IMPROVED SAFETY AND EFFICIENCY WITH GROUND SUPPORT AND REHABILITATION PRACTICES AT THE X41 COPPER MINE, MOUNT ISA MINES.

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Abstract

Primary ground support at the X41 Copper Mine is installed as part of a one pass mining system which provides immediate support to underground personnel. With such practices, safety standards have been improved with reduced mining risks and hazards. An additional benefit to these one-pass systems, has been an improvement to productivity. Efficiencies in the installation of secondary reinforcement during rehabilitation have been achieved with the successful reduction in cement grout curing times. The high standards of safety have not been compromised.

Introduction

Mount Isa Mines, located over 950 km West of Townsville, currently operates four mines in North West Queensland, Australia. Mining base metals copper, lead, zinc and silver, Mount Isa Mines is one of the three largest producing lead and silver mines in the world and among the top ten producers of copper and zinc.

Primary ground support practices at all the Isa and George Fisher (formerly Hilton Mine) operations adopt fully mechanised one pass support systems, which provide immediate support. The systems also include the installation of sheet mesh where applicable. Such practices reduce the residual mining risks and hazards (elimination of working under unsupported ground, working from height, performing arduous tasks, and reduced lengths of time exposed to heat), with the additional benefit of improved productivity.

The primary ground support systems currently in use across all the Mount Isa Mines operations consist of split sets and ungrouted PAG bolts for short-term support requirements. Fully encapsulated resin anchored bolts and cement grouted PAG bolts are used for the long-term support. The PAG bolt is a point anchored dywidag bolt which provides immediate support via a specially designed expansion shell. The available equipment fleet used to mechanically install the primary ground support is made up from Tamrock Powerclass Jumbos, Tamrock Robolters and Atlas Copco Boltecs. Split sets, ungrouted and fully cement grouted PAG bolts make up the primary ground support elements, which are installed by Tamrock Jumbos and Robolter at the Copper Mine.

Secondary reinforcement installed across the lease consists of either single or twin strand Garford bulb cable bolts. Cable bolts are either installed manually by hand or mechanically with the use of the Tamrock Cabolter (the Copper and George Fisher Mines currently have Cabolters operating underground).

X41 Copper Mine Ground Conditions

The Copper Mine extracts ore from two orebodies located in the massive altered shale sequence referred locally as silica dolomite. The shallow dipping 1100 Orebody is the major orebody source with a strike length of over 2 km, a maximum width of up to 500 metres and a height of 300 metres.

Ore is extracted from the 1100 Orebody employing the sublevel open stoping (SLOS) mining method, with the open voids filled with cemented backfill to allow for future adjacent pillar recovery. Stope dimensions are typically 40 metres by 40 metres in plan, with full orebody height extraction in a single stope (40 to 250 metres).

A series of South West dipping (40º to 70º) faults cut through the Copper Mine orebodies. These faults are continuous and range in thickness from 2 metres to 20 metres. Development mining has attempted to crosscut these structures to reduce the affects of poor ground conditions associated with the faults. In the transverse pillar areas, these structures have been repeatedly rehabilitated after adjacent stope firing and filling events. Some areas have formed into large cathedral shaped openings (see Figure 1). Maintaining access through these areas for subsequent stoping can be a slow and costly, but necessary, process.

Figure 1: A 'cathedral' profile following rehabilitation.

The common mode of ground failure observed at the Copper Mine is associated with the presence of faults and fault movement, with fault movement appearing to be related to post production firings. Such an observation has been re-affirmed with an analysis of falls of ground.

The common ground failure mechanism consists of rock unravelling from around the installed support and reinforcing elements, rather than the steel failing itself (Figure 2). This would be an indication of inadequate support. There are no common predominant joints sets that have been attributed to a re-occurring type of ground failure mechanism.

Ground Support and Reinforcement

The purpose of ground support and reinforcement is to maintain excavations open and safe for their required life span and ultimately, to allow for the safe, maximum extraction of producible ore (prevent injury to personnel and protect equipment from damage). This can be achieved through a combination of design of relatively stable excavations, with the correct design and installation procedures for internal and external support and reinforcement systems.

As ground support elements, split sets, PAG bolts and sheet mesh will adequately retain near surface failures. Cable bolts provide effective reinforcement of large spans and deep wedges where normal rock bolts would prove geometrically inadequate due to their short embedment lengths.

Each of the Mount Isa Mines operations requires its own ground support and reinforcement systems, which are tailored to the individual ground conditions and operational requirements.

This offers the best technical and operational solution. The most effective use of ground support and reinforcement is achieved by matching the ground support to the exposed ground conditions.

