Recent case studies using the remote ROCSIL® FOAM plug system

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RECENT CASE STUDIES USING THE REMOTE ROCSIL® FOAM PLUG SYSTEM

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ABSTRACT: ROCSIL® FOAM is a versatile product that has been successfully used to rapidly seal mines or critical areas of the mine directly in-seam or remotely via boreholes or shafts. The product is chemically stable, fire resistant, fast setting, has high expansion and excellent self-supporting characteristics making it an ideal product for these types of applications. It can also be used on sloping ground and with mine services such as conveyor structure or pipes remaining in-situ to form effective plug seals. For remote sealing, special mixing heads are designed to effectively deliver the product into mine roadways or shafts without the need for labour to be deployed underground or when exclusion zones are in place on the surface. This paper will describe the remote head technology, system development and process via a number of case studies where the remote sealing system was successfully used. Each case required novel techniques to meet particular mine constraints. Once the critical mine event is under control, the plug can be easily removed to facilitate safe re-entry of the mine. The remote ROCSIL® FOAM plug seal system is a world-class innovation available to deal with underground explosions, heating or fire events in a safe, cost-effective and rapid way.

INTRODUCTION

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 BENEFITS OF REMOTE PLUGS IN EMERGENCY SITUATIONS

Preventative applications provide the most favourable option for clients with current mining regulations requiring in situ provision of remote sealing of mine operations. This can be achieved by placing a mixing gun and two flexible hoses at an accessible point in the roof of selected roadways. The product can be applied from surface to seam using a high-volume delivery pump attached to the pre-installed hoses. The product pods are connected in the event of a potential incident from a safe location, pumped from the surface until it expands to the roof and ribs forming an airtight barrier as shown in Figure 1.
In certain emergency situations, shuttering is constructed underground by an emergency team and filled with foam to create an airtight barrier. In incidents where this is not possible, the application head can be lowered into the seam via a borehole with the foam being placed remotely without shuttering. Foam consumption is higher as there is no formwork to contain the products’ expansion, but it provides a crucial option requiring no personnel underground should an exclusion zone be in place. Remote pumping provides a much safer alternative than emergency crews building formwork and has been the only methodology employed by Wilson Mining (WM) in the installation of these seals in Australia.

![Figure 1: Example of a surface to seam setup](image)

Whichever method of remote sealing is chosen, using ROCSIL® FOAM in this manner provides a fast and simple solution. The seal integrity is maintained during any convergence experienced, with the matrix consolidating on its own due to its expansion properties. (Trevits and McCartney, 2008).

**WHY ROCSIL® FOAM PHENOLIC FOAM**

By design, the chosen seal material is supposed to flow and completely fill the mine roof-rib interface. Depending on the product used, however, this methodology is not always successful. The underground observations of remotely installed cementitious mine seals in Figure 2 (a and b) show that certain materials often do not fully close the mine opening.

![Figures 2: Cement-based remotely installed mine seal](image)

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.
ROCSIL® Foam is a LOBA (Arnsberg) and Mines Safety and Technology Centre approved phenolic resin introduced into the Australian coal mining industry in 2002. Since its introduction, WM have completed over 1300 successful applications in underground coal mines in Australia and New Zealand. Although ROCSIL® FOAM is most commonly known for the consolidation of longwall and development roof cavities, it has many other applications, including:

- Rapid underground sealing of mine roadways (Vent plug)
- Remote sealing of mine roadways via surface boreholes
- Vent plug installation on longwall faces to restrict ventilation from entering the goaf
- Sealing of underground heating and mine fires

The characteristics that make ROCSIL® FOAM ideal for remote plugs is that it is chemically stable, fire resistant and has a high expansion rate. It has a fast setting time, excellent self-supporting characteristics with ability to form around complex infrastructure such as conveyors, making it ideal for forming remote plugs. Figure 3 is an illustration of a typical installed seal utilising formwork.

