# Pre–Injection technology for mines

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## ABSTRACT

*Technology transfer between the mining and tunnelling worlds has historically been less than rapid. One tunnelling technology that has been used to a limited extent in mining is the pre-injection of grout into the ground to prevent water ingress. The main role of pre-injection grouting is to effectively seal, in the shortest possible time, all water and gas bearing fissures before they are exposed by excavation. Through recent examples of pre-injection techniques that have been used in mines and shafts, this paper identifies state-of-the-art pre-injection methods that can be adopted by mining companies, and illustrates the considerable operational benefits of such an approach. An overview is given of fast-setting microfine cements that can be adapted to various geological and hydrological conditions, and the production advantages they can generate. Furthermore, the paper highlights the necessary equipment and techniques required to ensure a successful pre-injection of the ground, and the latest grout products available to the pre-injection team, such as colloidal silica gels, to ensure greater watertightness and security in more diverse geological conditions.*

## INTRODUCTION

Technology transfer between the mining and tunnelling worlds has historically been less than rapid. However, recent advances in tunnel construction, such as sprayed concrete technology, has seen dramatic up-take in mining operations, as both industries require higher productivity, lower operational costs, and increased safety.

One tunnelling technology that has been used to a limited extent in mining is the pre-injection of grout into the ground to prevent water ingress. As in tunnelling, water ingress causes the underground worker serious safety concerns, can add substantial costs to the mine operation through additional pumping, and in some instances, water inundation can close a mine. Furthermore, the necessary control of contaminated groundwater has become a serious environmental concern for many mine operations worldwide. Such concerns can be addressed using pre-injection grouting technology.

The main role of pre-injection grouting is to effectively seal, in the shortest possible time, all water and gas bearing fissures before they are exposed by excavation. Modern shaft sinking methods are not compatible with water ingress exceeding 4 L/s, and any such ingress can detrimentally affect the shaft sinking progress and incur high costs. As with tunnelling, no single factor influences the total cost of shaft sinking as much as time.

Through recent examples of pre-injection techniques used in mines and shafts, this paper identifies state-of-the-art pre-injection methods that may be adopted by mining companies. An overview is given of fast-setting microfine cements that can be adapted to various geological and hydrological conditions, and the production advantages they can generate. Furthermore, the paper highlights the necessary equipment and techniques required to ensure a successful pre-injection of the ground, and the latest grout products available to the pre-injection team, such as colloidal silica gels, to ensure greater watertightness and security in more diverse geological conditions.

## PRE-INJECTION OF ROCK: APPROACH, STRATEGY AND BASIC PRINCIPLES

### BASIC CONCEPTS OF PRE-INJECTION OF ROCK

There is international pressure for all companies to reduce risks and achieve even further economy in shaft sinking and tunnelling activities. Furthermore, the control of waste or contaminated water from the mining process has become increasingly relevant in minimizing environmental impacts on the ground surface. To achieve these goals, contractors can:

- Limit groundwater in excavations by pre-injecting cementitious grout ahead of the excavation advance face
- Use modern drilling equipment in combination with state-of-the-art injection equipment and materials to improve and widen the application of pre-injection grouting

Pre-injection of rock in underground construction involves pressure grouting into the rock mass through drill holes. The actual injection is part of a cycle that comprises exploratory drilling (probe drilling), injection drilling, injection, and control drilling. The holes are mostly drilled with modern, conventional drilling equipment e.g. a jumbo drill, with drill hole diameters of 45 to 64 mm, similar to those shown in Figure 1.

Cementitious grouts are recommended (and also required) for most injection work, but different types of chemical grouts are available for particular situations. The grout is pumped into the drill holes through hollow lances that are connected to the grout pump with hoses. With sufficient pressure, the grout will penetrate into the joints and discontinuities of the rock mass and replace the groundwater with grout and hence, block the seepage channels. The holes are drilled in a cylindrical fan around the tunnel, in order to encompass the tunnel with a zone of low conductivity. The general layout of a pre-injection fan is shown in Figure 1.

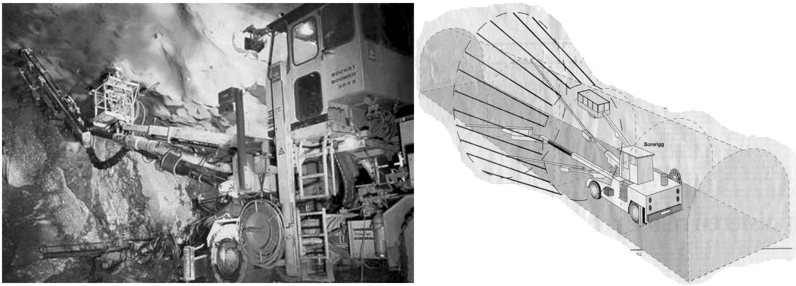


*Figure 1: Typical drilling jumbo for tunnel applications preparing fan of pre-injection holes ahead of the excavation face.*

The basic strategy for pre-injection is to define a maximum accepted level of water seepage into the tunnel (a certain allowed volume of water per tunnel meter). A systematic pattern of exploratory drill holes repeatedly performed with overlap ahead of the tunnel face is then decided. Action criteria for grouting based on observed water inflow through the exploratory drill holes are then defined based on the maximum allowed seepage levels.

