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RECOVERING FROM MAJOR ROOF CAVITIES ON THE LONGWALL FACE – A CURRENT PERSPECTIVE

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ABSTRACT: Recovering from roof cavities on the longwall face is an endemic aspect of longwall mining and this is especially the case today as longwall faces are wider and higher than they have ever been, yet powered support ratings are effectively technology constrained. There is little doubt that the ever-increasing dimensions of longwall faces are consequently increasing the likelihood of major roof falls occurring, especially in those more challenging geotechnical environments containing poor immediate roof conditions at depths of cover greater than 250 m. As a result, the efficiency and safety of longwall roof cavity recoveries is being given increased attention and is more relevant than ever to the success of the coal industry. This has led to the now almost universal use of cavity fills during the recovery of major roof falls on the longwall face, albeit that there is industry discussion regarding what constitutes ideal properties for cavity fill material. The paper discusses the geotechnical reasons why it is believed that major roof falls on longwall faces are becoming more likely with time and defines a conceptual geotechnical model for the cavity recovery process and the inherent ground control problems involved. Furthermore the paper considers the needs of mine operators during the cavity recovery process and how these can be best achieved. Specifically the paper contrasts foaming cements and phenolic foams as the two main generic types of cavity fill and ranks them according to such parameters as strength, foaming properties, rate of cavity fill, material cost, effectiveness, safety and overall cost effectiveness. The paper concludes that on a holistic basis, phenolic foams are the more suitable means of cavity filling on the longwall face, accepting that foaming cements are also an effective medium. However in the final analysis neither type of cavity fill is cost effective when compared to the benefits of preventing such cavities occurring in the first place through layout design, equipment maintenance and good operating practices and this is the major point of the paper.

INTRODUCTION

A primary focus of strata control practice at every longwall mine should be geared towards preventing major cavities on the longwall face.

The following controls are all of relevance and require due consideration in the longwall mining assessment and geotechnical design process:

- panel layout,
- panel width,
- extraction height and working horizons,
- depth of cover
- chain pillar design,
- overburden lithology and weighting,
- immediate roof competence,
- major geological structures,
- powered support rating and design
- powered support maintenance, and
- operational face management (including when to stop and apply pro-active remedial measures)

Frith (2005) provides a detailed commentary on many of the geotechnical aspects involved with instability on the longwall face, with the following summary points being given herein for reference purposes:

(i) certain geotechnical environments are more conducive to effective longwall extraction than others and some are totally unsuited,
(ii) longwall faces are generally getting wider and extraction thicknesses and depths of cover increasing,
(iii) powered support ratings are technology constrained,

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(iv) roof fall potential on the longwall face is strongly linked to face height and either face width or depth of cover (depending on the width to depth ratio of the panel), as well as the competency of the immediate roof measures,

(v) production requirements are ever-increasing and unit cost requirements are ever-decreasing.

Therefore, the coal industry is possibly at a point whereby major roof falls on the longwall face are becoming less tolerable, but conversely more likely in general terms. That is not to say that there will soon be "outbreaks" of major roof falls across the industry, but the geotechnical factors are being driven in a direction that in many instances will incrementally reduce roof stability on the face.

In the past twenty years our knowledge as to why major roof falls occur on the longwall face and more importantly how to go about preventing them, has improved significantly. This has been largely due to experience based improvements in powered support design, operational face management practices and knowledge regarding the role of the geotechnical environment. Nonetheless almost all longwall mines will from time to time be faced with a major cavity on the longwall face, such that its safe and efficient recovery becomes the key short-term focus of the mine.

Anyone who has been involved with longwall mining for more than 20 years will undoubtedly have war stories to tell regarding setting timber cribs in roof cavities above longwall powered supports. In fact, in the *Longwall Larrikins* section of the *International Longwall News* website, in response to the question "*what was your scariest time in a coal mine*?" Nick Fowler is quoted as saying "*on top of shields, timbering cavities. I hated it, we were mad and the use of foams, grouts and resins couldn't come soon enough*".

