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Grouting

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Introduction to Grouting in Tunnel Construction in Rock

Grouting in rock tunnels primarily serves two purposes:

- Control of groundwater ingress
- Improvement of rock mass properties and tunnel stability

The first purpose is clearly the dominant one, with a focus on preventing excessive water intrusion that could create difficult working conditions inside the tunnel. Alternatively, the ingress must be significantly limited to prevent surface damage, such as settlement, or environmental damage like the loss of water resources. Improved stability becomes an additional and positive side effect of grouting for groundwater control.

Pressure grouting in rock is performed by drilling holes with appropriate diameter, spacing, length, and direction, then placing packers approximately 2–3 meters into the boreholes. The packers have an expander at the end that creates a pressure-tight seal against the borehole wall, allowing the grout to be pressurized and injected into cracks and channels within the surrounding rock mass.

For tunnel grouting, two main methods should be considered:

- Pre-excavation Grouting (PEG): Boreholes are drilled ahead before the tunnel face reaches new ground. Cement-based grout (usually) is injected and allowed to set before the tunnel reaches the treated rock volume. PEG can also be performed from the surface.
- Post-grouting (PG): The same basic steps apply, but grouting is performed along already excavated sections of the tunnel. Be aware that drilling and grouting through the tunnel face can sometimes lead to backflow of a significant portion of the already pumped grout through connected leakage points from the surface or other locations. When it comes to necessary practical steps and the final outcome, this situation is best classified as PG.

Pressure grouting in tunnels has been practiced for over 70 years, with rapid development particularly in the last 30–40 years. Successful cases now cover a wide range of rock types and hydraulic groundwater pressures of up to 85 bar, as well as urban tunnels with water pressures ranging from 1 to 4 bar. The maximum allowable water ingress depends on local requirements, and most projects set limits in the “drip-free” range (e.g., 1–3 liters/min/100 meters of tunnel up to 40 liters/min/100 meters).

If a strict maximum allowable water ingress is specified, it is not recommended to rely solely on PG. The focus should be on meeting requirements with PEG to achieve results with the lowest possible time and cost.

A more detailed description of grouting is provided in the publication “Rock Mass Grouting” by the Norwegian Tunneling Society (NFF).



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Pretec grouting

There are many types of packers used for rock grouting, and it can be confusing to understand the exact meaning of the terms used. The packers presented in this catalog are all mechanical (as opposed to pneumatic or inflatable packers).

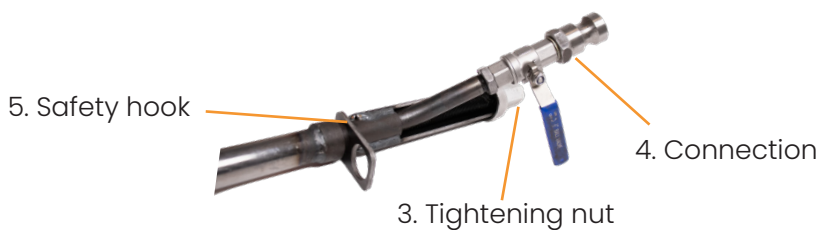
This publication describes the different components of a packer and the grouting tools used, along with some practical aspects of packer selection and use.

1. Packer



2. Injection tool

Grouting tool with mounted rubber packer, ready to be inserted into the hole.



5. Safety hook

3. Tightening nut

4. Connection

System components

1. Packer

- The packer is the rubber component with an outer diameter slightly smaller than the borehole diameter.
- It can be inserted to the desired depth and then expanded against the borehole wall.
- Locking rings slide forward on the packing tube during expansion, allowing the removal of the grouting tool while maintaining the packer's expansion force.

2. Grouting Tool

- The grouting tool is a double-walled injection tube.
- The inner tube connects to the rear end of the packer and to the grouting hose from the injection pump.
- Its purpose is to transport the grout under pressure through the packer into the sealed borehole ahead of it.

- The outer tube connects to the packer's locking rings and allows compression of the rubber by pushing the outer tube forward relative to the inner tube, causing packer compression and rubber expansion.

3. Tightening Nut

- This can be turned on the external threads of the inner tube to compress the packer and expand the rubber.

4. Grouting Hose Connection Unit

- Includes a quick coupling and a valve to open or close the grout flow.

5. Safety Hook

- Used to secure the grouting tool against the rock face.

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Grouting Equipment

Providing a comprehensive list of grouting manufacturers and their various products falls outside the scope of this catalog. This is a broad subject due to the vast range of project requirements, work strategies, schedules, and other factors. Below is a brief summary of different types of equipment required for rock mass grouting.