**MAIN MOTIVATIONS FOR PRE-INJECTION**

The problems that inflowing water can cause in an underground construction are numerous, and include:

- Consequences in the ground and at the surface caused by a lowered groundwater table because of the drainage effect of the tunnel
- Consequences in the actual tunnel caused by an increased amount of inflowing water, including the possible deterioration of the temporary road in the tunnel and need for pumping, as well as the deterioration of the immediate stability of unsupported rock after excavation and the reduced feasibility of producing a high quality single shell support based on sprayed concrete and rock bolts.
- Complete closure of shaft or mine workings due to inundation
- Unacceptably high costs to maintain excavation progress
- Excessive water ingress leading to rapid deterioration of the ground and excessive loading on ground support system, leading to unsafe conditions

In many situations, one simply cannot allow a water inflow to occur with the intent of treating it behind the advancing tunnel face because of possible difficult or devastating consequences. In most cases today, the construction of any underground structure will be required to limit the inflow of water to a defined maximum. This amount will depend on the type and location of the underground structure.

The difficulty and cost implications of handling a significant water inflow in an already excavated tunnel can be extreme compared to the cost of the probe drilling and injection works carried out ahead of the tunnel face. A total cost difference of a factor of 10 or more is not unusual.

However, controlling water seepage by probe drilling and pre-injection is a complicated and time-consuming operation and is unavoidably time critical. Hence, detailed focus on overall cost-effectiveness including definition of action criteria, determination of drill hole patterns, selection of grouting materials, and definition of grouting procedures will improve the total tunneling performance significantly.

## COST IMPLICATIONS OF INJECTION WORKS

Probe drilling and injection works are inevitably time critical, because these works have to take place concurrently with the actual excavation of the tunnel. Time spent at the excavation face for pre-injection will therefore normally have to be deducted from the time available for excavation. An hour of this time, the tunnel face shift hour time, comprising all the time-related costs for the allocated resources from the contractor, often totals more than US$ 1000. Efficient procedures for reaching the desired rock mass treatment against water seepage are crucial. The simplicity and predictability of pre-injection, compared to post-injection (or even worse, coping with the possible consequences of not injecting the rock mass at all), makes a strategy based on pre-injection the obvious choice from a contractor's point of view.

It is also quite clear that injection works in tunnelling are fundamentally different from surface-based injection work for ground treatment. The developments of equipment, injection materials and procedures for injection in tunneling have the critical time issue as the main objective.

## EFFECTS OF PRE-INJECTION; WATERPROOFING AND ROCK MASS IMPROVEMENT

What is it possible to achieve with pre-injection? It is very important to be aware of the fact that 100% waterproofing is not possible with pre-injection grouting. Hence, the term waterproofing is somewhat misleading when considering pre-injection. More correct terms would be permeability or conductivity reduction, or water ingress reduction. The fact that leakage characteristics along discontinuities in a rock mass are highly inhomogeneous, make it impossible, even under strictly controlled conditions, to predict the exact outcome of a pre-injection operation. It is possible, though, to reduce water inflow to a tunnel to a few percent of the original seepage.

When a very high degree of tightness is required, sophisticated methods (injection with microfine cements and chemicals, combined with post-injection methods) are required for removing the remaining seepage. However, it should be noted that the cost of removing the last 10-15% of the seepage is often higher than the cost of removing the first 80-85%. In terms of average permeability for a rock mass, $1 \times 10^{-7}$ m/s is often considered the limit of what is possible to achieve using microcement injection. Theoretical permeability values between $1 \times 10^{-8}$ and $1 \times 10^{-9}$ have been achieved, but with very time consuming and expensive chemical injection. The outcome of such injection works with respect to ambiguous tightness requirements are in most cases very uncertain.

The effects of improving the stability properties of the rock mass by pre-injection are often a side effect of the reduced flow of water through the rock mass towards the tunnel contour. Such effects are:

- Improved properties of the discontinuities of the rock mass and hence, improved stand-up time in bad rock caused by the filling of the discontinuities with cementitious grout (improved shear strength, replacement of weak material with hardened grout)
- Removal of seeping water on exposed joints, particularly on joints with clay coatings. This improves the performance of sprayed concrete and the establishment of a high quality sprayed concrete shell for rock support.
- Removal of flowing water, which can cause erosion or wash-out of clay fillings on discontinuities or weakness zone material

## INJECTION TECHNIQUES

### THE INJECTION CYCLE - A CYCLE WITH DECISIONS

The decision to commence injection is based on the results from probe drilling where a water seepage situation has been encountered. The definition of action criteria for injection is a very important part of the excavation-probe drilling-injection cycle. Careful attention therefore needs to be paid to the layout and performance of the probe drilling program. The goal is to arrive at the required result with as a little consumed time and effort as possible. Time spent for injection works is basically "down time" since these works are time critical. A typical injection cycle in hard rock can be represented as a flow diagram, as shown in Figure 2 below.

