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Evolution of grouting methods for dynamic supports in broken ground

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ABSTRACT
Rockbursts are seismic events of deep or high stress mines that often lead to damages to the ground support system. Even when the rock at the contour of the excavation is broken, rockbursts can occur behind this softened zone and further damage the support system. In these broken conditions, the ductility of the ground support system is still critical, but the installation of grouted tendons is rendered tedious or very inefficient by the problems associated with inserting cartridges of resin inside the boreholes. The same practical issues with resin cartridges arise while bolting in squeezing ground conditions or in damaged pillars.
This study aims to investigate alternative methods of grouting dynamic rockbolts by methods other than the polyester resin cartridges traditionally used by the mining industry. In particular, the use of injected resin grout for reinforcement is analysed in the field. The static anchorage capacities of the injected resin is evaluated using D-Bolts and Self-Drilling Bolts (SDB) by the mean of pull out tests, and compared with the performance of similar bolts anchored with resin cartridges in hard rock conditions, and grouted with cementitious grout. Drop tests evaluation of the resin were postponed due to scheduling difficulties.
The study also includes a field evaluation of the installation method, sequence and bolting speed, for typical length tendons. The implications of the installation with injected grout on the resulting capacity and estimated safety performance are discussed.

1. BACKGROUND

Rockbursts are seismic events of deep or high stress mines that often lead to damages to the ground support system. Even when the rock at the contour of the excavation is broken, rockburst can occur behind this softened zone and still damage the support system. In these broken conditions, the ductility of the ground support system is still critical, but the installation of grouted tendons is rendered tedious or very inefficient by the problems associated with inserting cartridges of resin inside the boreholes (Pritchard and McClellan, 2011; Simser and Pritchard, 2012).

Field studies performed by Normet have established that the typical time to install a fully grouted 2.4 metre long rock bolt with resin cartridges in very broken ground can vary between 5 and 25 minutes. Beside the very low productivity of such an operation, there is always the possibility that the anchorage may not be continuous along the bar, and that the bolt performance can be negatively affected by a poor anchorage capacity and risks of corrosion. Because safety factors rely on an adequate encapsulation of the rock bolt, uncertainty on the grout continuity is a major parameter that will affect the safety of the ground support.

Ground failures and rock ejection due to incomplete encapsulation of the rockbolt are rarely published outside of a mining organization, but have been observed (Figure 1). As mines operate deeper than ever before, the rockmass is increasingly under stress and broken, and at risk of experiencing severe energy release events. While the immediate contour of excavations rapidly deteriorates, leading to a crown of broken ground, the intact rock is still at risk for strain bursts. Moreover, fault slip bursts can occur at proximity of broken ground and lead to potentially serious damages to infrastructure and personnel injuries.

Cost considerations have often relegated pumpable resins to very specific applications, but improvements in formulations and manufacturing have led to basic volumetric cost similar to polyester resin cost.

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Figure 1: Bolt and rock ejected during a rockburst due to poor encapsulation of the rockbolt in resin.

The reconditioning of damaged excavations and pillars is also an operation that is almost always performed in broken ground conditions. Open fractures hinder the insertion of resin cartridges, and increase the time and costs related to the rehabilitation of excavations. Increases of up to 30% of the resin costs due to resin loss or cartridges deterioration have been observed in the field. As well, the uncertainty of full encapsulation creates a potential hazard that cannot be evaluated by pull testing or field observation, and situations like the one described at Figure 1 can occur.

Very often, the use of friction bolts is the only available solution to allow adequate anchorage of the ground support system (Yao et al, 2014); albeit not a permanent solution, it provides consistent, although limited, tendon capacity in difficult ground conditions. The use of injected resin was documented by Pritchard and McClellan (2011).

2. DIFFERENT ALTERNATIVES

As part of Normet's development projects, a polyurethane resin grout specially formulated for rockbolting was developed to be used in underground mines and tunnels. After laboratory installations and exploratory testing were successful, the resin was then to be tested in underground mine conditions. It was necessary to evaluate the environmental and mechanical performance parameters in order to assess the potential of the resin as an alternative to polyester resin cartridges and cementitious grout.

The resin formulation leads to a highly thixotropic behaviour that prevents the resin from flowing out of vertical upholes after injection is completed. The resin becomes thick in a matter of seconds and in most case will not flow readily through fissures less than 25 mm wide. In case of larger fissures, the resin will flow out but migration will be halted by the thickening process and resin loss will be minimized and the borehole completely filled. Once the movement of the resin slows down, the setting process begins. It should be noted that in those open fissures cases, polyester resin in cartridge will also flow out of the holes due to centrifugal force created by the spinning of the rockbolt inside the hole, and it is not possible to know what is grouted and what is not.

A first test using a mechanized bolting rig was performed in an underground testing facility in Finland (Figure 2). The operation was a success and the bolts were pulled up to a load of 170 kN (yield load of the D-Bolt 20 mm). The process was then reviewed to be used in North American mining operations, and the testing continued in Canada and USA.

Figure 2: Drilling and injection of pumpable resin using a fully mechanized bolting rig.