Current OH&S considerations would never allow such a practice to continue (even if someone mad enough was available to do the work!). However there is on-going industry discussion in regards to the safest and/or most effective/efficient method(s) by which major roof cavities can be recovered, this being largely based on two distinctly different commercial products, namely foaming cement (e.g. Tekfoam) and phenolic foam (e.g. Rocsil foam).

To provide credible comments on this subject, an appreciation of the geomechanics of longwall faces and the problems faced by operators once a major cavity has formed is required and this is a major focus of this paper.

ELEMENTS OF A MAJOR ROOF FALL CAVITY

Irrespective of the primary causes (eg periodic weighting, altered strata around a major fault etc.) of any particular major roof fall on a longwall face, the resultant face conditions (as seen in Figure 1) contain a number of common features. Figure 2 illustrates these features in schematic form for ease of illustration, which are as follows:

1. The coal face hading away from the AFC and powered supports, thus increasing the effective tip to face distance.
2. Highly fractured coal for some distance ahead of the face.
3. A large amount of broken material (coal and rock) with an angle of repose sat on the AFC. The AFC can be stalled under this load and/or contain large rock lumps that require blasting to allow conveying from the face.
4. Fractured and broken immediate roof measures just ahead of the coal face.
5. Large lumps of rock (that would require blasting if they fell onto the AFC) balanced precariously on top of the powered supports.
6. Poorly aligned powered support canopies.
7. The cavity itself with other potentially unstable pieces of material around its perimeter.

Assuming that the shearer is not buried under fall material and has been removed from the immediate fall area, it is either all or the majority of these features that the mine operator faces when attempting to recover the face from beneath a cavity and so re-establish normal face production.

Fig. 1 - Typical face conditions during a major roof fall

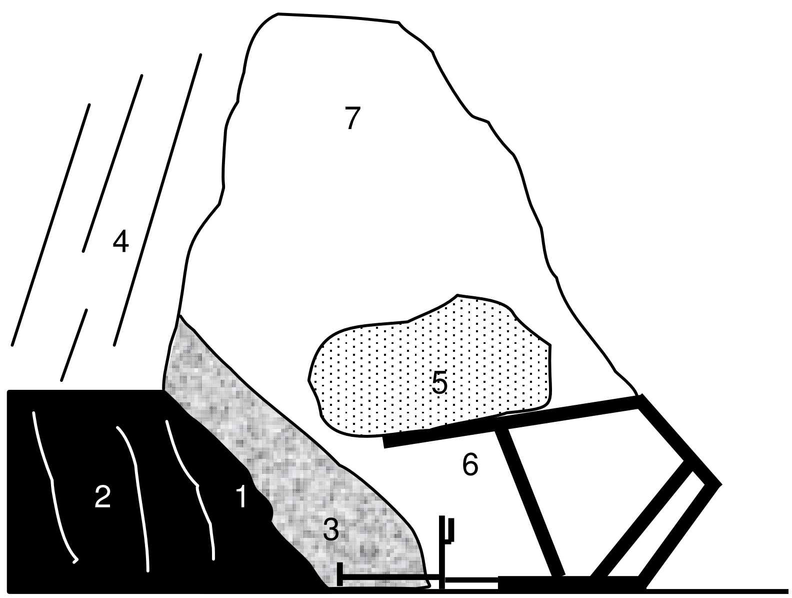

Fig. 2 - Schematic illustration of the primary features of a major roof fall on the longwall face

COMMON PROBLEMS EXPERIENCED DURING RECOVERY PRIOR TO THE USE OF CAVITY FILL

The scenario illustrated in Figure 2 was that commonly faced by longwall operators prior to the advent and use of monolithic roof cavity fill materials. As mentioned in the introduction, a traditional approach was to build timber cribs above the powered support canopies and this was a common practice for many years. However when this was discontinued due to safety concerns, face recoveries had to be undertaken without a cavity fill of any form in place and this led to a number of common problems as will now be described.