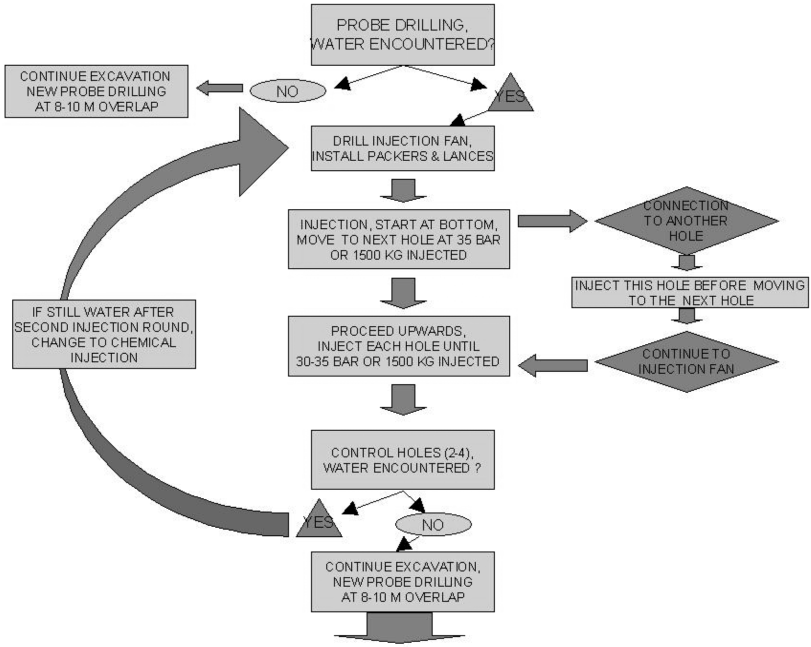



*Figure 2: An example of an injection cycle in hard rock tunneling represented in a flow diagram with tasks which each require a decision in order to be initiated. The injection criteria which are stated here are from a specific case.*

### PERCUSSIVE PROBE DRILLING

Percussive probe drilling carried out with a jumbo drill is an easy and safe way to get information about the rock conditions in front of the face. The safety increases proportionally with the number of holes, within a practical range of 1 – 10 holes. In areas with a high risk of encountering water, the minimum number of exploratory holes should be at least 4.

The length of the holes depends on several factors like drill equipment, shift sequences, round length etc. A length of about 30-35 m is normal. Still, an overlap of 5 – 10 m should always be kept. If one or more probe holes encounter water (more than accepted), decisions on injection need to be made.

During percussive probe drilling, information about the rock mass ahead of the tunnel face is obtained indirectly. Recorded features are leakage (inflow) through the drill holes measured at certain intervals, drilling parameters like torque, thrust and drilling advance rate, as well as flushing water characteristics (clay, change in rock type, weathering). Figure 3 below shows an example of a geometrical layout of a probe drilling program.

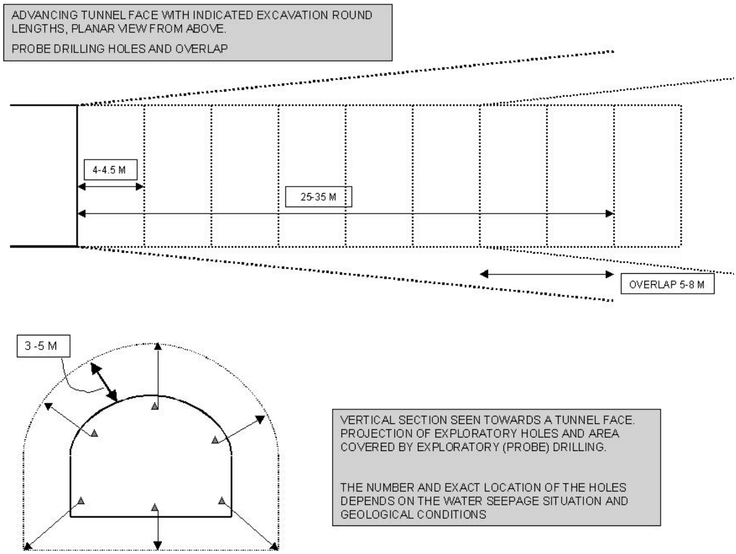



*Figure 3: Example of a geometrical layout of a probe drilling fan, planar view from above and vertical section towards the tunnel face.*

## DRILLING OF INJECTION HOLES

The fan or umbrella of injection holes should normally encompass the entire tunnel, including the bottom. The spacing between the holes is normally between 1,5 and 2 m. In certain cases, with clay-filled joints or seepage channels with a low degree of communication, it is necessary to have a smaller spacing to get a good grout distribution.

