Use of Rocsil® foam to remotely construct mine seals

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Abstract

The National Institute for Occupational Safety and Health (NIOSH) is conducting a program of research to evaluate and improve remote mine seal construction technology for mine fire control and suppression. The main focus of this work is to develop reliable technology that will remotely seal a mine opening from floor-to-roof and rib-to-rib. NIOSH, in partnership with Strata Mine Services Inc.,[1] is evaluating the capability of a two-component phenolic foam-based product, called Rocsil®, that is intended for cavity filling, air and gas sealing, and consolidation of highly fractured strata. Rocsil® can be rapidly applied, has a quick cure time, a high expansion rate, good compressive resistance and excellent anti-static properties. When the resin and catalyst are mixed, an immediate foaming reaction occurs followed by rapid expansion up to 30 times the original volume. By virtue of its fire-resistance properties, Rocsil® foam has application for sealing underground mine areas undergoing heating from spontaneous combustion, and it could be useful for remote mine seal construction to aid in mine fire control and suppression. This paper presents an overview of remote mine sealing technology, introduces the use of Rocsil® foam for remote mine seal installations, offers a case study of the use of this rigid foam material to remotely construct a temporary in-mine seal and discusses technology improvements.

Introduction

Previously, federal mining laws required mine operators in the United States to report to the U.S. Mine Safety and Health Administration (MSHA) any unplanned mine fire event that was not extinguished within 30 minutes of discovery (Code of Federal Regulations, 2007). Subsequent to the accidents at the Sago and Aracoma Alma Mines in January 2006, this regulation was modified to include all unplanned mine fire events that are not extinguished within 10 minutes of discovery. According to MSHA, in an underground environment, if miners attempt to fight a fire for 30 minutes and are unsuccessful, the fire will probably become uncontrollable. The revised reporting requirement is expected to result in earlier activation of fire-fighting plans as miners will notify supervisors more quickly who, in turn, can call in firefighting crews and allow miners to safely escape (Federal Register, Rules and Regulations, 2006.

During the time period from 1990-2007, there were 1,601 reportable fires that occurred in the U.S. mining industry (an average of 89 fires per year), and 138 of these fires occurred in underground coal mines (an average of eight fires per year) (DeRosa, 2008) (Fig. 1). The leading causes of mine fires include flame cutting and welding operations, frictional heating and ignitions, electrical shorts, mobile equipment malfunctions and spontaneous combustion (National Institute for Occupational Safety and Health, 2008). The fact that mine fires occur with an alarming regularity reinforces the importance of recognizing and eliminating the potential hazards and the overall need for improved fire control and suppression technology to ensure the best possible outcome during a mine fire.

The technology used to control and extinguish a mine fire is usually focused on removal of one or more sides of the fire tetrahedron (oxygen, heat, fuel and the chemical reaction). If a mine fire is discovered early in its development, extinguishing agents are directly applied to the fire. This approach can be very effective, but it also places miners in close proximity to the fire and can expose them to the deadly hazards of the fire.

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

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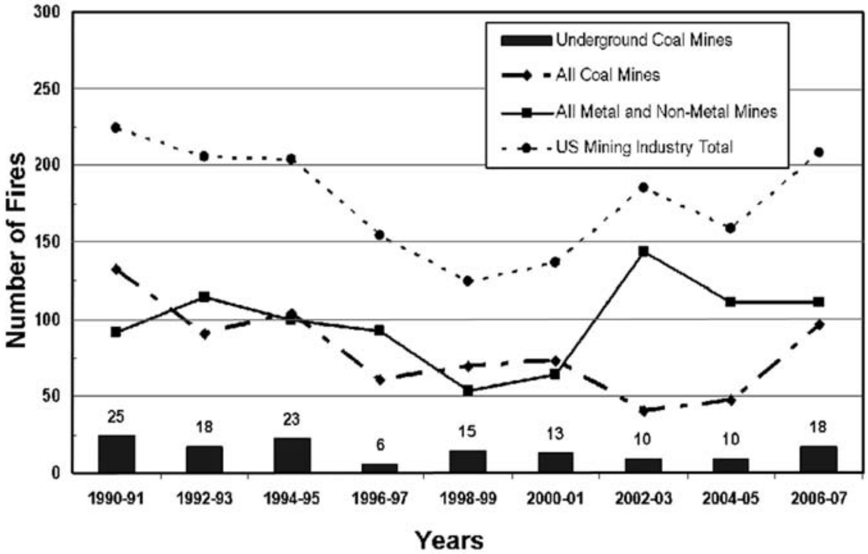

Figure 1 — Reported mine fires in the United States 1990-2007 (DeRosa, 2008).

