

Geomechanics and Tunnelling

Geomechanik
und Tunnelbau



Injection and bolting with pumpable reactive resins

Injektionen und Verankerungen mit pumpfähigen Reaktionsharzen

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Bolting with pumpable reactive resins – More than fixation of steel dowels in rock

Rock bolting in tunnelling and mining has been used for more than 100 years. The mechanism of how anchors behave, application and patterns have evolved into standard practices for all types of underground excavation. Passive acting bolts and dowels, as well as the active pre-tensioned bolts act in a way to limit shear and are subject to tension, which nails the rock mass together. Injection is used in underground structures to manage water ingress and less often to reinforce the rock mass systematically. Typically, the injected cementitious material fills the cracks and fissures in the rock mass and increases the shear resistance within the treated area. The use of pumpable, thixotropic, water insensitive, fast reacting resins to encapsulate rock bolts potentially offers to combine the nailing and shear resisting effect of the bolts with an injection approach. When using an accurately controlled pressure and volume regime, the rock mass can be bonded together, resulting in a significant improvement of the overall rock mass properties. A new rock bolt anchoring resin has been developed to improve the efficiency of underground support combining the positive effects of rock bolting and injections as outlined above. The driving idea behind this concept and test results are discussed in this paper.

1 Introduction

Rock support in tunnelling and mining has developed over time with step changes along the way. Today it comprises mostly of sprayed concrete and/or rock bolts. Sprayed concrete in various forms has been used since the 1950s in subsurface excavations as standard support, with emergence of wet spray applied concrete in the late 1970s. Rock bolting has been used even longer, in a more systematic approach in both mining and tunnelling.

The Northern European tunnelling industry developed a systematic approach for their hard rock geology, whereby pre-excavation grouting using cementitious material is utilized [1]. This approach reduced any effects of water ingress and improves ground stabilization enabling the contractors to potentially reduce support requirements.

Rock bolts in tunnelling are fixed in most cases with cementitious grouts. The mining industry uses several different methods to secure bolts. By considering the use of an alternative bolt grouting product such as a lower viscosity resin, the benefits of injection and bolting can be combined. This will be discussed below with a focus on hard rock excavations.

2 The theoretical approach

2.1 History of bolting

To strengthen the rock mass, steel bolts were used for the first time in the late 19th century in the US mining industry with the first systematic documentation in 1920 (St. Joseph Lead Mine, USA) [2]. In tunnelling they were first being used in the 1940s in the US and Australia [2].

In those days, bolts were only secured at the toe of the hole by mechanical anchors which required rather competent rock, the annular between the bolt and the rock was left unfilled. In some applications bolts were tensioned but the typical loading came from ground deformation. Slipping of the fixation has often been experienced [3], followed by a loss of tensile capacity of the bolt, resulting in potential fall of ground.

2.2 Grouted bolts

The grouting of rock bolts has been established in Norway in the 1930s, where at the Store-Norfors cavern bolts were secured, using fast setting mortar (bolts then named SN bolts). The grout is pumped into the borehole prior to the insertion of the steel bolt. Therefore, the grout tends to be confined to the annular gap only, with minimal material penetrating intersecting joints. Since the annular gap is fully filled with grout, the load transfer from steel into the surrounding rock takes place along the entire length of the bolt as with a larger shear resistance than for bolts with toe anchor points only. These bolts need deformation to take load, no deformation means consequently unloaded bolts.

In hard rock tunnelling and mining deformations are often to be minimized, whereas in rather softer ground formations the NATM (New Austrian Tunnelling Method) philosophy allows a certain deformation to occur in order to find the optimum for the support to be placed (Fenner-Pacher curve).