Cement Grout Mixers

Cement grout mixers, often referred to as "colloidal mixers," would be more accurately described as "high-shear or high-turbulence mixers." Selecting a high-quality mixer is essential to achieving optimal particle distribution and ensuring the grout's ability to penetrate effectively. The standard rotation speed is typically 1500 rpm. Slow-rotating paddle mixers are not acceptable, as has been clearly demonstrated when testing grout bleeding.

Storage Tank / Agitator

The storage tank or agitator plays a crucial role in the grouting process. Mixing a standard batch of cement grout takes approximately three minutes. To prevent overheating due to high mixing energy, the mixture must be immediately transferred to the storage tank, which holds multiple batches from the mixer. Continuous slow-moving paddles keep the grout fresh and prevent it from hardening or increasing in viscosity.



Figure 1: Modern injection rig and truck assembled for storage of grout. *Courtesy of AMV Norway.*

Injection Pumps

Injection pumps used in Scandinavian tunnel grouting practices are exclusively piston or plunger pumps. These pumps are electro-hydraulic and have a maximum pressure capacity of 100 bar. Most grouting is performed at pressures ranging from a few bars up to 50–80 bar, depending on project requirements.

Modern High-Capacity Grouting Systems

With the increasing use of PEG in tunnels, particularly in long underwater road tunnels and urban tunnels that require nearly drip-free tunnel advancement, modern high-capacity grouting systems have evolved. Today's systems can be equipped with four pumps, allowing simultaneous grouting of four boreholes. To support these pumps, at least two mixers and storage tanks are required. Cement is supplied in large bags or in bulk, and an advanced digital system assists in the mixing process while also logging all grouting parameters and the amount of grout injected into individual boreholes.

Additionally, there should be dosing capabilities for adding accelerators to modify viscosity and gel time of the cement grout. The dosing pump must be linked to the cement pump to ensure that the desired dosage percentage remains constant even if the cement pump output fluctuates. This dosing system also enables two-component pumping of Colloidal Silica (CS) using cement injection equipment, allowing for real-time adjustments of gel time during the injection process. Furthermore, the grouting hose from the pump to the packer, along with all necessary couplings, pressure gauges, and valves, must be pressure-rated to ensure safe operation.

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Pretec Single-Use Packers

Pretec grouting packers are available for either single-use or multiple-use applications. The grouting tool has two different coupling units depending on injection pressure and flow rate. The standard length of the grouting tool ranges from 0.5 to 6 meters.

Single-Use Packers

All Pretec single-use packers (PSU) have two special features:

1. Sliding lock rings that permanently keep the rubber expanded, even when the tightening nut is released, and the injection pipe is removed.
2. A one-way check valve that opens for pumping grout into the borehole but closes against backflow when the grout pressure on the tunnel side becomes lower than the pressure inside the borehole.

These two features allow for the immediate disconnection of the pump hose and removal of the grouting tool, leaving the packer expanded in the borehole while maintaining pressure so that the grout can set. The grouting tool, containing fresh and soft grout, can be easily cleaned and reused.

The PSU packer is available with two different check valves. The conical cross-cut valve (type P) is designed for high flow and high pressure (HP), while the check valve (type PX) offers better control at lower flow rates and lower injection pressures (LP).



PSU packer type P



PSU packer type PX

The two packer versions are identical in all aspects except for the check valve. There is no predefined pressure level above or below which the HP or LP version must be used. In general, the selection of HP or LP follows the preferences mentioned above, but local testing and experience should determine the final choice.



The rubber length of the packer is 140 mm, and the recommended minimum torque force to be applied to the tightening nut is 100–120 Nm to ensure a secure anchorage in the borehole and to prevent leakage between the borehole wall and the packer.

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Pretec Multi-Use Packer

The Pretec multi-use packer (PMU) has the same rubber length as the PSU packer but lacks a check valve and locking rings. This means that a fully expanded packer can be released and removed from the borehole by loosening the tightening nut, allowing the rubber to return to its original shape. PMU packers are available in the same dimensions as PSU packers.

During injection procedures, it is generally required to measure and record the water inflow from probe or injection holes. PMU packers, which collect all water from the hole, are often used for this purpose as they allow for precise flow measurement.



In the event of a pump stop, the valve on the connection unit must be closed before disconnecting the injection hose. The injection pipe with the PMU packer cannot be removed from the borehole until the injected grout has developed sufficient stiffness to retain groundwater pressure without support from the packer. Careful handling of the packer removal timing is necessary to ensure proper cleaning of the injection tool and packer. Premature removal of the packer will cause backflow of grout and water.