The length of the holes for injection depends on several factors, like safety, round length, and tightness requirements, but generally lies between 15 and 25 m. The drilling of longer holes is generally too time-consuming, and the risk of excessive drill hole deviation is too big. It is easier to get a good result with shorter holes, but this will also require much drill time. Careful optimization of the drilling-injection cycles with proper hole lengths and overlaps is important in order to achieve the best possible total cost effectiveness.

Thorough washing of the holes after drilling is very important for removal of drill cuttings and loose ground material that could cover the joints in the drill hole. If left in the hole, this can block the penetration when the injection starts.

As mentioned under probe drilling, it is important to have an already injected bulkhead from the previous injection round in front of the tunnel face. Problems with backflow of grout into the tunnel and difficulties with fixing the packers could result if the overlap treated by injection is too short.

The diameter of the injection holes can be adjusted to the most practical. There is no need for large diameter holes. The main point is that the holes intersect the seepage channels. Diameters between 48 to 60 mm are most common. When encountering high water pressures, small diameter holes make the practical work far easier, e.g. the installation of packers. The use of small diameter packers also enables the packer itself to resist higher pressures, in comparison with a packer with a larger diameter.

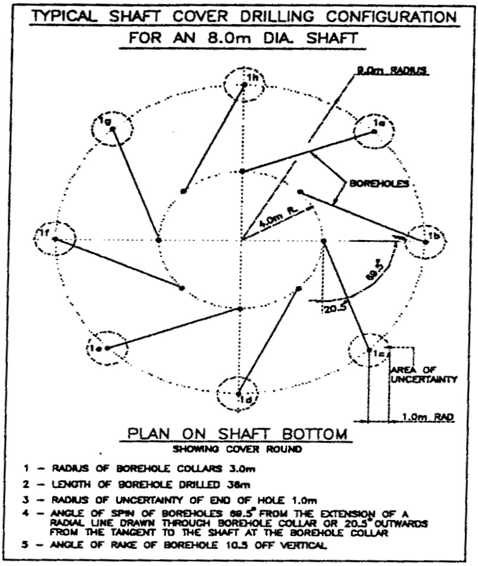



*Figure 4: Drilling fan layout for shaft sinking*

## INJECTION FAN LAYOUT

Normally, injection holes are drilled in a fan, with an angle out from the tunnel contour. In most cases, it is not necessary to treat the rock mass directly in front of the tunnel. Typical drill angles are between 10 and 15° longitudinally out from the tunnel contour. The goal is to place the grout in a cylindrical body in the rock mass around the tunnel periphery. The intended thickness of this grout body depends on many factors. An important factor is the length of the rock anchors in use. If the grouted body is 3 m thick and the anchors have a length of 4 m, the anchor hole will create a seepage channel through the grouted body.

Experience from the 800 m deep Sedrun Access Shaft as part of the new Alp Transit rail tunnels in Switzerland had pre-injection drilling patters as illustrated in Figure 4. The drill holes were executed in 36m intervals, and were drilled through pre-set grouted casings fitted with HP drill cocks and stuffing boxes to ensure shut-off capability in case strata bearing high pressure water or gas were intercepted. Typically, if the drill holes encounter water-bearing fissures, the hole should be extended 1m past and be prepared for injection.

## INJECTION

When the entire fan is drilled, injection can commence. The injection should generally start at the bottom, and move upwards towards the ceiling in order to assure a well treated base for the upper part of the grout body. The importance of treating the bottom part thoroughly is emphasized, since a leakage through the floor will create problems with the road later on. These problems will be difficult to handle by post-injection at a later stage. Therefore, it is important to be particularly aware of the positioning of the injection holes in the bottom to ensure sufficient coverage of the injection fan. Often the drilling booms aren’t directed sufficiently downwards.

Before injection of a hole can start, the packer needs to be installed. Normally the packer is placed at a depth between 1,5 and 2 meters at the end of a hollow lance. The packer has to be placed in sound and solid rock to be able to tight enough. The packer has to fill the entire drill hole. The stepwise procedure of the use of disposable packers is shown in Figures 5 and 6.