![Figure 3: Example of ROCSIL® FOAM seal with formwork](image)

A LONG HISTORY OF LESSONS – EARLY CASE STUDIES

The first remote plug seals in Australia were undertaken by WM as early as 2003 at Southlands Mine to provide a plug for their longwall heating event. Previous applications had been undertaken in both France and USA, with Weber Mining playing a crucial role in developing this technology and partnering with WM in developing and improving these systems over the last 16 years.

Since Southlands in 2003, WM have completed remote emergency seal projects at Newlands in 2007, Blakefield South in 2011, Pike River in 2011 and 2019 and a QLD Operation 2019. Over this 16-year period, many refinements and much experience has been learned and developed, with WM offering extensive experience in the safe and effective application of remote and surface to seam plug seals using phenolic foams.
THE IMPORTANCE OF REMOTE HEAD TECHNOLOGY

The most important consideration in the safe and effective remote installation of ROCSIL® FOAM is maintaining the correct mixing ratio. The correct mixing ratio is essential to provide the appropriate foaming characteristics to appropriately seal the roadway and to ensure the correct mechanical properties as shown in Figure 4.

In many instances, WM have had to ‘pump blind’. This is where there has been no provision to lower a camera into adjacent boreholes to monitor the quality of the installed product. WM have invested significant efforts into developing the remote head that provides peace of mind when pumping remotely without visibility on the outcome.

A considerable amount of pressure is exerted by the product at the mixing head during operations, especially those with a high depth of cover. As the Part A and Part B of the ROCSIL® FOAM has different densities, maintaining correct ratios is critical as this can have significant impacts on the technical properties of the foam. Designing a mixing head (Figures 5 and 6) that controls the back pressure and maintains consistent mixing ratios has been a key development of the WM business.

Product components need to be contained inside the delivery lines while the pump is switched off, therefore valves have to cope with pressure exerted to prevent overflow and clogging of the mixing head. In balance, they have to be sufficiently versatile to open once the pumping commences and product is mixed and delivered through the head.

Figure 4: Remote ROCSIL® FOAM plug seals installed at Blakefield South in 2011

Figure 5: Mixing head internal
RECENT CASE STUDIES

Case study 1 – Pike River Mine

The Pike River Recovery Agency (PRRA) was tasked with the recovery operation of the Pike River Mine, located 46 kilometres northeast of Greymouth as shown in Figure 7, following the coal mining incident that began on 19 November 2010. At the time of the incident thirty one miners and contractors were present in the mine. Two miners managed to walk from the mine, the remaining sixteen miners and thirteen contractors were believed to be at least 1.5 kilometres from the mine entrance.

Figure 7: Pike River Mine location (Inset) and aerial image of drift location

WM were contracted to install a remote ventilation plug seal down the 102 m # 48 borehole at the head of the drift as shown in Figure 8. The plug is a key ventilation control measure for the recovery of the mine, allowing forensic teams to recover the bodies of the deceased that remain within the mine. The plug provided a seal between the nitrogen filled mine workings on one side and the fresh air to be pumped through borehole # 53 to allow access back into the drift, (Te Kahui Whakamana Rua Tekau Ma Iwa, 2019 a and b).
The remote location of the worksite at Pike River Mine required logistics to be well planned both in advance and throughout execution. Aside from equipment, personnel and product being shipped from Australia, the remote work site was accessible by helicopter only (Figure 9).

Weather conditions were challenging with a highly variable climate. The product was being shipped from the warmth of Australia to the extreme cold where it was to be applied. Maintaining temperatures is critical in the safe application of phenolic foams as too low temperatures can affect product mixing at the head and reduce expansion. To ensure the quality of application for such a critical project, WM utilised reverse cycle air-conditioned containers to cool the material down when in Australia and then warm up the product before it was flown to the work front. Once there, a heater was rigged to ensure correct product pumping temperature was maintained.