Figure 2: Unravelling of ground from around twin strand Garford cable bolts installed in the sidewall. Poor ground conditions associated with the J46 fault.

For the requirements of the X41 Copper Mine, the ground support and reinforcement systems have fulfilled the following characteristics:

- Recognise rock mass failure modes during bolt selection
- Ground support design should match scheduled life, size and use of excavation
- Minimise the potential of working in unsupported ground
- Minimise total operational costs (Total Cost = Bolting Cost + Opportunistic Cost)
- Reduce the cycle time for face development (reducing bolting cycle)
- Minimise the residual risk
- Bolting system should be simple, robust and easily installed

In order that the ground support and reinforcement requirements continue to be met, several procedures have been implemented at the Copper Mine. Individual development headings are inspected by the X41 Copper Mine Ground Support Engineer. The recommended primary ground support requirements are discussed with, and then issued to, the Development Superintendent and Supervisors. The inspection considers the exposed ground conditions and the suitability of the installed support system, the expected change to ground conditions (associated with stope firings and filling), and the need for any reinforcement systems. Future ground conditions are predicted, with any potential problems highlighted.

In addition to these inspections, a feedback process from the operators has been achieved through the use of the 'X41 Copper Mine Ground Condition Risk Assessment' sheet. The risk assessment sheet considers the general ground conditions, time spent mechanically scaling (indicating the level of fall off) and the potential for wedges to exist in the development heading.

These sheets are completed for each heading by the Development Miner and returned to the Development Supervisor and Superintendent. The risk assessment sheet was developed and implemented to allow for a quick identification of changing ground conditions and the possible need to change the primary ground support design.

Split Sets and Mesh

The split sets used at the X41 Copper Mine are 2.4 metres long and 47 millimetre in diameter. The split set is forced into a drill hole of smaller diameter, which provides an outward radial force, inducing friction between the split set and rock to provide the support.

The split set provides an effective back and sidewall support in most ground conditions at the Copper Mine, particularly in the fissile shales and sheared rock. In moving ground, the split set has the ability to deform, providing support along its entire length.

Mesh installation during the ground support cycle is highly desirable, both in terms of safety and cost (elimination of a second pass). Rolled arc mesh was originally installed from a Getman platform, which exposed employees to hazards such as manual handling, fall from height, and hot work conditions. With the advent of mechanisation and sheet mesh, such practices no longer exist.

As a passive form of support, meshing forms an integral part in providing a safe working environment. Mesh provides surface restraint at the exposed excavation boundary. The sheet mesh used at the Copper Mine is a 5.0 mm gauge wire, with 100 mm square apertures. Overall dimensions for each sheet is 2.4 metres wide and 4.0 metre long.

Mesh is not designed to carry excessive loads of broken rock, and can be easily damaged by flyrock from blasting when installed very close to an active face. This is particularly the case when the sheet mesh has not been tightly installed against the rock face. However, mechanically installed sheet mesh can usually be installed tight against the rock face (see Figure 3). With such a configuration, even though the ground may have failed, the failure is arrested from progressing upwards - there is no space for the failed rock to occupy, and therefore no means for the failure to propagate.

Figure 3: Sheet mesh and split sets installed tight against the back of a development drive.

From an analysis of falls of ground at the Copper Mine since 1997, it was seen that 55% of all falls were in the range <1 to 5 tonnes in size. The strength of sheet mesh, used in combination with the primary support elements, will support loads of up to 5 tonnes (provided the sheet mesh is installed tight against the rock surface). Since the introduction of sheet mesh, the number of falls up to 5 tonnes in size has reduced.

The Point Anchored Grouted Bolt (PAG Bolt)

The PAG bolt is a standard dywidag bolt with a specially designed expansion shell (see Figure 4), which was developed ‘in-house’ at Mount Isa Mines. The bolt assembly is mechanically installed in the hole by means of the Tamrock Robolter. With the modifications to the shell anchor, immediate support can be generated even in a post cement grouted hole. The PAG bolt is now commercially available through ANI Arnall, under the product name MP bolt (Mechanical Point anchored bolt).

Figure 4: The PAG bolt.

Prior to the introduction of the PAG bolt, fully cement grouted rebar or dywidag bolts were the preferred ground support system in use across the Isa and George Fisher lease. Such support systems have been used extensively, with proven reliability through many years of continuous use. However, fully cement grouted rebar and dywidag bolts do not provide immediate support, are installed by hand and require a three-pass system to be installed. With the introduction of fully mechanised bolting rigs, a move was made to improve safety and productivity of the ground support installation process. With the limitations of installing grouted rebar and dywidag bolts, alternative ground support systems were investigated.