2.3 Injection

The systematic pre-excavation grouting method developed in the Nordic countries, can reduce the water ingress into tunnels significantly. Additionally, some improvement of the rock mass properties through filling of the rock joints with a cementitious material can be ex-

pected, resulting in an increased shear strength of the joints. The rock mass is injected prior to excavation, using an injection umbrella along the excavation contour. All holes are drilled and grouted from the excavation face, with injection length typically more than 20 m. The next drilling and grouting operation commences after several advances, leaving several metres of overlap [1]. The injected material is cement, which fineness depends on the requirements. Through this method the water inflow is minimized as well as the rock mass strength further improved. This enables the subsequent placed sprayed concrete and rock bolt support regime to be reduced. The excavations that follow the pre-injection process typically trigger relatively small deformations, and rock bolts are used, fixed with grout, in addition to a thin sprayed concrete layer. The support decision is often based on the Q-System [4], which considers joint spacing and shear strength along the discontinuity planes as well as the rock stress situation.

The use of chemical injections in underground construction is an established method. Mostly it is used to control unexpected water intrusions with polyurethane resins and/or to repair concrete structures with acrylics. The use of polyurethane for a systematic ground property improvement has its origin in coal mining [5]. Polyurea silicates started to replace polyurethanes as a bonding and consolidating agent due to its superior properties, such as being insensitive to water, faster strength development and hardened properties that remain unchanged, even in a hot underground environment (since there is no glass-transition temperature).

2.4 The combination – Theoretical considerations

The method of how rock bolts function is described in many publications, however in this case the definitions explained in “Rock Bolting” [6] are used. Suspension, beam building or wedging (keying) effects are described. What can be clearly seen is that the bolts used there are fixing jointed and/or layered ground together, acting under tension and/or shear and the joints remain as they are (Figure 1).

These “untreated” joints are exactly where our considerations start. What, if all these joints were injected, at best bonded together, would this significantly improve the rock mass strength allowing for reconsiderations of the support needed – bolt pattern and length, sprayed concrete or other support?

As explained above, injection resins that can act as a bonding agent are well known in the (Coal) industry. But this approach is rarely used in hard rock mining and tunnelling. Injections require an additional work step, with special equipment needs and will require definitely some additional time.

But what about combining the securing of bolts with an injection approach? Not by using a standard mortar that can and will act as additional shear resistant agent, but by using a resin that acts as a real and strong adhesive.

To enable this approach, an easily pumpable, low viscous, water insensitive glue is needed as injection material, also the same glue is needed for the bolt fixation, but now with the additional properties of rapid strength devel-



Fig. 1. Wedging [6]

opment and reasonably high and reliable final strength. For both applications, a truly thixotropic behaviour is beneficial.

Since this approach has yet to be fully studied with respect to practical applications, a look at two separate examples of application is useful: the use of the resin in injection and at the use of resin for bolt placing and securing.

3 The use of an injection resin to repair a broken sprayed concrete shell, Semmering Tunnel Austria

In Austria, the 27 km long Semmering rail tunnel is under construction and is also accessed via intermediate tunnels and shafts. At lot SBT 2.1, a 420 m deep shaft, was constructed. At the shaft base, a large cavern was excavated for the launch of the TBM (Tunnel Boring Machine) and later to serve as an emergency stopping area for trains (Figure 2). The primary support of this cavern comprises of sprayed concrete and rock bolts. As bigger deformations were foreseen, deformation gaps were also included into the concrete shell.

As the excavations progressed, ongoing deformation in the cavern and cracks in the concrete shell were observed (Figure 3) [7]. Several remedial actions were executed, such as repairing the concrete cracks and additional bolting. But the deformations continued (see Figure 7), the concrete shell cracked again (Figure 4, left). Then an injection approach was chosen to repair the sprayed concrete shell.

As mentioned previously, to bond concrete and/or rock together, several material properties are needed for a successful result. The material should avoid foaming or reacting under moist or wet conditions, must develop bond strength to moist substrates, should be of low viscosity to travel far under low pressure, be at best truly thixotropic to avoid excessive wastage of material that exits out of joints, develop reliable strength after a reasonably short time, at best avoid being brittle with even some degree of flexibility. Suitably developed polyurea silicate resins offer these properties.