WM maintain high environmental standards at all times, but in this case the work front was in a National Park, requiring the highest level of controls. Through the entirety of the project, fully bunded equipment was used to contain any possible spill. The installed plug was tested to prove that it had the required resistance to keep the chamber between the plug and the roof fall full of nitrogen with no oxygen ingress. It also provided enough resistance to ensure the
nitrogen could flow out of the chamber and into the old mine workings past the rock fall. Testing proved positive to the required resistance allowing PRRA to continue the recovery operation.

**Case study 2 – Queensland Mining Heating Event 2018**

In September 2018, WM assisted a mine in Queensland combat an underground heating event. This involved the rapid installation of temporary seals into mine roadways, drifts and mine fan using novel remote application methods. The requirement of the project was initially to isolate the longwall heating event. As the event escalated the requirements changed to mine sealing then progression to segregation of mine workings into zones. The purpose at each stage was essentially to control or extinguish the fire by reducing the oxygen concentration in the mine atmosphere to a level that would no longer support combustion.

Starting at the tailgate chute road in the recently active longwall panel, Zone E, shown in Figure 10, all headings had two ROCSIL® FOAM plugs installed with a cementitious plug in between. Once Zone E was segregated, WM progressed through all headings in the mains with ROCSIL® FOAM plugs to create Zone D, then another line of plugs to create Zone C and so forth through to Zones B and A.

![Figure 10: Underground treated active mine zones](image)

Given the scale and varying requirements of each plug, the project provided numerous challenges to the WM Operations Team. The project was an active underground heating event, requiring a quick response to minimise damage and maximise recovery. With exclusion zones in effect and no underground access available, WM utilised remote control machinery where possible.

With insufficient time to drill another borehole, only one borehole was available from surface to seam pumping. With no second borehole in proximity for a camera, WM were unable to observe plug construction. As a result, several boreholes were ‘pumped blind’ using the WM operational expertise from previous projects.

In addition, there was no casing on the lower 15 m of the boreholes as well as mesh and cable bolt obstructions. This prevented the mixing heads being able to be lowered into the roadways at certain boreholes. In these instances, where no suitable boreholes were available nearby they were re-reamed to ensure clear access for the mixing heads. There were also occasions of bore holes being drilled at an angle to contend with power lines in close proximity. For the sealing of the drifts at 1:4 and 1:7 grade decline, ROCSIL® FOAM was pumped building on itself to form a plug with no formwork. The fact that ROCSIL® FOAM fills in, under and around structure was essential to form seals where there was existing infrastructure such as the vent fan above the upcast shaft or around conveyor systems.

The checks performed post construction proved that each seal, even those pumped blind, provided excellent sealing (Figure 11). Many of the seals had been in place for in excess of eight months had minimal deterioration and no leakage. Each seal was subject to different conditions, including a pressure differential of approximately 3000 Pa between zones and...
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holding 2 m head of water. The plugs have shown to provide a durable and resistant seal over an extended period.

![Image of ROCSIL ® FOAM seal forming around mine infrastructure]

Figure 11: Example of a ROCSIL ® FOAM seal forming around mine infrastructure

THE FUTURE OF SURFACE TO SEAM REMOTE PLUGS

Overpressure rated ROCSIL® FOAM seals

WM engaged Burke Engineering Services and Inducta Engineering to complete a theoretical analysis using finite element modelling to determine the required thickness of a mine plug seal utilising ROCSIL® FOAM, to aid in assessing the feasibility of utilising the product for load rated seals in underground mine applications.

The single analysis for given roadway dimensions and imposed loading, was completed to determine the required plug depth. A preliminary seal thickness based on de-bonding shear failure of the interface between the seal mass and the surrounding roadway was calculated. A value of 16.2 kPa for shear adhesion between the seal mass and the perimeter strata, and a load factor of safety of 1.1 was utilised in the design calculations. This resulted in a preliminary plug depth of 17 m measured at the roof line.