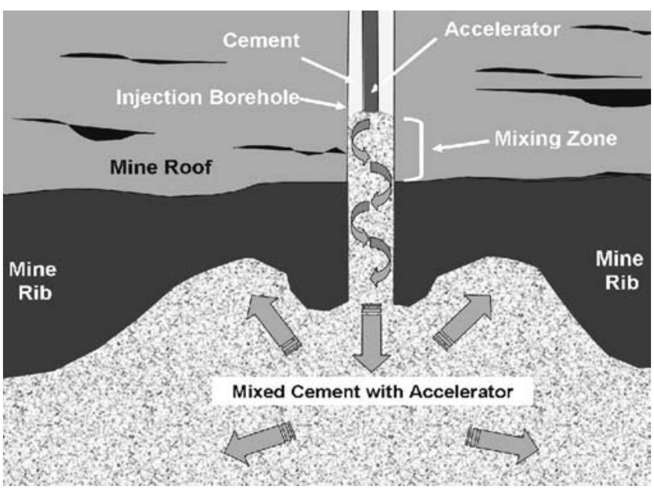

Figure 2 — Downhole depiction of a conventional remote mine seal installation.

Mine fires are fought indirectly when access to the fire zone is impossible because of safety reasons, blocked underground access, a limited supply of available firefighting materials and a fire zone that is too large for available underground personnel. This approach involves sealing the mine or construction of in-mine temporary seals (ventilation-control structures, hereinafter referred to as mine seals) to isolate the fire area. These in-mine seals can be constructed from within the mine or remotely through boreholes. Sealing the mine (or isolating the fire area) is designed to control or extinguish the fire by reducing the oxygen concentration in the mine atmosphere to a level that will not support combustion. The benefit of remote mine sealing technology is that the size of the fire zone enclosed by the seals can be reduced without exposing miners to the fire dangers. Once the fire zone is sealed, the affected area can be flooded with water, inert gases or gas-enhanced foam to control or extinguish the fire. This paper presents an overview of remote mine sealing technology, introduces the use of Rocsil® foam for remote mine seal installations, offers a case study of the use of this rigid foam material to remotely construct a temporary in-mine seal and discusses technology improvements.

Background

Cement-based remote mine seal construction. Commercially available remote mine seal placement technology places cement-based mine seal material (commonly without the use of downhole cameras) to the mine level in the following manner. A tubing string is placed into a borehole that has been drilled and cased to the mine void. Attached to the lower end of the tubing is a mixing tool, and accelerator material is pumped into the borehole via the tubing string (Fig. 2). Cement is concurrently pumped into the annular space between the tubing and the borehole casing. The cement and accelerator then mix in the lower portion of the borehole. The mixed material then flows into the mine opening and away from the borehole. The material is designed to set up quickly as it exits the borehole resulting in an accumulation of cement at the bottom of the borehole that flows outward towards the mine ribs and upward towards the mine roof. When sufficient pressure builds (indicating a significant build-up of material directly below the bottom of the borehole) in the borehole, pumping is stopped and the pressure is monitored. If the pressure falls (indicating that the material build-up has slumped), pumping is resumed until another pressure build-up is observed. The cycle of pumping and observing pressure decline continues until the pressure does not fall. If the pressure does not decline, pumping is terminated.

By design, the seal material is supposed to flow and fill the mine roof-rib interface areas. However, this technology is not always successful, as underground observations of remotely installed mine seals show that the material often does not fully close the mine opening (Figs. 3 and 4). If a mine seal does not completely close the opening, then oxygen inflow cannot be stopped, which can lead to growth or further expansion of the fire. Mine seals that do not completely close the mine opening may be used to restrict or control the amount of air or inert gas that passes in or out of a fire area (depending on the size of the remaining open area in the seal).