The proposed polyurea silicate was tested in-situ and then used for the repair job (MasterRoc MP 368 TIX). Drill cores taken clearly showed the penetration of the injection resin into the concrete cracks and the fine rock joints (Figures 4 and 6). It can be seen, that the thixotropic version used later in the process has advantages as significantly less wastage of material from the concrete cracks



Fig. 2. Cavern at shaft bottom, Fröschnitzgraben, Austria

was experienced after the pumping had been stopped (Figure 5). Finally, cores were drilled into the rock, to check the quality of the interface and to determine the extent of resin penetration into the rock mass (see Figure 6).

The concrete as well as some rock fissures were filled, and effectively bonded together. However, the question remained: Did this stop the cavern deformation completely, which was the key goal of this operation? Before the injection operation the deformation averaged to about 0.5 mm/d [8]. It can be clearly seen, that the deformations levelled off, the key goal was achieved (deformation-time graph in Figure 7). The reader should be aware, that the distance of the ongoing excavation to the monitoring sections grew bigger which potentially also contributed to the levelling off of the deformations.

The quality of the resin and its mechanical properties were high enough (> 30 MPa compressive strength), the application well planned and executed. This remedial work is already more than one year old, so it can be deemed as successful.



Fig. 4. Concrete core, as drilled out and re-assembled (left) and cored sample after injection (yellowish – colour of injected resin)



Fig. 3. Broken concrete shell

The resin used above was tested prior to its field application. Special attention was paid to the penetration capabilities, to identify any limitations for site applications and conditions (Figure 8). The first test version of this resins already showed its penetration capabilities, with penetrations into fissures ≥ 0.24 mm. The final test results indicate penetration capabilities into fissures ≥ 0.14 mm, tested at 30°C [9]. Based on these tests it can be confidently assumed, it will penetrate joints with about 0.5 mm minimum opening at typical rock temperatures.

In summary, it is possible to repair a broken sprayed concrete shell utilizing an injection resin applied in a systematic manner.

4 Polyurea silicate resin for bolt fixing, considerations and performance tests

4.1 Considerations for bolt installation and encapsulation

Cementitious grouts, which are often used for bolt fixations, require several hours to harden. Since bolting is often a time critical operation in underground mine development and production, faster reacting alternatives to cementitious grouts were developed.

Resin cartridges, which are mostly polyester based, are extensively used. The cartridges are pushed into the





Fig. 5. Drilling and injection operation

drill hole and are then activated and mixed through the bolt insertion and turning actions. This approach allows for quite several shortcomings, such as collapsed boreholes prior to insertion, incomplete mixing of resins, and insufficient resin volume for full encapsulation due to enlarged boreholes. This could also result in quite some areas along the bolt length being exposed and subjected to all environmental conditions such as ground water, which could lead for example to a fast-acting corrosion process. But let's assume, all is properly done.

Since the cartridge volume is fixed, and the inserted steel is producing the “pressure” to fully fill the annular gap, hardly any grout can penetrate the surrounding fissures. Additionally, as mentioned previously, the grout volume is limited and therefore unlikely to penetrate the immediate zone of the bolt and thereby unlikely to enhance the ground properties in the borehole vicinity. Additionally, the grout properties fail to fulfil the viscosity parameters that support the penetration of grout into fine cracks and joints.



Fig. 6. Interface rock mass to sprayed concrete, injection resin (yellowish) also penetrated into fine rock fissures

To overcome these shortcomings, a low viscosity resin needs to be pumped into the borehole, whereby the resin volume and the injection pressure can be determined based upon the site conditions.

