

The phenolic foam chosen was Rocsil® foam. It is manufactured by A. Weber SA in Rouhling, France, and represented in the US by Jennchem. It is a two-part foam, consisting of a resin and a catalyst. The theoretical mixing ratio is four parts of resin to one part of catalyst, but under actual conditions this ratio is typically nearer to 3.5-3.6:1. The expansion ratio and finished product density depend upon a number of factors, and are typically in the ranges of 20-30:1 and 1.9-2.8 lbs/ft^3 (30-45 kg/m^3). Compressive strength at 10% deformation is 14.5-29 psi (0.1-0.2 MPa).

The injection hardware consisted of externally threaded hollow bar, 1-5/8 in (42 mm) button bits and threaded couplers. The bar has an external diameter of 1-3/16 in (30 mm), an internal diameter of 5/8 in (16 mm), and was supplied in 10 ft (3 m) lengths. Some of these were then cut into 6 ft (1.8 m) and 4 ft (1.2 m) sections. This system was used at the recommendation of A. Weber SA, as it was equivalent to that used to great effect in Germany. It was sourced from Europe through the North American supplier.

The initial single-use 'sacrificial' drill strings consisted of a 1-5/8 in (42 mm) button bit, a 6 ft (1.8 m) section of bar, a threaded coupler and a 10 ft (3 m) section of bar. This allowed for the operators to stand back under the safety and relative openness of the canopies when drilling, rather than having to work in the more confined areas around the legs.

DRILLING

Drilling was accomplished with jackleg drills, striker bars and threaded couplers. Water flushing, with a flow rate of at least 2 gpm (7.6 lpm), was used to prevent any sparking or heat-related methane ignition potential. None occurred.

It was intended to drill two holes between, or at the edge, of each shield. An upper one, towards the back of the canopy/ caving beam and at an angle of approximately 45°, and a lower one at chest height straight back into the gob. Holes were initially drilled to a depth of approximately 6 ft (1.8 m). Each drill string was drilled in until the proximal end of the threaded coupler was flush with the back of the shield/gob line. The drill string was then disconnected from the threaded coupler on the end of the striker bar and left in position, ready for injection. Further threaded couplers were modified by the addition of staple-lock couplers to one of their ends for connection to the mixing gun. The mixing gun could then be connected to these modified threaded couplers with a single staple, and pumping started. This system allowed for a safe and simple transfer from one drill string to the next (Figure 14). Once pumping on a specific drill string was finished, the proximal 10 ft (3 m) section was then wound back out of the threaded coupler whenever possible, leaving the distal 6 ft (1.8 m) section behind in the gob. This helped to clear the working area of unwanted obstructions, and minimised the potential risk of drill string hang-ups on the shields when they were pulled, and then possibly getting thrown around the work area. It also allowed the remaining 6 ft (1.8 m) sections to act as 'rib' bolts, thereby helping to reinforce the gob (Figure 15).

Where shields pairs were so close together that one or the other, or both, of the holes could not be drilled between them, additional foam was pumped into adjacent drill strings on either side, or both sides, to compensate.

FOAM CALCULATIONS

The shields at San Juan Mine are 5 ft 9 in (1.75 m) wide, and at the time of the ignition were set to a height of 10-12 ft (3-3.7 m). Initial calculations for the volume of foam required behind each shield were based on a width of 6 ft 7 in (2 m), a set height of 13 ft (4 m), a desired gob consolidation ('wall') thickness of 6 ft 7 in (2 m), and an assumed void space in the gob of 50%. The shield width and set height were both deliberately chosen to be on the conservative side, and the void space was reckoned to be overly so. This gave a volume of approximately 280 ft^3 (8 m^3) per shield, or approximately 140 ft^3 (4 m^3) per drill string. At an assumed mixing ratio for the resin to catalyst of 3.5:1, this equated

Figure 14. Pumping and changing drill strings.

Figure 15. Drill strings in gob between shield pairs.

to approximately 4 drums of resin at a density of 2.5 lbs/ft^3(40 kg/m^3), or approximately 4.5 drums at a density of 2.8 lbs/ft^3 (45 kg/m^3). The decision was made to start with five drums of resin per drill string.

FIRST FOUR SHIELDS

The first four shields on the tailgate end of the longwall face were pumped with 108 drums of resin in 9 drill strings, equating to approximately 12 drums per drill string, with no show of resin anywhere on the face, or between or into the shields. As a consequence additional resin and catalyst were ordered to cover the new anticipated maximum usage of 15 drums of resin per drill string. The first four shields were pulled without incident. Unfortunately, no photographs of this were taken, but the tailgate corner had a near perfect right-angle at the contact between the roof and the gob in the tailgate entry.

REFINEMENT

Having seen no show of resin with the first four shields, drill strings were then tried at depths of approximately 3 ft (0.9 m) and approximately 6 ft (1.8 m) into the gob to see if there was any change or improvement. If they were drilled too far into the gob, then it might have created the potential for better consolidation of the gob and a thicker 'wall' further back into the gob, thereby reducing the possibility of any major flushing or failure of the gob. However, at the same time, it might have created poorer consolidation of the gob immediately behind the shields, thereby increasing the possibility of some minor flushing or dribbling.