A finite element model utilising three dimensional elements was constructed and pressure loading increased incrementally until the select failure mechanism occurred. In this case the failure mechanism was sliding along the contact surfaces with a maximum principal shear stress of 110 kPa. The surface where the pressure was applied initially deformed, sustaining principle shear stresses larger than 70 kPa, which indicated localised failure in the first third of the seal length. Other elements, deep in the seal, had shear less than 70 kPa at this point in the analysis. Subsequent to this, the bond failed along the contact surfaces. It has been assumed that this failure mechanism is stable. Figure 12 shows the conceptual shear failure mechanism development.

The analysis results were as follows:

- Failure criterion: Drucker-Prager (3D general elastic-perfect plastic yield surface) with control of max principal shear stresses Tau_{13}=|G1-G3|/2, (stresses Tau_{13} > 70 kPa are denoted by red dots) (see Figure 13)
- End of non-linear P-Delta analysis (failure): 769 steps, 39 PSI = 268.94 kPa = 5083 kN
- Maximum displacement: 0.85 m (sliding)
- Failure type: sliding along the contact surfaces, with max principal shear stresses in the body 110kPa.
The design seal depth of 17m placed into a roadway 5.4m wide x 3.5m high is structurally adequate to resist an imposed pressure load of 35 PSI with a factor of safety of 1.1.

Pre-Installed emergency sealing systems

In 2019, WM where engaged to provide a permanent remote emergency sealing system in the workings of a coal mine in the Hunter Valley, NSW. This pre-installed system provides a significant time reduction in the event of a mine fire or explosion, allowing remote plug seals to be installed in the best suited location with gas monitoring systems in fixed positions. This installation project is currently in construction phase. The emergency seal system consists of a remote ROCSIL® FOAM head being positioned 30 m inbye of each of the five portal entries. The portal position allows for drone camera technology to monitor the remote plugs whilst pumping is underway.

Each of the remote heads are fed using purpose-built and pre-installed hosing from a single 200mm cased borehole drilled 63.7 m down from the surface. The borehole casing is capped with a customised flanged manifold allowing the hosing to be permanently fixed to the borehole manifold, providing a 120 PSI rating. The borehole is located on the highwall, clear of the expected blast radius in the event of a mine fire or explosion as per mining regulations. The surface and mine infrastructure is designed significantly improve the speed of mobilisation, allowing WM to connect hosing and commence the emergency sealing sequence much quicker in the event of an emergency. Comparative to reactive emergency sealing, pre-installed systems are estimated to reduce plug installation times by 70%. In addition to reducing the speed of installation, pre-installed systems provide numerous additional benefits, including:

- Mine sealing plan designed for optimal outcome
- Remote seal locations in optimum locations
Pre-installed gas monitoring on inbye side of plug location
• Opportunity to skill workforce in sealing system
• Rocsil quantities known and understood
• Fewer boreholes reduces costs

To further reduce mobilisation time for surface to seam operations or emergency plug sealing, WM are developing a ‘Surface to Seam Relocatable Pumping Container’ as illustrated in Figure 14. This container has all equipment and consumables ready, and can simply be loaded onto the truck should the requirement for pumping arise. This further reduces the installation timeframe of seals which can be critical during emergency response installations.

![Surface to seam relocatable pumping container](image)

**Figure 14: Surface to seam relocatable pumping container**

### SUMMARY

ROCSIL® FOAM plugs are a proven system for the effective sealing of critical areas of the mine in-seam or remotely via boreholes. The material’s rapid setting and high expansion characteristics make it ideal for maximising roof-rib interface and for forming a seal around complex infrastructure. Importantly, WM provide technical expertise and experience to be able to apply the product safely and to a high standard in a wide variety of conditions. They recognise the importance of working with mining operations to provide pre-installed systems to rapidly respond to emergency events as well as the required engineering support in-keeping with legislative requirements.

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### REFERENCES


Te Kahui Whakamana Rua Tekau Ma Iwa, 2019b. Pike River Recovery Agency, Remote Ventilation Plug (ROCSIL) p.3