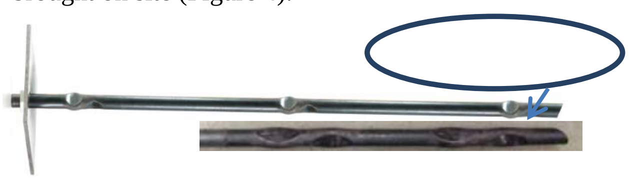
The approach of resin injection in Canada was first evaluated under a reconditioning framework, with less time pressure on the operation than regular development bolting. A slower set resin was used and the holes were drilled previous to the injection and bolts installation, allowing us to measure full exposure to the chemicals and to perform bolt tensioning shortly after installation. The site chosen for this first field testing was the Norcat test mine, located in Onaping, Ontario. The measurement of the exposure levels was performed by Workplace Safety North, a Division of the Government of Ontario Ministry of Labor.

The resin injection application was then expanded to the usage in extreme ground conditions, where Self-Drilling Bolts (SDB) are nearly the only efficient way to install tendons. The underground mine site was located in Carlin, Nevada.

3. FIELD TESTING

3.1 D-Bolts Application

The first field evaluation included the injection of resin and the installation of D-Bolts, a high strength yieldable tendon (Figure 3). The D-Bolt is used extensively in Ontario and in Sweden, as a highly energy resistant ground support. The objectives of the tests were to evaluate if the rockbolts could be installed and tensioned within a reasonable amount of time, and if the loading capacity was only realistic for reconditioning or if it allowed a normal bolting sequence to take place. For this small scale test, a small air operated pump was used, and 22 kg containers of the resin materials brought on site (Figure 4).



a) D-Bolt and plate

b) Self-Drilling bolt and accessories

Figure 3: Normet bolts: a) D-Bolt rockbolt (top) used as dynamic support in underground mines, and b) Self-Drilling Bolts (SDB) used in extremely broken ground conditions.

Figure 4: Pump and resin containers used during the test grouting of the D-Bolts.

The test with D-Bolts was performed with manual drilling equipment, i.e. stoper and jackleg drills. For the sake of simplicity, the holes were pre-drilled, which allowed to focus on the specifics of installation and air quality monitoring. A total of 18 bolts were installed on the site, 6 at a lower wall level and 12 in the back, from a scissor truck (Figure 5). The bolts in the wall were used to get comfortable with the operation and the air monitoring instruments and procedures. Then for every hole in the back, resin was injected and a rock bolt was inserted immediately. The operation took approximately 10 minutes for the 12 bolts. Then, all the rockbolts were immediately tightened to approximately 150 lbs-ft; tensioning delay from installation varied from 10 minutes to approximately 5 minutes. From Van Ryswyk (1983), Tadolini (1991) and Barry et al. (1956), such tensioning torque values could lead to a load in the order of 6000 to 10000 lbs or 3 to 5 tons.

Figure 5: Scissor truck used to install rockbolts in the back of the excavation.

Unfortunately, it was not possible to pull the bolts immediately after the installation. Pull testing of some of the bolts (2 in the wall and one in the back) was performed after 24 hours and the results are presented in Figure 6. For comparison, a typical laboratory pull test result is also presented on that graph and it confirms the excellent anchorage of the bolt in the resin.

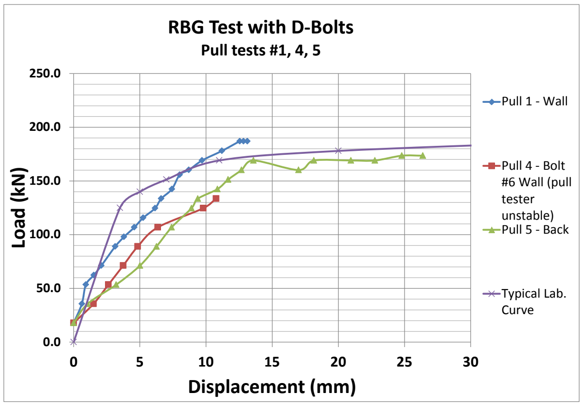


Figure 6: Pull out results of D-Bolts anchored with RBG grout.

3.2 Self-Drilling Bolts Applications

The second trial was performed in very broken and weak ground. Self-drilling bolts, referred here as SDBs or often referred as Self-Drilling Anchors or SDAs (Figure 3) were installed with a mechanized bolting rig (Figure 7) and grouted using the RBG resin grout, and pull tested after 2 hours, 3 hours, and 24 hours. Another set of two (2) bolts were grouted using regular cementitious grout. Results are presented in Figure 8. The bars are hollow threaded bars on which a one-time use drill bits can be fitted.

The pull out curves showed that the resin grout allows at least 12 tons of pull out after 2 hours, and also stiffens rapidly (3 hours pull out exhibit a much steeper loading curve than 2 hours pull out curve). For this trial, the short term pull out were conducted up to 12 tons only, to make sure the grout was not damaged for future pull tests. Also, stiffness of the resin after 3 hours compares well with cement after 24 hours.