These investigations were initially based around the concept of the Kiruna Bolt, which was developed at the Kiruna Mine in Sweden. The Kiruna bolt consists of a standard rebar, with a slot cut into one end into which a 'Kiruna bolt wedge' is inserted. The rebar and wedge are inserted into a pre-cement grout filled hole, with the bolt and wedge combination driven home by means of percussion from the bolting rig. The wedge then spreads the slotted end of the bolt, which then engages against the sidewall of the hole. Such a system provides an immediate anchor support until the cement grout cures. The plate can be installed immediately after the bolt and wedge have been fully inserted to the back of the hole, resulting in a one pass bolting system.

Underground and surface trials were carried out at the Mount Isa Mines operations with the Kiruna bolt. However the wedge anchor design was found to be unreliable for the varying ground conditions across the mining lease (Potvin et al, 1999). The trials found that the Kiruna bolt was particularly sensitive to installation procedures and ground conditions.

Several modifications were then made to the design and shape of the wedge in order to improve the reliability of the anchoring system. The angle, thickness and length of the wedge were all key design parameters. Although some improvement of was achieved, the wedge mechanism did not provide continuous reliability in varying ground conditions.

Further trials focused on a specially designed expansion shell anchor in order to improve on the unreliability of the various wedge designs (Tyler, 1999). Past attempts to push expansion shells into cement grout filled hole proved to be unsuccessful. As such, the point anchored expansion shells were trimmed down in order to allow the cement grout to be displaced as the bolt and shell was inserted into the pre-grouted hole (see Figure 5).

Figure 5: Modified expansion shell anchor for use with the PAG bolt. Note the differences between the trimmed and standard barrel.

Full-scale underground trials of the PAG bolt were undertaken at the Copper Mine. The trials revealed that (Tyler, 1998 and 1999):

- the modified shell anchor can engage when installed in a cement grout filled hole.
- the PAG bolt can be mechanically pushed through a thick grout (a W/C ratio of 0.4 or less).
- when pushed through cement grout filled steel tubes, full column encapsulation of the PAG bolt was achieved.
- push testing of 50 mm sections of cement grouted PAG bolts indicated little variation in the strength of the grout along the length of the bolt and shell.
- pull testing of cement grouted PAG bolts indicated full mobilisation of the ultimate tensile strength of the dywidag bolt occurring at embedment lengths of 250 mm or greater.
- pull testing of dry PAG bolts in both poor and good ground conditions resulted in loads in excess of 9 tonnes (testing taking place immediately following installation).

Cable Bolting

It is standard practice at the Copper Mine to install cable bolts in the backs of turnouts and intersections and areas identified with potential wedges. Over the years, there have been different types of cable bolts installed at the Copper Mine, namely plain strand, Garford and combination cables.

With regard to the different types of cable bolts that can be used underground, a modified geometry cable bolt, in most instances, is a better option than a plain strand cable bolt. At present the Garford bulb is the best and cheapest form of modified geometry cable bolt available on the market. Modified geometry cable bolts generate significantly higher bond strengths when compared to the plain strand cable bolt. As a result, a higher load carrying capacity is developed in the system, equating to a reduction in the number and length of cables that are required to carry a simular load (when compared to plain cables).

The bond strength of a cable is defined as the resistance to slip (at the cable/grout interface). With the Garford bulb, there is greater interaction between steel and grout, resulting in increased mobilisation of the strength of the steel (it is easier to pull out a plain strand cable from the grout than it is with a Garford bulbed cable.

Pull testing carried out at Mount Isa Mines has indicated a 40% improvement in the bond strength of cable bolts, if Garford bulbs are placed on the cable at 0.5 metre intervals. This means that a plain strand cable bolt tends to fail in pull tests at 15 tonnes and the Garford bulbed cable bolt will fail at around 25 tonnes. The Garford bulbed cable bolt will therefore carry greater loads up to the tensile strength of the steel.

Rehabilitation

The ground support and reinforcement that is usually installed as part of the rehabilitation process involves a combination of Garford cable bolts and steel fibred shotcrete (see Figure 1). Depending on the exposed ground conditions, split sets or dry PAG bolts and sheet mesh are installed prior to the installation of the cable bolts and shotcrete.

Because of the nature of rehabilitation and the associated ground conditions, the standard practice of rehabilitation is to install only two rings of cable bolts within the 12 hour cement curing period. Such a practice is required for safety reasons. However, the unavoidable draw back is the inefficient utilisation of manpower and equipment. Trialing of various Sika Australia Pty cement grout admixtures was initially instigated as a result of investigating possible improvements to overall mining and ground support cycle times. This would be particularly attractive with cable bolting during rehabilitation.