In an effort to improve the technology, NIOSH contracted Howard Concrete Pumping Company and GAI Consultants Inc. to develop an alternative method for remotely constructing cement-based mine seals. After much testing at the NIOSH Lake Lynn Experimental Mine, an improved new grout-based material was developed along with a novel material placement technology (Gray et al., 2006). The system developed creates a mine seal in two stages. The first stage uses a string of pipe and a directional elbow that is positioned at the bottom of the injection borehole. The pipe string and elbow are designed to place bulk material into the mine void in a series of lifts to fill most of the mine opening. The second stage uses two strings of pipe (one inside of the other) in the injection borehole to convey two components of a specially designed grout material to a spray nozzle. The spray nozzle blends a two-part grout and accelerator mix while allowing sufficient air velocity to transport the grout to the mine roof-and-rib areas (Fig. 5).

Once the spray nozzle is positioned in the mine opening above the bulk fill, the spray nozzle is rotated in a back-and-forth motion towards the mine rib areas to fill in the gaps between the bulk fill and the mine roof-rib interface. As the mine roof-rib intersections areas are filled, the grout builds up and migrates back towards the spray nozzle and the injection borehole. Filling of the remaining area near the borehole is accomplished by lowering the spray nozzle into the accumulated wet grout material below the nozzle and then rotating the spray nozzle through a 360-degree arc. Eventually, the material builds-up around the nozzle and closes the mine opening. In practice, the spray nozzle could be used to construct the entire mine seal; however, this would increase the cost of constructing the mine seal. This system can construct a 60 m^3 (80 cu yd) mine seal in about 12 hours. It should be noted that for effective mine seal construction, this technology requires a second nearby borehole that is outfitted with a downhole camera to observe and direct seal material placement. This new technology offers a viable alternative to the commercially available system and should improve cement-based remote mine seal construction.

Rigid foam remote mine seal construction. The final area of remote mine seal testing under the NIOSH research program involves investigating the use of rigid foam (polyurethane and phenolic foam). Rigid foam offers a unique capability, such that when the components of this material are mixed, it expands up to 30 times the original volume. This property is important and can be useful when trying to fill a mine void because the cement-based materials do not expand and often leave open areas along the intersection of the mine-roof and rib (as discussed earlier). However, because rigid foam material can be negatively affected by the heat of a mine fire, it is thought that mine seals constructed of this material would be placed farther away from the mine fire zone.

Rocsil® foam is a unique two-component phenolic foam (phenol-formaldehyde) distributed by Strata Mine Services in the United States. The product is typically used for cavity filling, air and gas sealing and consolidation of highly fractured strata in underground mines (Fig. 6). When the components of Rocsil® foam are mixed in a 4:1 volume ratio, the resin and catalyst produces an immediate foaming reaction that is followed by a rapid expansion to as much as 20 to 30 times its original volume. Once the mixed material has polymerized, Rocsil® foam sets up in 5 minutes at 15°C (59ºF) and 2 minutes at 25°C (77ºF) (Fig. 7). Rocsil® foam has a high compressive strength for rigid foam, i.e., the compressive strength at 10% deformation is 100 to 200 kPa (14 to 29 psi); an excellent antistatic properties and is reported to be fire resistant (Strata Mine Services, 2008). Because of its unique properties, NIOSH in partnership with Strata Mine Services, decided to test the application of Rocsil® foam for remotely constructing mine seals.

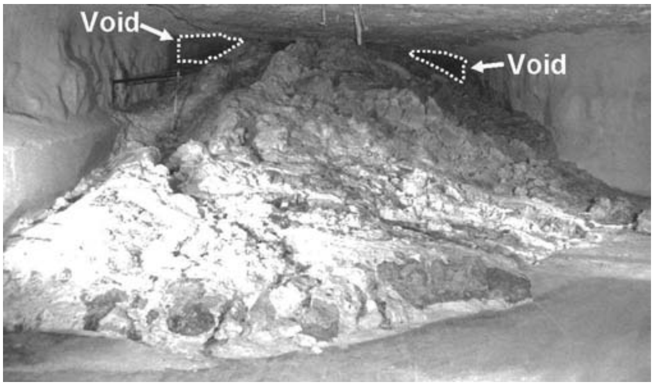

Figure 3 — Cement-based remotely installed mine seal. Note the open void areas.