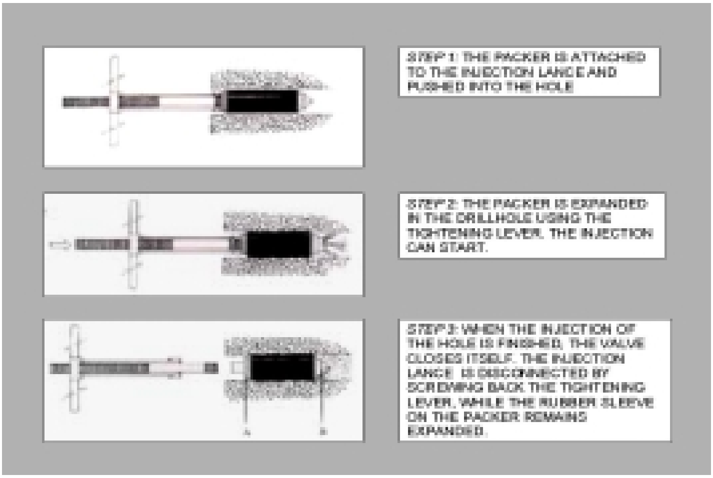



*Figure 5: Installation of a packer (disposable type).*

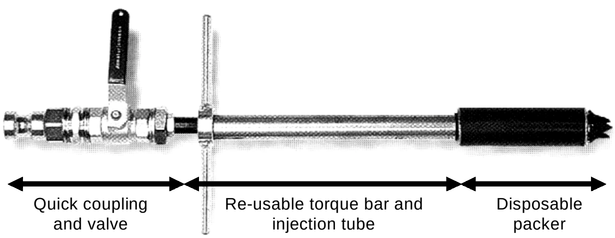



*Figure 6: Main components of disposable pre-injection packer.*

It is recommended that only a few packers be installed in the beginning. In this way, an eventual connection between different injection holes can be observed. If contact between holes occurs, the communicating holes are injected before moving back to the initial injection pattern (decision flow diagram Figure 2).

**CONTROL HOLES**

After the injection is finished, the achieved result has to be controlled before the next excavation round can be drilled. This is done by drilling holes into the injected area to check if any water seepage remains. If excessive water is encountered, a supplementary round has to be drilled and injected. The control hole pattern and acceptance criteria for achieved tightness will depend on the functional requirements of the injection program. Safety increases with the number of control holes. It is recommended that at least 2 control holes be drilled. In critical or difficult areas, as many as 6 or even 8 holes should be drilled.

The standard practice in South Africa is to re-drill and if necessary extend the pre-injection drill holes to their full designed depth (if it was cut short due to intercepting water). If Ordinary Portland Cement (OPC) is used, re-drilling can only start after 16 hours to allow setting; however, if microcement is used, this can be reduced to 3 to 4 hours, saving 12 hours, and consequently significant costs.

**INJECTION PROCEDURES**

The injection procedure is normally given in the technical specification. The procedures may be very different from tunnel to tunnel, due to factors like the type of tunnel, type of rock, overburden, environmental issues etc. At a minimum, an injection procedure needs to specify the cement type and mix design for the injection grout, termination criteria for each hole and measures to take for special situations like backflow into the tunnel along joints, communicating holes or lack of pressure build-up during injection.

First of all, the specification of the cement is essential. If the rock mass discontinuities are persistent and the apertures of the joints are of certain size, it will be fairly easy to inject and achieve good penetration. Normal rapid hardening cement will in most such cases be sufficient. If the rock conditions are difficult, e.g., clay covered or clay filled discontinuities, where the flow channels have a low degree of communication or persistence, injection grouts with higher penetrability and stability might be required. Also strict requirements on tightness will in most cases make microcements the obvious material choice in order to achieve the best possible penetrability

Injection criteria for each hole can be related to maximum grout take (a certain defined maximum amount of grout per meter drill hole), minimum standing pressure during injection or a combination of the two, often referred to as the GIN-method. (GIN stands for Grout Intensity Number, which is defined as the injected amount [dry weight, kg] multiplied with the standing pressure [bar])

Some specifications recommend starting with a high water/cement ratio and reducing the water after some time. More modern specifications are more concerned about the quality of the grout. An example of a specification could be:

*Marsh cone time:* *< 35 sec.*
*Bleeding:* *< 2%*
*Maximum kg per hole:* *1000 microcement*
*Minimum standing pressure:* *30 bars over water pressure*

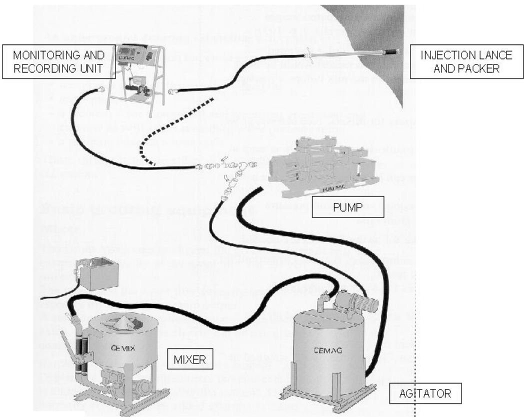
If the injection of a hole is terminated after a defined maximum, e.g., 1000 kg, even if there is no pressure achieved, it is very important to have a stable grout. If not, the water that separates out will create “bleeding channels”, which are almost impossible to treat later. If a stable grout is used, the grout will block the cracks to a much larger extent and the result after injection will be better.