(a) AFC operational

The first requirement of the face recovery process is to ensure that the AFC can be run as and when required, as without it there is no ability to move the face forward. After a large fall affecting a significant length of the longwall face, it is common that the AFC is either overloaded and stalled (thus requiring the hand removal of large quantities of material from the AFC) or as a minimum, the breakage (often via blasting) of large rock lumps into smaller pieces is necessary.

Large lumps balancing on top of the powered supports commonly have to be dropped onto the AFC (to allow the powered support canopy to be re-aligned later on) and blasted to allow removal by the AFC.

Returning the AFC to an operational status in itself can be a time-consuming and very frustrating process, this reiterating the point that "prevention is undoubtedly better than cure" when it comes to this particular strata control problem.

It is noted that prior to the stabilisation of both the coal face and roof strata ahead of the face, running the AFC for any period of time was ill-advised as it inevitably resulted in more broken material falling down onto the AFC, potentially initiating more hand work or blasting of large rock lumps. The requirement at this stage in the process is for the AFC to be able to run, not to necessarily run it for any significant period of time.

(b) Stabilisation of fractured coal and/or roof strata ahead of the face

As just mentioned, running the AFC with an unstable coal face and immediate roof ahead of the face was usually counter-productive without cavity fill in place, as it commonly resulted in more broken material falling out on the AFC.

Methods of attempting to stabilise the coal face and immediate roof are either the injection of some form of consolidation agent (eg polyurethane or cement grout) and/or the installation of ground support elements.

By far the most common method of consolidation used is polyurethane (PUR) injection largely due to its expansive and adhesive (i.e. its sticks to rock and coal) properties (Figure 1 shows PUR injection lances coming out from the broken coal face).

Injected cement grouts are generally non-expansive and have little or no adhesive properties, so that they act only as fillers. In a situation whereby there is a large free face (i.e. the walls of the cavity itself), improved stability close to the free face is unlikely to be achieved by just void filling. Adhesive properties are required, hence the more common use of PUR in such situations.

However PUR does have significant downsides which can detract from its effectiveness in this situation, the major technical downside being almost entirely due to pumpable volume limits per hole as a result of the exothermic reaction and heat generated during its curing process. Due to legitimate concerns regarding the heat generated by PUR and its ability to potentially promote combustion of broken coal, regulatory authorities in Australia have imposed volume limits on the amount of PUR that can be pumped into broken coal at any one time. This is typically 200 litres per hole, although it is understood that the Queensland Mines Department has more recently removed this restriction in those situations whereby the PUR will not be injected into coal.

When one considers the likely volume of open voids within both the coal seam and roof measures ahead of the longwall face containing a major roof cavity, 200 litres per hole is a very small quantity indeed. Experience would suggest that in many cases, the void space present is anything but filled (as evidenced by a common lack of back pressure on the pump injecting the PUR), so that a significant portion of broken material remains isolated from a competent rock mass at the cessation of PUR injection activities.

Additional PUR injection campaigns can be undertaken to further fill void space, but only after a defined period of time to allow heat generated by the first injection campaign to be dissipated. This is often counter-productive as face conditions demonstrably deteriorate with time (see Frith and Stewart 1994) so that more strata fractures and resultant void space are being created during the waiting period.

Overall, PUR injection is anything but an ideal method of attempting to re-consolidate broken strata ahead of a longwall face, but at the current time it is the best method available. Whilst its success cannot be guaranteed, it is almost certain that attempting to recover a major cavity without it will substantially increase the likelihood of the cavity propagating further and so increase the delay to normal production being resumed.

In terms of installing ground support elements, by far the most common method is to leave the PUR hollow injection rods in the hole, these acting as a crude type of spile. These can be either steel or made of cuttable material, although caution is recommended in the use of steel injection rods as they will cause significant difficulties if they should end up on the AFC.