The 24 hours pull out results showed also that the bolts can be loaded to a very high level, and the test on Bolt #4 and Bolt #9 were halted only due to issues with the pull testing equipment.

3.3 Environmental Assessment

The measurement of the potentially hazardous isocyanates was performed by a consultant hygienist from Workplace Safety North. The Iso-Check method was used on 2 operators as well as upwind and downwind locations, and the measurements were conducted during the injection in the wall, and in the back of the excavation. Results of sampling lead to an exposure level that was extremely low, for all people participating to the sampling process.

Figure 7: Mechanized bolting rig used to install the Self Drilling rock bolts.

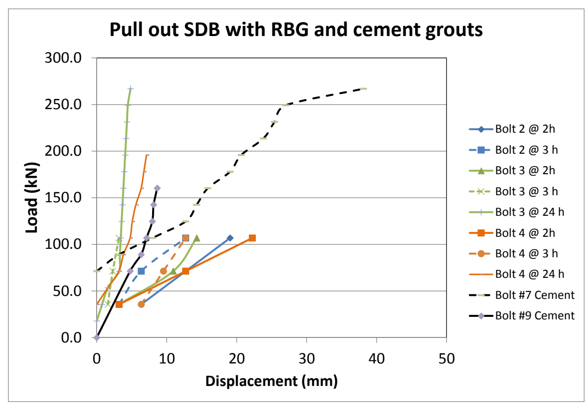


Figure 8: Pull out results of SDBs anchored with RBG grout.

4. PERFORMANCE EVALUATION

During the field tests, basic operational data was recorded. Drilling time, installation time including bolt handling, grouting, and tensioning was recorded. Average values are listed in Table 1, and an estimate of the bolting rate was also calculated from the field data. For the case of the cemented self-drilling bolt, the tensioning was performed during the next shift or day, so the performance of the next shift was affected by the tensioning time. Using a faster setting resin allows for a higher productivity but necessitates more experienced operators and well maintained equipment. The calculations are based on a conservative 360 minutes of effective bolting operation during the shift.

Table 1: Probable performance calculations based on field measurements.

Operation	DBolt/Rockbolt		SD Bolts		
	Slow resin (min.)	Fast resin (min.)	Slow resin (min.)	Fast resin (min.)	Cement grout (minutes)
Drilling	2	2	2	2	2
Grouting	3	3	3	3	3
Tensioning	5	2	5	2	3+24h
Total:	10	7	10	7	8+24h
Bolts/shift	36	51	36	51	(36+25)/2 =30

Note 1: basis of 360 minutes effective work per shift
Note 2: cement grout effective time is 360 minutes minus 36 bolts from previous shift x 3 minutes tensioning per bolt = 252 minutes

5. CONCLUSIONS

The field testing of the RBG resin was successful in showing the potential of using injection resin to replace resin cartridges or cement injection in ground support operations in broken rock masses that makes cartridges injection in boreholes difficult.

The first advantage of the method is to provide a better and safer anchorage for the rockbolt. Because of the thickness of the injected resin, the bolt is fully encapsulated in the borehole, also filled of resin. Contrary to the rotation of the rebar or D-Bolt necessary to mix resin cartridges, the insertion and rotation do not push away the grout in the open fractures in the borehole. The uncertainty of proper encapsulation is eliminated or reduced to a minimum.

The anchorage capacity of the resin is also equivalent to the polyester resin used in cartridges, with a similar stiffness after a few hours. The anchorage capacity is also as good as when using cementitious grout.

Cost wise, the pumpable resin is not really more expensive than resin in cartridge when one considers the resin loss, broken cartridges and handling time associated with cartridges in broken ground. Although it would be seen as using more material than resin in cartridge, it is because the hole is filled and the bolt fully encapsulated. Some resin loss in fissures will not negatively alter the performance of the bolt, and will likely reinforce the rock mass. So in that sense, the injected product is cost competitive with polyester resin cartridges and offers a high performance alternative in broken ground conditions that reduces tremendously the risk of anchorage failure due to poor encapsulation.

6. ACKNOWLEDGEMENT

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7. REFERENCES

Barry, A.J., Panek, L.A., McCormick, J.A., 1956. Use of torque wrench to determine load in roof bolts. Part 3, Expansion type 5/8 inch. R.I. 5228, 8p.

Pritchard, C.J., McClellan, R.S. (2011). Injectable resin, A highly adaptable ground support anchoring system. In Proc. CIM Conference and Exhibition, Montreal, Canada.

Simser, B., Pritchard, C.J. (2012), Innovative ground control at Xstrata's Nickel Rim South mine, Sudbury, Ontario. In Proc. Workplace Safety North Ground Control Conference, Sudbury, Canada, April.

Van Ryswyk, R. (1983). Mechanical rockbolt performance evaluated from pull tests. In: Proceedings of the International Symposium on Rock Bolting, Abisko, August 28-September 2, Stephansson, O., editor. Balkema.; pp. 473-476.

Yao, M., Forsythe, A., Punkkinen, A. (2014). Examples of ground support practices in challenging ground conditions at Vale's operations in Sudbury. In Proc. Workplace Safety North Ground Control Conference, Sudbury.