Some technical specifications may also require when injection is required (action criteria). For example, this could be if there is more than 2 L of water running out of a probe hole per minute. Other times, the total acceptable seepage for the entire tunnel is specified. A small seepage on the face may seem to be no problem, but when many of these small seepages add up, the total allowed seepage might be exceeded.

To get a good injection result, it is important to be open-minded to new ideas. Nobody knows exactly the right cure for each and every tunnel. The best result is achieved if everyone co-operates and is willing to try new approaches. By way of example, specifications requiring the use of maximum 30 bar injection pressure are completely useless if the rock mass at the jobsite starts to take grout at 40 bars. In such cases, it is vital that all interested parties acknowledge the conditions and modify the criteria for successful pre-injection.

**PRACTICAL PERFORMANCE OF INJECTION**

As with all equipment for underground activities, the injection equipment has to be in good condition and reliable. The investment in drilling the holes, the costs of the injection cement and the time-related costs of stopping the advance of the tunnel make little sense without having appropriate injection equipment available. The equipment must have at least 3 parts: mixer, agitator and pump as indicated in Figure 7. After mixing the grout, it has to be pumped over to the agitator where it is kept in constant slow movement. The agitator is connected to the pump.



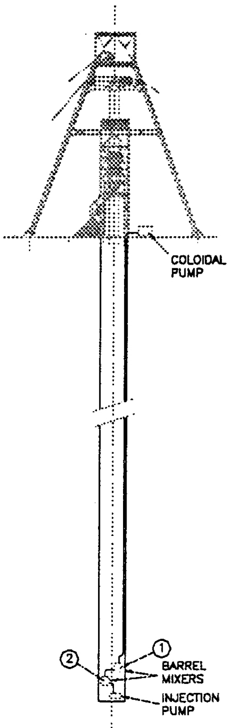




*Figure 7: Elements of the injection equipment and suggested location in shaft sinking operations.*

The best-suited mixers are the colloid types. This kind of mixers gives high shear forces to the mix. This is important to be able to crush the cement lumps. The right order to put the different components in the mixer is: 1$^{st}$, water; 2$^{nd}$, cement; and 3$^{rd}$, additive. The mixing time should be about 3 minutes. If mixed too long, the friction from the shear forces in the mix will create heat, which will reduce the open time. As soon as the grout is ready mixed, it has to be pumped over to the agitator. It is important not to mix more grout than needed. It is better to mix several small batches rather than one large volume.

After the grout has been pumped into the rock mass, it ideally should set as fast as possible. This is important because the tunnel operation cannot start before the grout has set.

There are microcements on the market today with an open time of about 45-60 min, and a set time of about 2 hours. This is ideal as the contractor may proceed almost immediately with the next tunnel process after finishing the injection work. If the cement in use has a slow set, you may have to wait between 6 and 16 hours. If the time related cost of a shift hour of the advancing tunnel face is $1000, it is easy to understand the importance of choosing the right cement.

## TYPICAL DIFFICULTIES DURING INJECTION

Most injection problems are related to the installation. A typical problem is installing the packer, say due to loose material blocking the hole. In worst case scenarios, it may be necessary to use special drill anchors through which injection can be performed. Other times, it is enough to re-flush the holes, and try again.

If the drill holes have a lot of water with high pressure, it is impossible to install the packer by hand. It is then necessary to try to install the packer with the jumbo. This is a very difficult and tiresome work, particularly if the water is cold. If very high water pressures can be expected during the drilling of exploratory holes, a shut-off device (with HP valve, drilling cock and stuffing box mounted to a grouted HP casing) should be installed.

During injection, a typical problem is back-flow of grout to the face. There may be water channels that lead the grout out towards the tunnel face. These flow channels need to be plugged before the injection can continue. There are basically three ways, or a combination of the three, to do this:

- Plugging with rag and wooden wedges
- Cut-off injection with polyurethane injection resins
- Using accelerator in the grout

As soon as the backflow is plugged, the injection process can continue.

## ACCELERATED GROUT

Acceleration of grout has been known for some years. Recently, alkali-free accelerators typically used for sprayed concrete have been adopted, giving a system where the setting time of the grout can be easily controlled. The accelerator is added to the grout in a nozzle on the injection lance. In this way, there are no problems with clogging in the injection equipment or injection hose. With this technique, it is possible to adjust the open time of the grout from about 5 minutes to 20 minutes. Used in the right way, this is an excellent tool to stop grout running too far away from where it is targeted, and to stop leaks on or directly behind the excavation face.