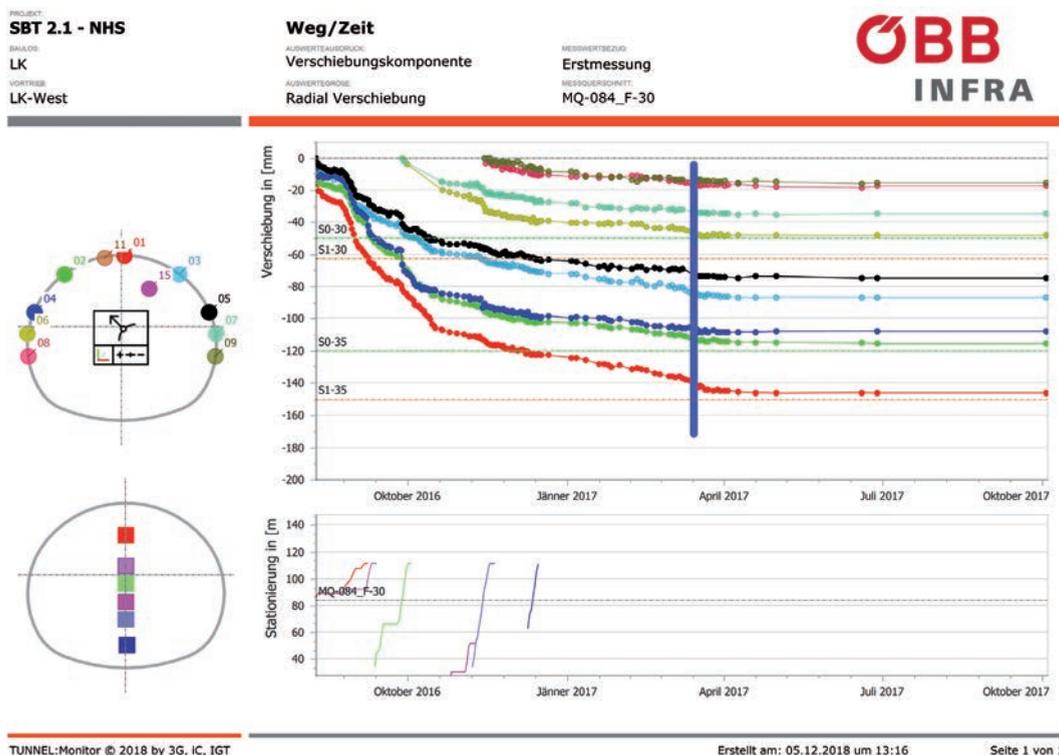


Fig. 7. Deformation-time graph, blue line indicates beginning of injection operation [8]

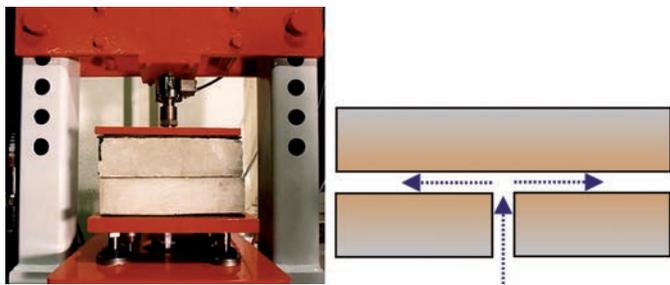


Fig. 8. Test setup at DMT for penetration testing [9]

Once material is pumped into the borehole or the annular gap, depending on the bolt types used, the volume and pressure control as well as visual observation allow for any gaps/spaces around the bolt to be filled completely. This ensures a proper protection of the steel bar against corrosion, guarantees a better load transfer along the interface to the rock and is a better shear stud where needed.

4.2 Polyurea silicate resin

The material of choice is a polyurea silicate, with all the desired properties as mentioned above for the injection. But here, more attention must be paid to a rapid hardening process, reliable strength gains as well as no deterioration of properties over time. Since bolts are also installed overhead, a true thixotropic behaviour would allow for less wastage and more efficient installation (“Thixotropy is a time-dependent shear thinning property. Certain gels or fluids that are thick, or viscous, under static conditions will flow (become thin, less viscous) over time when shaken, agitated, sheared or otherwise stressed (time dependent viscosity) [10]”). To use a thickening approach for the resin would only partly work, since a material with higher viscosity has limited penetration characteristics into the surrounding rock in addition to yielding significantly higher pumping pressures for longer length bolt installations.