(c) Running the AFC

With the AFC able to be run and the coal and roof ahead of the face consolidated (within the limits of what can be achieved), the next stage is to run the AFC as part of clearing away the broken material and so attempting to move the face forward.

If the consolidation process has been fully effective, the AFC will remove the broken material from the face and no more lumps of coal or stone will fall onto the face. However this was rarely if ever the case prior to the use of cavity fill as strata consolidation was almost never sufficiently effective to allow this to happen. As a general rule, running the AFC to clear broken material from the face will simply cause more broken material to drop down, thus requiring that the process of lump breakage and removal recommence.

It is typically a very frustrating process of removing broken material and re-clearing the AFC before the face can be advanced in an attempt to cut under the broken roof ahead of the face and so form a stable lip that the tips of the powered supports can be set against.

(d) Establishing a competent lip

With the AFC running and clear of large lumps of broken rock, the face can be moved forward with the intent of having the shearer cut under the re-consolidated roof in an attempt to establish a stable lip that the powered support canopy tip can be set against.

This is rarely done for the entire cavity length in one go, the preferred method being to commence at either or both ends of the cavity and establish a lip adjacent to an already stable immediate roof. In this manner a fully stable immediate roof can be re-established over a small number of, rather than in a single shear.

As with the initial re-running of the AFC, the success or failure of attempting to re-establish a lip beneath consolidated roof will depend on:

(i) whether the immediate roof was in fact fractured and broken in the first place – NB just about all major falls have a finite outbye limit and a competent roof will eventually naturally form, regardless of what remedial measures have been applied, and
(ii) the effectiveness of the consolidation measures injected into the immediate roof material.

As already stated, due to the volume limits associated with the pumping of PUR in close proximity to broken coal, it is hit and miss as to whether all of the pre-existing void spaces in the immediate roof have been effectively filled and adjacent rock fragments "glued" together. With significant void space remaining and the presence of a significant free face (i.e. the cavity walls), re-establishing a solid lip that the tip of the powered support can be set against can be a difficult process, failure to do so often exacerbating the roof cavity and allowing further broken material to fall down onto the AFC.

Hence the process of fall recovery has to start again, frustrating mine operators and incurring further costs associated with both the application of remedial measures and lost production.

(e) Summary

If the described process and problems associated with recovering from a major roof cavity without void filler in place are reviewed on an engineering basis, the following conclusions can be readily drawn:

(i) PUR injection and support elements (i.e. spiles) in isolation cannot (and in fact should not) be relied upon to internally "glue" broken roof material together to form a re-consolidated roof mass that is readily suitable for re-establishing a competent lip on the face.

(ii) The key problem is that the roof cavity itself forms a very effective "free face" within the immediate roof horizon (i.e. effectively creating a rock cantilever ahead of the powered supports) that prevents any form of confining or stabilising horizontal compressive stress being generated. Therefore roof stability has to rely on the tensile strength of the immediate roof measures, which will be minimal if they contain open voids, as well as natural vertical joints etc.

(iii) Elapsed time undoubtedly works against longwall face conditions, so that the need to undertake several iterations of the recovery process by definition, makes an effective recovery harder to achieve.

(iv) Some of the required tasks in a major fall recovery are by necessity undertaken in close proximity to large amounts of rock material that is essentially, uncontrolled. Whilst the history of major safety breaches during such recoveries is quite reasonable (eg fatalities are an extremely rare event as are even major injuries), the fact remains that the recovery process exposes mine workers to higher risk levels than would be encountered in most other day to day mine operations. The reasonable safety record is possibly as much to do with the low time-based exposures (i.e. major fall recoveries do not occupy a large proportion of the available time on a longwall face) rather than the fact that it is a relatively safe operation to undertake.

When all of the relevant points are analysed, the conclusion can be quickly reached that effective roof fall recoveries should benefit significantly from the use of cavity filling. In the past this was achieved via the construction of timber cribs above the powered supports, which over time has been replaced by the application of pumpable monolithic type fillers.