Figure 4 — Cement-based remotely installed mine seal (Urosek, 2005). Note the open void areas.

Figure 5 — Spray nozzle directing material towards mine rib (Gray et al., 2006).

Case study of remote sealing using Rocsil® foam

An underground mine operator was interested in remotely constructing temporary seals in a slope area of a coal mine that contained a beltline conveyor structure. This is typically a difficult opening to remotely fill because conventional cement-based seal material does not always flow around and through the structure and can easily result in open voids in the seal. Strata Mine Services' engineers determined that this would be an ideal mine application for Rocsil® foam because the material would flow laterally for a short distance below the conveyor and would then grow upwards through the conveyor structure as the chemical reaction between the resin and catalyst occurred. The mine area of interest was accessed using multiple boreholes; two boreholes were used for placing the Rocsil® product into the mine and another was used for observing the sealing operation by means of a downhole camera. The approximate dimensions of the arched-shaped mine opening were 4.6 m (15 ft) wide by 4.6 m (15 ft) high. The injection and monitoring boreholes were located about 6 to 9 m (20 to 30 ft) apart.

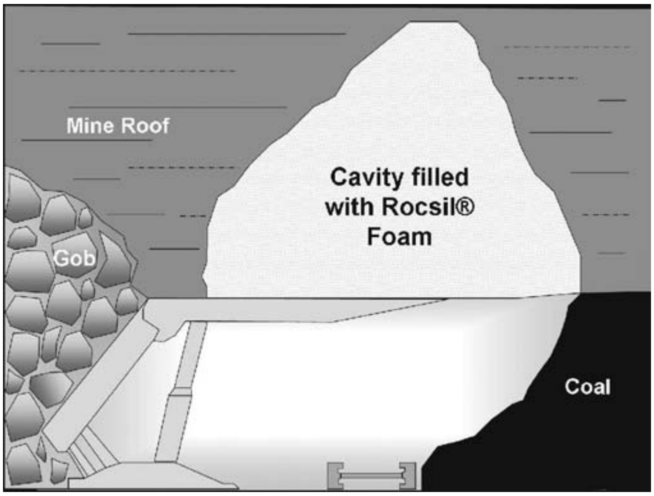

Figure 6 — Use of Rocsil® foam to fill a cavity (Strata Mine Services, 2008).

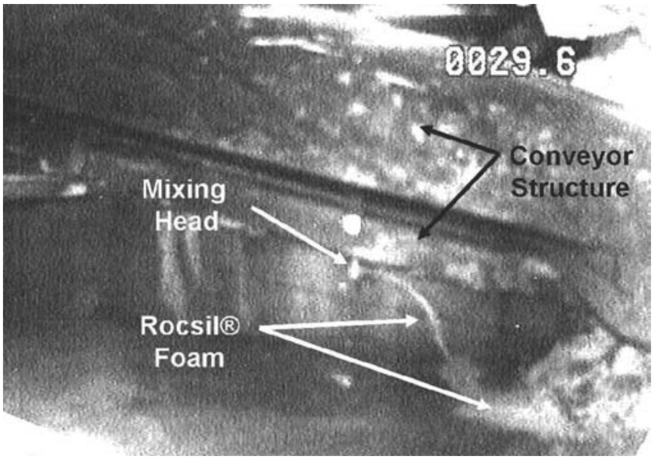

Figure 8 — Screen capture from video showing early backfilling operations. Note numbers in the upper right hand corner of the image indicate to borehole depth.