## DESIGN OF CEMENTITIOUS INJECTION GROUTS

## CEMENT PARTICLE SIZE, FINENESS

Any type of cement may be used for injection purposes, but coarse cements with relatively large grain size can only be used to fill bigger openings. Two important parameters governing the ability to inject cement are the grain size, and the grain size distribution of the cement particles. In average, the grain size can be expressed as the specific surface of cement grains in a given quantity. The finer the grinding, the higher the specific surface, or Blaine value ($m^2$/kg). For a given Blaine value, the grain size distribution may vary and the important factor is the maximum grain size, or as often expressed, the $d_{95}$. The maximum grain size should be small, to avoid premature blockage of fine openings by the coarsest particles and filter creation in narrow spots. The typical cement types available from most manufacturers, without asking for special cement qualities, are shown in Table 1 below.

| **Cement type \ Specific surface** | **Blaine ($m^2$/kg)** |
|---|---|
| Low heat cement for massive structures | 250 |
| Ordinary Portland cement | 300-350 |
| Rapid hardening Portland cement | 400-450 |
| Microcements | 650-1000 |

*Table 1: Normal cement types and their typical Blaine values.*

From an injection viewpoint, these cements have the following basic properties:

- Highly grinded cement with small grain size will bind more water than coarse cement. The risk of bleeding (water separation) in a suspension created from fine cement is therefore lower and a filled opening will remain more completely filled.
- The finer cements have a quicker hydration and a higher final strength. This is normally an advantage, but has the disadvantage of short open time in the equipment. High temperatures will increase the potential problems of clogging of lines and valves. The intense mixing required for fine cements must be closely controlled to avoid heat development caused by the friction in the high shear mixer.

The finer cements will have a better injectability, or ability to permeate into fine cracks and openings. This advantage will only be realized as long as the mixing process is efficient enough to separate the individual grains and properly wet them. In a pure cement and water suspension, there is a tendency of grain flocculation after mixing, especially with finer cements. This is counter productive. It is commonly said that the finest crack that may be injected is about 3x the maximum grain size (including the size of flocculates). For standard cements, this means openings down to about 0.30 mm, while the finest microcements may enter openings of 0.06 mm.

The effect of a water-reducing admixture (or dispersive admixture) on a microcement suspension can reduce the $d_{85}$ significantly, e.g., from about 9 μm to 5 μm, strongly influencing the injection capability of the suspension.

## PROPERTIES OF INJECTION GROUTS

The design of injection grouts may be very different from country to country and also from consultant to consultant. In some projects, there are almost no design requirements, while elsewhere, the requirements may be very rigid. The focus also varies from place to place. Even so, the following parameters should be taken into consideration:

| | |
|---|---|
| Water-cement (WC) ratio: | Too much water destroys the grout, too little limits penetration. |
| Bleeding: | Has to be minimized (bleeding channels, stable grout) |
| Marsh cone time: | Viscosity good enough to penetrate and not block the water channels |
| Mud balance: | Testing the density of the grout |
| Open time: | Long enough to be pumped and spread into the fissures |
| Setting time: | If too long, this will have a negative time effect on the whole cycle |
| Blaine: | Fineness of the cement |

| | |
|---|---|
| $D_{95}$: | Size that 95% of the particles will pass |
| Strength: | Not very important in moderately jointed hard rock; in weak or heavily jointed rock, a certain mechanical strength (ca 10 MPa compressive strength) of the hardened grout is favorable |

Most of these parameters are linked together. If you have a high W/C ratio, you get high bleed, very low viscosity, long open time, longer setting time, and low strength. If you use a low W/C ratio, you get no bleed, low viscosity, shorter open time, and shorter setting time and better strength. To make a good grout, you therefore have to balance these factors.

To get a stable liquid grout, it is important to use a well-suited additive in the grout. The additives used are strong water reducers, commonly called superplasticizers. These superplasticizers help to generate a liquid grout, but even more important is their ability to reduce electrical charges and loosen up cement lumps. A normal dosage of the additive is between 1 and 2% of the cement weight.

The W/C ratio should be as high as possible without giving too much bleeding. With good microcement, this means a W/C ratio of about 1. Bleeding should be as low as possible. Most specifications require maximum 2-5% bleeding. A W/C ratio of 1 for normal fine cement will give a marsh cone time of about 33 seconds and a bleeding of about 10-15%. A W/C ratio 1 for good microcement will give the same marsh cone time, but a bleeding between 0-2%. In most cases, microcements give better results than normal cements, though generally, there is too much focus on the Blaine value. Microcement with a high Blaine value is not automatically better than a coarser one. In order to achieve the best possible penetration in the rock mass, the sieve curve and the maximum particle size are much more important properties.

When the pressure starts to build up during the pumping, the cement grout has to be stable so the water is not squeezed out of the grout. If that happens, you get a “filter cake”, which blocks further penetration. To avoid this effect, the shape of the sieve curve is very important. If you have cement with much oversized grains, the oversized ones will block the small grains.