The subject of cavity filling is therefore the next logical topic of discussion.

THE USE AND APPLICATION OF CAVITY FILLING

Figure 3 provides a schematic representation of the potential impact of a cavity fill as part of a roof fall recovery, it being a development of the earlier used Figure 2. Figure 4 and 5 contain photographs of the longwall face during a cavity fill application using Rocsil foam (courtesy of Wilson Mining).

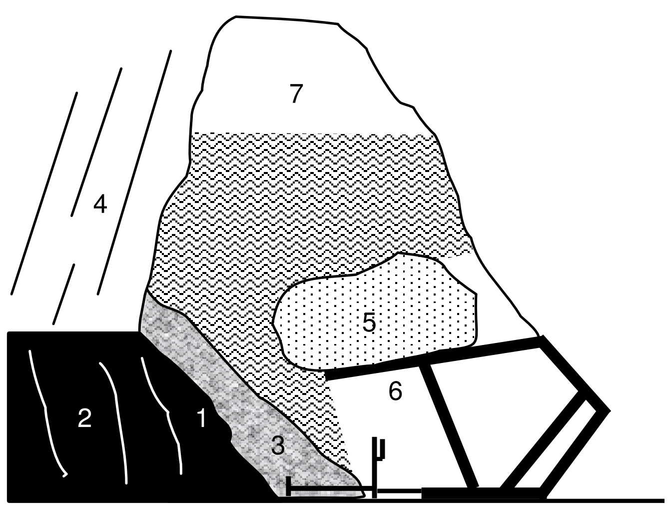

Fig. 3 - Schematic illustration of the impact of cavity fill in and around a major longwall roof fall

Fig. 4 - Rocsil foam having been applied to a roof cavity on the longwall face

Fig. 5 - A full face of Rocsil foam following a major cavity fill application

The main points that emanate from the use of a cavity fill are as follows:

- Fractured material in the roof measures ahead of the face is to some degree confined by the cavity fill material (especially foaming or expansive fillers), thus offering it some additional stability. Therefore when the AFC is run and broken material is removed from the face, the potential for more material to fall out onto the AFC is greatly reduced.
- Similarly, the fill material offers horizontal confinement to any broken reposed material that may want to flow onto the AFC as well as the coal face itself, providing additional stability to both.
- Any large rock lumps sat on top of the powered supports will to some degree by stabilised by the fill. Such lumps will also tend to be pushed backwards towards the goaf as the powered supports advance, rather than riding forward with the powered support. This process should eventually cause them to fall into the goaf behind the face rather than onto the AFC during recovery operations.
- The powered supports will have a roof horizon to set against before the tips reach the lip of the roof cavity. Even though they may not be able to be set at full set pressure (due to the inherent strength of the fill material – see later), there are advantages in having a flat, albeit false roof to work to when advancing the face forwards towards the roof lip.

When the ability of cavity filling to mitigate against the primary risks associated with the recovery of a major roof fall on a longwall face is considered, the potential benefits are self-evident and they explain why there has been such a rapid take-up of monolithic pumpable cavity fillers.

The question therefore remains as to which (if either) of the generic cavity filler types (foaming cements or phenolic foams) is best suited (in general terms) to effective roof fall recovery.

GENERAL COMPARISON OF FOAMING CEMENTS AND PHENOLIC FOAMS

In order to undertake a comprehensive comparison of these two generic cavity fill technologies, their varying attributes in the following areas need due consideration:

- Short-term or instantaneous strength
- Levels of foaming - impacting directly upon the quantity of material needing to be transported to site to fill a cavity of a given volume and also well as speed of cavity filling
- Shuttering requirements on the face
- Flow properties (in particular thixotropic properties that may limit the gravity driven flow of material into unwanted areas – eg AFC sigma section etc.)
- Environmental issues (eg noxious or poisonous fumes being emitted into the mine ventilation)
- Rates of bulk application
- Pumping distances

Each of these particular parameters will in some way impact directly or indirectly upon the three issues that will be of most interest to the mine operator:

1. Safety of operations
2. Effectiveness in terms of recovering the face
3. Total cost to the operation (including minimising production losses).