Underground trials were carried out at the X41 Copper Mine investigating curing times and uniaxial compressive strengths (UCS) of cement grout with the various admixtures (Thin, 1999a). The trials involved pull testing rebar bolts and cable bolts from cement grout installed in situ, with the addition of either the high early age strength admixture (Sikament®-HE

200NN) or the hardening accelerator admixture (Sika Rapid®-1 and Sika Rapid®-2).

For comparison purposes, with each variation in cement grout mixture and curing time, pull tests were performed on 'control' rebar and cable bolts from a standard cement grout mixture (cement and water only).

With the pull testing, testing continued to failure (where failure was defined as de-bonding between the bolt or cable and grout interface). A failure criteria of less than 5 tonnes was set with the pull testing of the cable bolts. Once cement grout has cured, the cable is then jacked to between 3 and 5 tonnes. Therefore, an acceptable reduction in curing time would only be achieved if the pull testing exceeded 5 tonnes. The cement grout UCS tests represented strengths after 7 days.

Although the trials considered both rock bolts and cable bolts, emphasis was placed on the use of the admixtures with cable bolts as it was believed that such a combination would have greater benefits, especially when used by the Tamrock Cabolter.

Sikament®-HE 200NN was the preferred admixture trialed because of the water reducing and high early strength properties of the admixture. Sikament®-HE 200NN is a liquid admixture that combines the advantages of rapid hardening technology with a high range water reducer super plasticiser. It can be added to cement grout to produce a high early strength grout and maintain flowability characteristics.

Sikament®-HE 200NN does not influence the setting time or workability of the grout. It is not a set accelerator, but a hardening accelerator that super plasticises grout. Sikament®-HE 200NN is classified as non-hazardous according to Worksafe Australia.

Prior to the introduction of Sikament®-HE 200NN, PAG and cable bolts were fully encapsulated with cement grout (general-purpose cement), with a water / cement ratio of 0.35 and 0.4 respectively. With the previous Safety, Health and Environment (SH&E) Ground Support Standards, ground support and reinforcement which involved the use of cement grout had to be allowed to cure for a duration of at least 8 hours for rock bolts and 12 hours for cable bolts before any further mining activity could take place.

With the case of cable bolts, underground personnel were not allowed to travel or work under an area with newly installed bolts until the 12 hour curing cycle time had lapsed. After these curing times, the relevant accessories would then be installed before the plate load was applied.

From the underground trials conducted the optimum mix design was developed. With this design, it was found that after a period of 4 hours, pull testing of the cables resulted in a load of 13 tonnes without failure (Thin, 1999b). This implied that the curing time of the cement grout, with the addition of Sikament®-HE 200NN, could be reduced from 12 to 4 hours.

The overall results of the uniaxial compressive strength showed that there was no compromise in the quality of the cement grout with the addition of the admixture. Average UCS values of 55 MPa were being developed after 7 days of curing (historical values of the uniaxial compressive strength of cement grout across the operations have averaged 45 MPa after 7 days).

With significant reductions in cement grout curing times, mechanical equipment such as the Tamrock Cabolter and its operator, work continuously during rehabilitation (rather than the limitation of only 2 rings per 12 hours) – drill and grout two rings of cable bolts in the back, then drill and grout the sidewall. After such a cycle, four hours would have lapsed, allowing the operator to safely advance forward into the newly reinforced ground. The cable bolt accessories are then installed in a campaign fashion.

Conclusions

- The practice of installing primary ground support and secondary reinforcement systems has improved the safety standards at X41 Copper Mine.

- All primary ground support systems currently in use at the X41 Copper Mine allow for a one pass mining and ground support system and provide immediate support.
- The potential risks and hazards associated with the installation of ground support and reinforcement have been reduced as a result of mechanisation.

- All the primary ground support systems can be mechanically installed with the available equipment fleet, thereby eliminating the need for people working under unsupported ground, working from height, performing arduous tasks and reduced exposure to heat.

- The number of falls of ground have reduced due to improved support and reinforcement practices.

- The primary ground support systems currently installed at the Copper Mine can generally support the overall exposed ground conditions. This is re-affirmed the reduction in the number of falls of ground since their introduction.

- Cable bolts can be installed mechanically (and thus remotely) with the use of the Tamrock Cabolter. This is of particular significance when dealing with ground rehabilitation.

- Reduced cement curing times have resulted in an efficient process associated with ground rehabilitation, without compromising the high standard of safety.

References

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