Conversely, if they weren't drilled in far enough, it may have created the potential for better consolidation of the gob immediately behind the shields, thereby reducing the possibility of some minor flushing or dribbling. At the same time, it may also have created poorer consolidation of the gob and a thinner 'wall' further back into the gob, thereby increasing the possibility of some major flushing or failure of the gob, and also lead to possible inundation of the shields. In reality there was no appreciable difference in behaviour observed between the approximately 3 ft (0.9 m) holes and the approximately 6 ft (1.8 m) holes.

STEADY STATE

Within a short space of time, a steady state practice was established whereby a maximum of 15 drums of resin were pumped through each drill string. This was unless additional resin was being pumped to compensate for adjacent drill strings in the pattern that could not be drilled between shield pairs due to the shields' proximity, or unless inundation of the shields with foam occurred prior to the desired quantity of resin being reached. In the former case, the quantities were increased by differing amounts based on the different possible scenarios. These could include 'partner' drill strings missing between one shield pair, adjacent drill string missing on one side or other, adjacent drill string missing on both sides, adjacent drill strings missing on one side or other, adjacent drill strings missing on both sides, etc. The maximum number of drums of resin pumped into any one drill string was 50. This was the upper drill string between shields 5 and 6 on the headgate end, and even then it only showed a modicum of return into the shields before pumping was halted. At the end of the foam injection phase of the project, a total of 3,305 drums of resin, and 904 drums of catalyst had been pumped, at a ratio of 3.7:1. Close to the original estimate of 3.5-3.6:1.

FACE WIDENING

The shearer, drives and panline were recovered once gob consolidation had been effected. The face was then widened by about 10 ft with a continuous miner, bolted and dusted to provide sufficient clearance for shield recovery (Figures 16 through 19). Widening was done one section at a time: tailgate to Chute 1, Chute 1 to Chute 2, Chute 2 to Chute 3, and Chute 3 to headgate. To prevent damage to the shields, the left hand end of the miner drum was modified.

SHIELD RECOVERY

Once the face had been widened, bolted and dusted, the shields were recovered. As with the face widening, shield recovery also took place one section at a time. Shield recovery was carried out in the same manner as it would have been for a 'normal' recovery, using a mule and a pair of walkers.

Due to the size of the project, and the number of holes that needed to be drilled, it was inevitable that there would be some

Figure 16. Miner tramming to take cut.

Figure 17. Cut taken.

Figure 18. Bolting.

missing drill strings at various locations along the face. In these areas, where the injection of foam was maybe not quite as uniform as planned, the recovery face conditions were good. Only a minimal amount of flushing occurred in isolated pockets, and there was never any inundation of the face with gob. As shields were pulled, the roof above them also stayed in place. Where the

Figure 19. Dusting.

injection of foam was as uniform as planned, the recovery face conditions were excellent. So good, in fact, that the gob was held back at a negative 'angle of repose', with the backs of multiple shields quite clearly imprinted in it. Most importantly, all the conditions were significantly better than they would have been without recovery mesh or foam. Without either of these, gob flushing would have been almost inevitable, and the face could have been inundated (Figures 20 through 27).

Figure 20. Walkers at Shield 116.

CONCLUSION

Success was achieved in the face of technical adversity. In spite of the fact that this method of gob stabilisation had not been knowingly successfully demonstrated in the United States to date, adherence to the procedure and hardware successfully used in other coal mining regions of the world delivered a product and technique that not only worked, but did so better than expected. It is not very often that you can get to see a negative 'angle of repose' on the longwall gob.

The entire face was recovered without incident, accident or injury of any kind. It serves as the most fitting testament and legacy of the efficacy of the foam as an alternative to the use of recovery mesh for longwall gob consolidation.

Figure 21. Minor flushing.

Figure 22. Minor flushing, and excellent gob control.

Figure 23. Minor flushing, and excellent gob control.

Figure 24. Walkers at Shield 59.

Figure 25. Minor flushing.

Figure 26. Minor flushing.

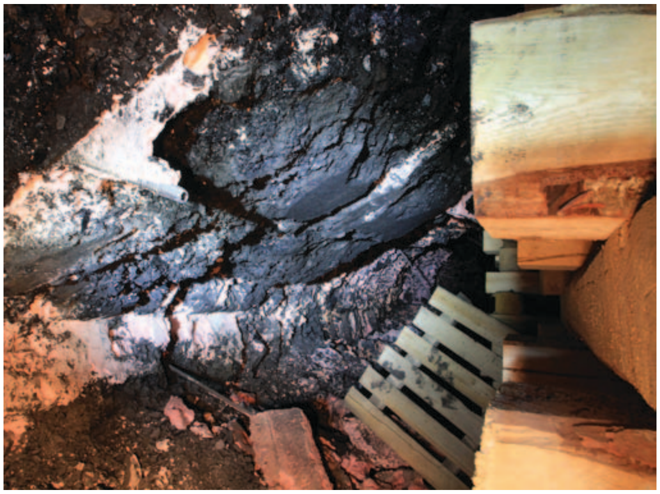

Figure 27. Negative angle of repose?