It is in this context that the varying attributes of foaming cements and phenolic foams will be compared, a summary being given in Table 1.

Based on the contents of Table 1 the following observations are made:

- Higher rates of fill emplacement and reduced bulk material usage being claimed by the suppliers can be logically linked to the higher foaming properties of phenolic foam.
- The quicker emplacement of phenolic foam cavity fill should have a positive impact in the context that face conditions typically deteriorate with time, especially in the early stages of a cavity developing. Therefore being able to attempt to re-establish a competent lip faster has geotechnical advantages.
- The faster curing time and thixotropic nature of phenolic foam are the logical reasons as to why shuttering requirements are significantly less as compared to foaming cements. This not only increases

- the speed by which shuttering can be erected but also effectively eliminates the need for mine operators to work on the AFC when erecting it.
- There is little difference between the two in terms of environmental issues. Both have safety issues to manage in terms of both handling and emplacing the material.
- With longwall faces becoming incrementally wider, the significantly increased pumping distance of phenolic foam should become an ever important advantages favouring the use of phenolic foam.

Table 1 - Parameter comparison between foaming cements and phenolic foams (based on publicly available information from product suppliers)

Parameter	Foaming Cements (eg Durafoam, Tekfoam)	Phenolic Foams (eg Rocsil Foam)
short-term strength	0.15 MPa (2 hours) 0.25 MPa (1 day) 0.40 MPa (7 days)	0.1 to 0.2 MPa at 10% deflection in 5 minutes at 15°C and 2 minutes at 25° C
foaming characteristics	12 to 14 times original volume 100 to 140 kg/m^3 of cavity filled nothing stated regarding positive pressures being generated on cavity walls	30 to 35 times original volume 40 kg/m^3 of cavity filled positive pressures generated against cavity walls
bulk rate of application	up to 24 m^3/hour (Poland) up to 76.5 m^3/shift (USA)	50 to 75 m^3/hour up to 300 m^3/shift
flow properties	nothing stated in regards to flow properties	thixotropic to minimise potential for AFC blockages due to flow of material under gravity
shuttering requirements	structural type frameworks to contain emplaced material during the curing process	brattice and pogo rods installed from behind the AFC spill plates
environmental	non-toxic and non-flammable, precautions required for various forms of person contact	FRAS, relatively benign when solid, precautions required whilst handling constituents and applying at face
pumping distances	up to 200 m	up to 600 m
other		exothermal reaction up to 187°F which is of no significant concern in coal mining

Cleary then in a number of technical areas, phenolic foam has distinct advantages as compared to foaming cements when used as a cavity filler on a longwall face. The one technical area where it may possibly be at a disadvantage is in the area of short-term strength and this is worth considering further before reaching any firm conclusions.

SIGNIFICANCE OF LOW SHORT-TERM STRENGTH OF CAVITY FILL MATERIAL

A modern-day longwall powered support will typically generate a canopy support load density of around 100 tonnes/m^2 or 1 MPa as a pressure. This is an average pressure across the canopy and depending upon the configuration of the powered support, peak canopy pressures can be at least twice this at 2 MPa and greater. Therefore for the powered support to generate its maximum load capacity against the roof, the roof itself must be able to accommodate such pressures without undergoing significant yield.

Examining the short-term strengths for both foaming cements and phenolic foams, it is evident that neither comes close to 1 to 2 MPa, even after seven days in the case of foaming cement. It is noted that shotcrete will only reach 1 MPa in around four hours, even if significant doses of accelerator are used.