4.3 Performance tests

The thixotropic resin was tested at DMT in Germany [11] [12]. There the DIN 21521-2 bolt test procedure was followed [13]: Concrete casted and hardened in steel pipes, with pre-made boreholes that were pre-wetted, the bolt inserted and then grouted (Figure 9). The resin hardened rapidly, such that pull tests after only a few minutes – the anchor length for pulling was only 600 mm – resulted in the destruction of the bolt, whether hollow or solid bars were used (Figure 10).

The same penetration tests were performed as with the injection resin above. The resin used for the bolting operations, shows comparable penetration characteristics, as can be seen in another DMT Report [14]. This is no surprise, because both resins originate from the same idea and have a comparable chemistry. All the tests clearly show that the polyurea silicate resin (MasterRoc RBA 380 family) is suitable to be used for rock bolt fixations.

5 Polyurea silicate resin for bolting, site trials

The successful laboratory tests were followed by tests in underground hard rock mines. There the thixotropic rock bolt resin was used in the application of self-drilling anchors (SDA, up to 6 m long) and up to 12 m long cable bolts, both used extensively in mining operations.

5.1 Bolt test in Sweden

The tests were performed in the Atlas Copco/Epiroc test mine in Nacka, Sweden (Figure 11). The main focus was, to prove the suitability of the resin in a routine operation. Epiroc have developed a new generation of mechanized bolt installation equipment, which enables the use of resins. Joint development work with BASF finetuned the application interface, the dispensing part of the bolter as well as the desired resin properties for continuous bolt installation, since the goal of this cooperation was a fully automated bolt installation. A highly rapid hardening process was required, immediately after mixing and pumping of the resin, with a clear thixotropic behaviour to avoid spillages and material wastage. 2.4 m long bolts were extensively tested, all could be installed successfully.

5.2 Bolt test at mine sites in Asia Pacific

Extensive bolt tests were performed at two more mines in Asia Pacific. The goal was to confirm proof of the concept in a more natural environment, which also includes high humidity and elevated temperatures. Figure 12 document details of the tests undertaken with self-drilling bolts and with long cable-bolts. Site focus was given to tensioning the bolts as soon as possible after installation. This could be achieved after minutes compared to about 12 hours as is the case using cementitious fixations. Other geotechnical aspects were not discussed. In summary, both bolt types were successfully installed and tested under site conditions.

6 Discussion of results and further philosophy development

All bolt installations described above were successful, all results evaluated and discussed on site. But all efficiency



Fig. 9. Bolt test at DMT Germany, bolts already fixed in concrete

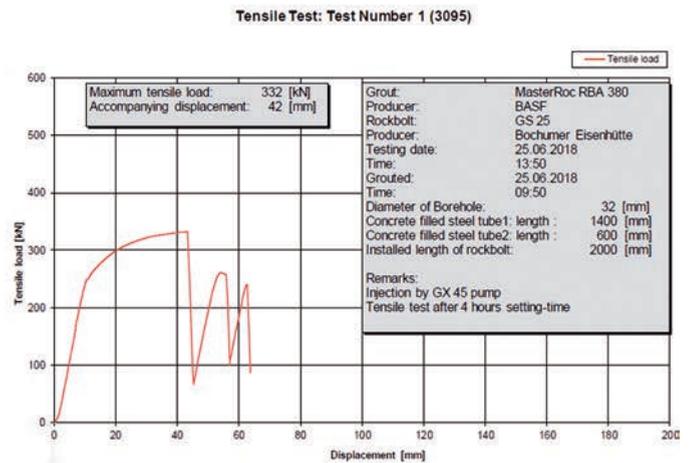


Fig. 10. Details of bolt testing at DMT, ruptured steel bar and loading cycle



Fig. 11. Bolt testing at Nacka test mine in Sweden

considerations were only based on bolt-fixation-properties, mostly on the time gained through the rapid resin strength development and the reliability of the installation procedure. The added benefit of the resin penetration into the fine fissures next to the drill hole, was only taken into consideration as an afterthought.