Another important issue is the age of the cement. Microcements for injection should be as fresh as possible. It is difficult to say exactly how old the cement can be before it loses its quality, but it should not be older than 6 months. If the cement is too old, you get more bleeding, slower set times, and a higher risk of cement lumps. Also, cement should be stored in ventilated rooms, not in the actual tunnel. The humidity in the tunnel will get to the cement, and you will get pre-hydrated cement as a result.

The most important daily test is to have control over the W/C ratio. The easiest way to do this is to use the Marsh cone or the Mud balance. Testing the bleeding and setting time is also easy to do in the tunnel: just fill a graded cylinder and read how much free water there is on the top after 2 hours. The cement grout is, under normal conditions, hard enough to start drilling again when the cylinder can be turned upside down without the cement grout running out.

## NEW MATERIALS - COLLOIDAL SILICA

Chemical grouts might be necessary under difficult rock conditions with silt and clay fillings on the rock discontinuities. In the past, grouts containing acrylamide were used. These grouts have very good technical performance, but they had a potential negative influence on the environment. Acrylamide today is banned in most counties. However, a new injection material, colloidal silica, is available to the grouting teams. Colloidal silica is a sol with sub-microscopic particles of amorphous silicon dioxide and a viscosity of 5 mPa, allowing the grout to penetrate fine rock fissures or fine sands like water. An example is MBT’s MEYCO MP320, which can be termed a “mineral grout”.

As demonstrated in Figure 8, pre-injecting fine rock fissures down to 0.02mm crack can be quite onerous. Cements can generally penetrate fissures down to two to three times the largest cement particle size. In the example shown, OPC cannot penetrate, standard microcements, such as Rheocem 650 may or may not work, and an ultrafine microcement, such as Rheocem 900 would probably function well; however, colloidal silica, such as MEYCO MP320, would penetrate all cracks at 0.02mm and finer. This statement is also true for fine silty sand strata. Tunnel projects in the UK are currently performing pre-injection with MEYCO MP320 into extremely fine sands with considerable quantities of clay to create stable ground for tunnel boring machine breakouts and break-ins to shafts.

Certainly, there are many occasions in mining activities where this technology will be of great benefit, particularly where, for example, ground freezing is being used to stabilise sands near ore bodies, or perhaps in uranium mines where the ingress of water containing heavy metals is to be prevented or reduced as much as possible. In such cases, the bulk of the injection work may be carried out with microcements, followed up by proof grouting with colloidal silica.

The open time can be adjusted from a few minutes to 2½ hours, and the equipment required is the same as normal cementitious grouts. Colloidal silica, based only on silicon dioxide and salt water, is environmental friendly, and replaces the acrylamide-based gels used in the past. Internal and external tests with colloidal silica have shown that:

- Shear and compressive strength will increase over time.
- Strength is more than 3 times higher in grouted specimens containing sand than in pure gel.
- Dissolution of silica is very low, and depends on exposed surface area.
- It is important to have measured porosity of soil and performed laboratory trials to decide the right gel time for best penetration.
- The colloidal silica will eventually (millions of years) turn into quartz.

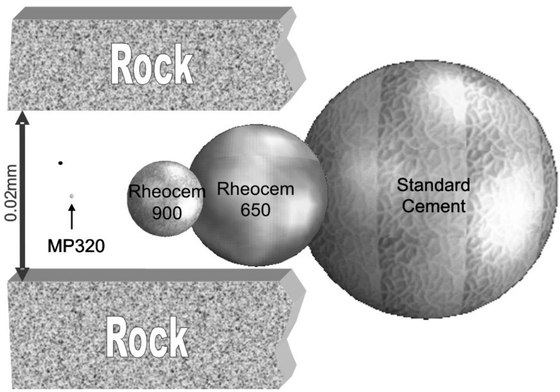



*Figure 8: Size comparison of different microcement particles (MBT Rheocem range) and the new Colloidal Silica (MBT MEYCO MP320).*

## CONCLUSION

Many mines are spending enormous amounts of money to pump water to the surface and then treat it so that it can be discharged. Perhaps it is time to start to consider things differently. As an alternative to investing large sums of money to build pump chambers, install huge pumps, and construct water treatment facilities, only to then spend more money and large amounts of energy to pump-and-treat, pre-injection grouting techniques to prevent the water from entering the mines could be extremely cost effective. Though there are big differences between tunnels and mines, there are also a lot of similarities. We are fully aware that tunnel construction technology can not be directly copied and used in the mines. However, the authors strongly believe that it is time to consider pre-injection as a possible method to implement in mining.

Pre-injection grouting employed in shaft sinking operations has demonstrated enormous cost benefits, and the use of performing, fast setting microcements has speeded up the construction process compared to using standard cements. New material technology, such as colloidal silica grouts, provide the injection team with wider opportunities and greater degrees of success in completely sealing underground structures from water ingress. With these latest technology advances, it is now possible to specify acceptable water ingress down to 3 to 5 L/min per 100 m of tunnel (or adits and shafts) at quite acceptable costs.