Therefore on the basis that many successful longwall recoveries have been achieved with both cavity fill types, the question has to be asked as to whether the strength of the fill material relative to the maximum support load density of the powered is of any real significance to facilitating an efficient face recovery?

By reference to well established surface bearing pressure principles, an allowable bearing stress can be three to six times the UCS of the bearing material (Pells, Mostyn and Walker, 1998). This is due to the confined nature of a bearing surface and the fact that true uniaxial failure conditions cannot be generated within it. Therefore as an initial comment, the UCS of the cavity fill material does not necessarily need to be equivalent to the bearing stresses generated by the powered support canopy for the full load capacity of the powered support to be developed. Certainly load densities several times higher than the cavity fill UCS can potentially be generated into the roof when the powered support is set against cavity fill.

From a face roof control point of view, the role of the powered support during normal face operations is to actively reinforce the immediate roof measures, not necessarily those above it but certainly ahead of it. It does this by limiting roof convergence above the face (hence also reducing face spall) and limiting the effective tip to face distance by having the load centre of the canopy as close to the face as possible.

It is during normal face production that the full rating of the powered support is required; in particular it's setting load density and on-going hydraulic integrity so as to maintain leg pressures at or above set. However once a major roof cavity has formed (as shown in Figure 2) and the face has been stood for a period (so that a significant portion of the roof convergence that will occur has now done so), the need for active reinforcement of the immediate roof ahead of the face is significantly reduced. The cavity itself (even when filled) also limits the powered support generating active reinforcement action in the strata ahead of the face.

Based on the previous comments it makes good sense that the low strength of foaming cavity fill in comparison to the load capacity of the powered support, does not significantly detract from the efficient recovery of the face. During recovery operations the immediate roof ahead of the face is typically injected with PUR to try to re-consolidate it and the fill material offers some confinement to the walls of the cavity to minimise loose pieces falling out on the face. These are the main short-term controls against further roof instability once the face starts cutting again.

During the fall recovery process the powered support often only acts as a means of holding back goaf material from the working areas and pushing over the AFC to allow the face to be advanced when attempting to re-establish a lip. Neither of these functions relate to the powered support being able to exert its full load capacity against the roof, goaf material behind the supports allowing the AFC to be pushed over with the canopy off the roof in fact.

When the differences in short-term strengths between foaming cements and phenolic foams (in relation to the full load capacity of the powered supports) are considered, along with the role that the powered support plays in the recovery process, it is concluded that there is little to choose between the two cavity fill types. Other properties are of far greater significance as has been discussed previously.

ECONOMIC EVALUATION

One comment that is often made by mine operators is that phenolic foams are "very expensive in comparison to foaming cements". Therefore it is worth undertaking a basic economic evaluation of a major longwall roof fall and its recovery to put this aspect into a more realistic context.

In a high production longwall operation, time is by far the most significant factor when it comes to overall economics. Production losses of $1-$2 million per day (i.e. 20,000 tonnes x $50-$100/tonne) are commonly quoted if one days longwall production is lost, but such numbers are possibly misleading when considering the financial impact of unplanned downtime.

Firstly the coal not mined during the production delay will be mined eventually, such that the loss is NPV based. There will also be other costs that are not incurred as a result of the longwall not producing (eg washing, rail freight, royalties), but these are included in the assumed \$50-\$100/tonne sale price.

It might be assumed for example, that the longwall face being stopped for one day will typically result in fixed costs of say \$200,000 (wages, power, depreciation etc) being incurred that can never be recovered. This is assessed to be a more meaningful method of examining the financial impact of one days lost production at a high production longwall mine than simply examining revenue losses in their totality.

All of the available technical information demonstrates that phenolic foams can be applied to cavity filling at a faster rate than foaming cements. This is due to both the less onerous shuttering requirements and most significantly, the higher foaming rate so that a larger void is filled for each unit of raw product and unit time.