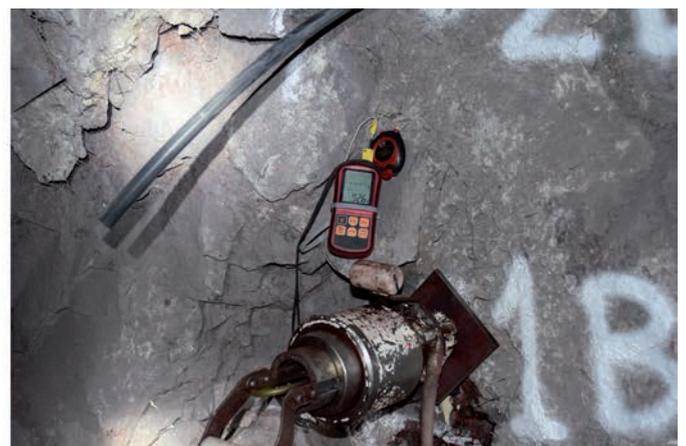
This additional resin amount, that improved the surrounding ground to a certain extent, should have been the entry door for an additional discussion. The key question that should be asked: How to best benefit from the gluing properties of the bolt resin, that increases the rock mass strength to a certain extent? Shouldn't this be discussed prior to the bolt installation, to review the proposed rock support? The idea behind this approach can be seen in Figure 13.

Dedicated volume/pressure parameters during bolt installation, with the borehole effectively sealed mechanically for a limited time, should allow a significant volume to penetrate joints next to the bolts, to overall improve the rock mass. This would allow potentially for wider spaced bolt pattern and/or a reduced additional support, such as mesh and sprayed concrete.

The reader should reflect some basic geotechnical considerations. In hard rock environments joints dominate the rock mass strength, the support requirements and the deformations into the opening. Any means, that improves the shear strength of the joints, would improve the overall situation. Bolts that intersect the joints act already as shear studs, with completely filled boreholes as even better shear studs.



Fig. 12. Tests of cable bolts



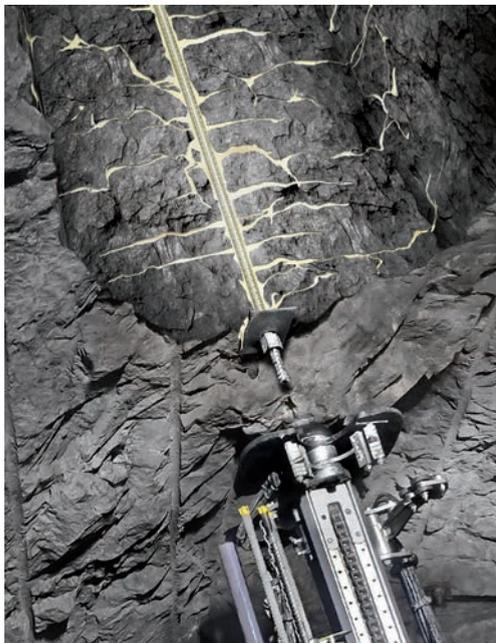


Fig. 13. Rock bolt resin penetration into intersecting joints

Any injection material of reasonable mechanical properties, that only fills the open joint space, is again beneficial and reduces any relative movement. A strong filling material with adhesion properties, such as the poly-urea silicates, should be superior to any non-bonding materials. In addition, the adhesion provided by a non-brittle material still contributes to stability after some rock mass deformation, whereas cementitious material might already loose part of its benefit. In the case of highly jointed rock masses, the more one could benefit from the resin properties, whether used as injection material or rock bolt anchoring.

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