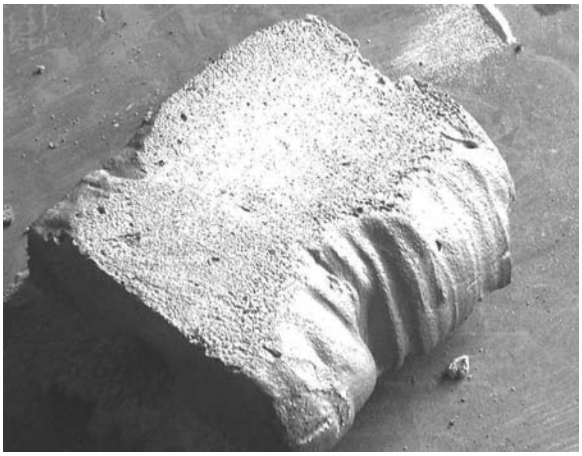

Figure 7 — Rocsil® foam.

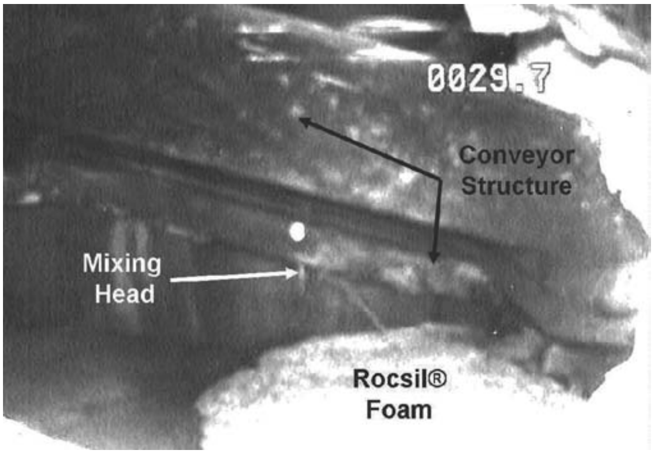

Figure 9 — Screen capture from video showing backfilling operations progressing. Note that the numbers in the upper right hand corner of the image indicate borehole depth.

Due to the shallow overburden conditions at this mine site, the downhole mixing head was lowered into the mine void using the material delivery hoses instead of using a string of pipe. The downhole mixing head contains a static in-line mixing element that ensures that the Rocsil® resin and catalyst products are properly mixed before they are pumped into the mine void. Injection of Rocsil® began with the mixing head positioned near the lower portions of the conveyor. The mixing head was then moved upward towards the roof as the foam product polymerized and expanded (Figs. 8 and 9).

The position of the mixing head was adjusted and the extent of mine void filling was constantly monitored, from an adjacent borehole, using the downhole camera. The second injection borehole was used when it was observed that the foam had not completely closed the area below a walkway on the conveyor system that had not been previously identified to Strata Mine Services. Injection of Rocsil® was completed when it was observed by the downhole camera that the mine void had been filled (Fig. 10). In all, a total of 240 m^3 (314 cu yd) of Rocsil® foam were used to seal the mine opening.

Technology modifications and improvements

Although the mine seal discussed in this case study was not constructed for the purposes of fighting a mine fire, the successful remote installation of this seal has important implications on the use of this technology in a mine fire situation. It was demonstrated that a difficult mine opening could be effectively closed using Rocsil® foam, albeit that multiple boreholes were used. As a means of improving the technology for placing and monitoring the extent of mine seal construction, a new delivery system was designed and constructed to combine the downhole mixing head and the camera system. This design eliminates the need for a second observation borehole and could facilitate directed placement of the foam material. The mixing head is mounted to a rigid frame and an explosion proof housing (containing a low-lux camera, two high-intensity LED lights and batteries for power) is positioned immediately above the mixing head (Fig. 11). A coaxial cable connects the camera to a compact digital video recorder on the ground surface for viewing and recording mine seal construction operations. The system's