Based on recently obtained raw product unit cost estimates for both phenolic foam (i.e. Rocsil) and foaming cement, combined with quoted foaming ratios, it is evident that phenolic foams (at around \$1000/m^3 of filled cavity) are approximately 2.5 times the cost of foaming cements (at around \$400/m^3 of filled cavity). Hence the common statement that phenolic foams are very expensive.

For a large roof cavity of say 750 m^3 it is estimated that a phenolic foam system could effect a complete fill (including set-up, emplacing shuttering etc.) in around four days, whereas foaming cements would take at least two if not three times this length of time. This has both geotechnical (i.e. face conditions will tend to deteriorate with time, especially in the early stages of a major fall) and also cost implications, the latter of which will be considered in more detail.

If the mine site costs associated with longwall face downtime are also considered (as detailed above), it is evident that the total incurred cost for the phenolic foam cavity fill at around \$1.55 million (750 m^3 x \$1000 + 4 x \$200,000) is in fact significantly lower than that for foaming cement at \$1.9 - \$2.7 million (750 m^3 x \$400 + 8-12 x \$200,000).

Therefore in order to realistically evaluate the relative costs of foaming cements and phenolic foams, it is necessary to factor in the difference in mine site losses that are incurred due to the varying rates at which the two products can be applied.

Clearly there will be other methods by which the financial impact of a major roof fall can evaluated (eg the difference between the profit with the longwall operating as compared to the loss incurred with it stopped). The important point to make is that "value for money" should be the determining factor, not simply material cost.

CONCLUSIONS

The recovery of large roof cavities on the longwall face demonstrably benefits from the provision of some form of cavity fill prior to attempting to move the face forward and re-establishing a stable lip along the face. Historically this was achieved via the erection of timber cribs above the powered support canopies and this has evolved to the remote application of monolithic cavity fill materials.

The cavity fill material primarily acts to confine the perimeter of the cavity and so attempts to hold loose material in place that would otherwise fall out onto the AFC and so impede the recovery process. It does so largely through foaming action that allows the foam to fully fill the void and potentially offer an active confining pressure to any surrounding marginally stable rock.

In contrast the strength of the fill material is a secondary issue as utilising the full supporting capacity of the powered supports is significantly hindered by the presence of the cavity void in the first place and offset by the almost universal use of re-consolidation measures (eg PUR injection) in broken strata ahead of the face. Nonetheless it should not be assumed that the powered support is limited to load densities equivalent to the UCS of the cavity fill material, as the bearing type nature of the problem dictates that a bearing material (i.e. the cavity fill in this case) can accommodate bearing pressures several times its own UCS.

In comparing the relative merits of foaming cements and phenolic foams, as a general rule it is apparent that phenolic foams such as Rocsil are more suited to rapid, safe and effective roof cavity recoveries, this being largely due to their higher foaming ratios and reduced shuttering that is required to contain the fill material. This is not to say that foaming cements cannot be used to recover such cavities (as indeed they can), simply that the properties of phenolic foams are more suited to the task.

In terms of engineering the most effective cavity recovery possible, it is important to evaluate both the cost of cavity filling and technical attributes together, in particular ensuring that the true cost to the operation includes an allowance for the different time periods taken to effect the placement of the cavity fill. Based on some broad assumptions made herein, it appears that despite being a more expensive raw material, the overall economics of phenolic foam are generally better than foaming cements.

Overall there is no guarantee that the recovery of a major roof cavity on the longwall face will be successful at the first attempt, largely as the control of a failed and broken rock mass contains a much greater level of behavioural uncertainty than an intact mass. Cavity fills are one of a series of controls that aims to improve the odds in favour of the mine operator and industry experience indicates this to be a largely effective strategy.

In the final analysis the most economic strategy of minimising the economic impact of major roof cavities on the longwall face is to maximise the effort to prevent them in the first place. Many of the controls, both geotechnical and operational, are well understood and including them within mine planning and operational management should be a key focus if the true cost of remedial measures is to be minimised to the lowest practical level.

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