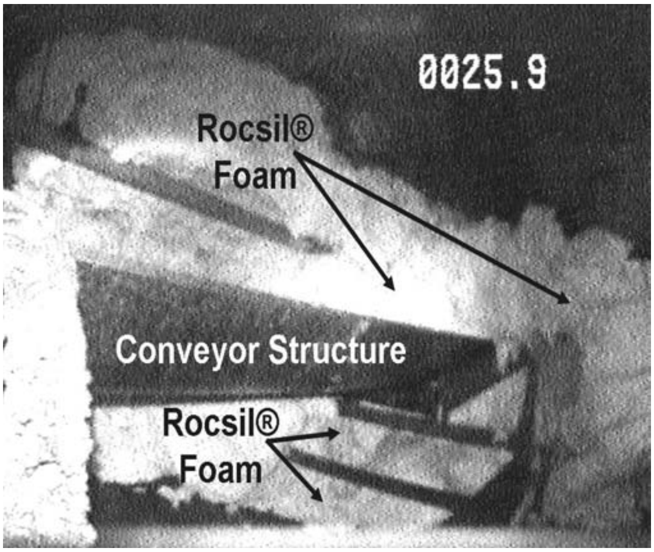

Figure 10 — Screen capture from video showing completed seal. Note that the numbers in the upper right hand corner of the image indicate borehole depth.

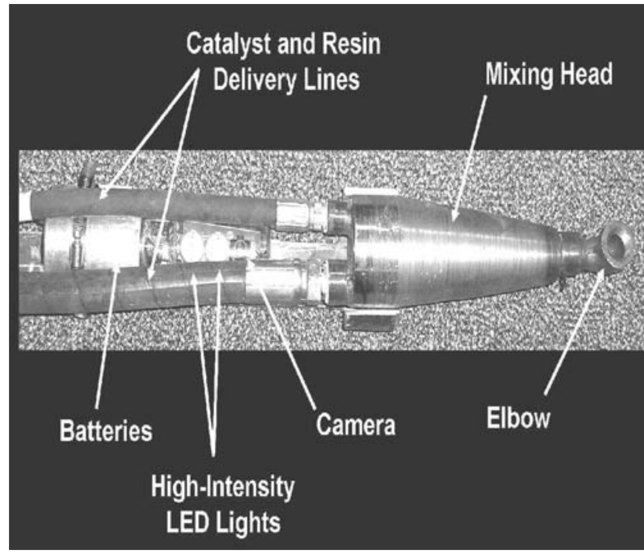

Figure 11 — Improved foam delivery system that combines the downhole mixing head and the camera system.

rigid frame is connected to a string of pipe that extends to the surface to enable engineers to raise, lower and pan the system during seal construction. The entire system (mixing head and camera equipment) is designed to fit in a 152-mm (6-in.) cased borehole, ensuring application at most mine sites. The camera and lights are designed to illuminate and observe mine seal construction activities at distances up to 6 m (20 ft) from the mixing head. This entire system will be fully evaluated during remote mine seal construction work using Rocsil® foam at the NIOSH Lake Lynn Experimental mine is the spring of 2008.

Results and conclusions

Mine fires occur with an alarming regularity in the United States, which reinforces the importance of recognizing and eliminating the potential hazards and the overall need for improved fire control and suppression technology to ensure the best possible outcome during a mine fire. NIOSH is conducting a program of research to evaluate and improve remote mine seal construction technology for mine fire control and suppression. One part of the work is focused on the development of reliable technology that will remotely seal the mine opening from floor-to-roof and rib-to-rib. Underground observations indicate that conventional cement-based remote mine sealing technology often does not close the mine opening which can lead to growth or further expansion of a mine fire. NIOSH-research has led to the development of novel downhole spray nozzle technology and improved grout mixtures.

Rocsil® is two-component phenolic foam that is typically used for cavity filling, air and gas sealing and consolidation of highly fractured strata in underground mines. Rocsil® foam expands to as much as 20 to 30 times its original volume and is fire resistant. Rocsil® foam has application for sealing underground mine areas undergoing heating from spontaneous combustion and it was thought that it would be useful for remote mine seal construction to aid in mine fire control and suppression.

Rocsil® foam was successfully used to close a sloping mine opening that was obstructed with a conveyor structure using multiple boreholes. A new foam delivery system was designed and constructed to combine the downhole mixing head and the camera system. This design eliminates the need for an observation borehole, will allow for directed placement of foam material and should be a significant improvement in the technology. The new system will be fully evaluated during remote mine seal construction work at the NIOSH Lake Lynn Experimental mine in the spring of 2008.

Disclaimer

The findings and conclusions in this report are those of the authors and do not necessarily represent the views of NIOSH.

Acknowledgments

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