PMU packers can be reused multiple times, provided that proper cleaning of the unit and lubrication of threaded and moving parts are carried out.

| Packer type | Drill diameter (mm) | Recommended borehole diameter (mm) | Color code |
|-------------------------|---------------------|------------------------------------|------------|
| PSU-P / PSU-PX / PMU 45 | 45 | 44-47 | Red |
| PSU-P / PSU-PX / PMU 48 | 48 | 47-50 | White |
| PSU-P / PSU-PX / PMU 51 | 51 | 50-53 | Pink |
| PSU-P / PSU-PX / PMU 54 | 54 | 53-56 | Yellow |
| PSU-P / PSU-PX / PMU 57 | 57 | 56-59 | Blue |
| PSU-P / PSU-PX / PMU 60 | 60 | 58-62 | Orange |
| PSU-P / PSU-PX / PMU 63 | 63 | 61-65 | Green |

Standard dimensions for grouting packers

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Injection Tool and Connection

Pretec injection tools can be used with both Pretec single-use packers (PSU) and Pretec multi-use packers (PMU). Depending on the intended placement depth of the packer in the borehole, the injection tools are available in standard lengths ranging from 0.5 to 6 meters. The injection pipe of the tool is designed for a maximum injection pressure of 100 bar.

Connection

The connection consists of a coupling for the injection hose and a valve to control the grout flow.

There are two different configurations available, and the user must make a conscious choice based on the maximum allowable injection pressure:

- A high-pressure connection (HP) allows for a maximum working pressure of 100 bar. All components of the packer unit can be used at an injection pressure of 100 bar.
- A low-pressure connection (LP) has a maximum pressure of 50 bar. This connection includes a quick coupling (claw coupling) and a valve with a pressure rating of PN50. It is the only part of the injection system that cannot be safely used at pressures up to 100 bar. Therefore, the injection pump must be locked and sealed to ensure it does not deliver more than 50 bar.



Hydraulic quick coupling (JIC 1 1/16") with ball valve pressure class PN 500 dimension DN15.



Quick coupling with ball valve pressure class PN 63 and dimension DN15.

Note: All Pretec packers are designed for injection pressures up to 100 bar. If an injection pressure exceeding 50 bar is expected, an HP connection unit must be used.

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Injection in Practice

In typical rock tunnel and PEG applications, the borehole diameter is usually around 63 mm, which is well-suited for borehole lengths up to 30 meters while maintaining reasonable borehole deviation. If the maximum borehole length is shorter and the drilling equipment functions better with a reduced drill bit diameter for any reason, options such as Ø48 or Ø51 mm may be considered.

In most cases, the PSU packer would be the primary choice, with a diameter of either Ø63 or Ø60 mm. This choice saves both time and cost and, under normal conditions, effectively anchors and seals the borehole. Generally, the injection tool can be reused up to ten times, provided it is thoroughly cleaned and lubricated after each use.

In zones with poor rock conditions, the 140 mm long packer may not always be able to fully seal the borehole effectively, sometimes requiring the use of two or even three packers in the same borehole. To mitigate this issue, it is advisable to have alternative solutions available.

1. One approach is to prepare a few PMU packers with a length of 4 meters (or longer injection tools) so that different positions in the borehole can be tested to find a spot where the packer seals properly.
2. Another option is to keep a supply of mechanical or pneumatic packers with rubber lengths of 0.5 to 1.0 meters, which significantly increases the likelihood of achieving a satisfactory borehole seal. In this case as well, the total assembly length should be at least 4 meters.

Even in high-quality rock, there may be conductive channels for water and grout that intersect both the borehole and the tunnel face. If the packer is positioned outside one of these channels, the path of least resistance during injection will lead back to the tunnel, resulting in a significant loss of injected grout.

For such situations, the use of a movable packer (not the PSU version) may be a good alternative. Alternatively, a PSU packer can be placed inside the channel to complete the injection process. If necessary, a second packer can be placed outside the channel, and injection can be performed with an accelerator dosage at the packer to block the backflow through the tunnel face.

Selection of Injection Material

Cement-based grouts are always the first choice for tunnel grouting, and currently, no viable alternatives to cement exist. At the same time, the wide variety of cement types, differences in rock conditions, and varying groundwater infiltration limits for different projects make the selection of cement and the specification of grout properties a complex task.

Pretec packers and injection tools are all suitable for standard cement-based grouting products, as well as for the application of various chemical grouts and colloidal silica mineral grout.

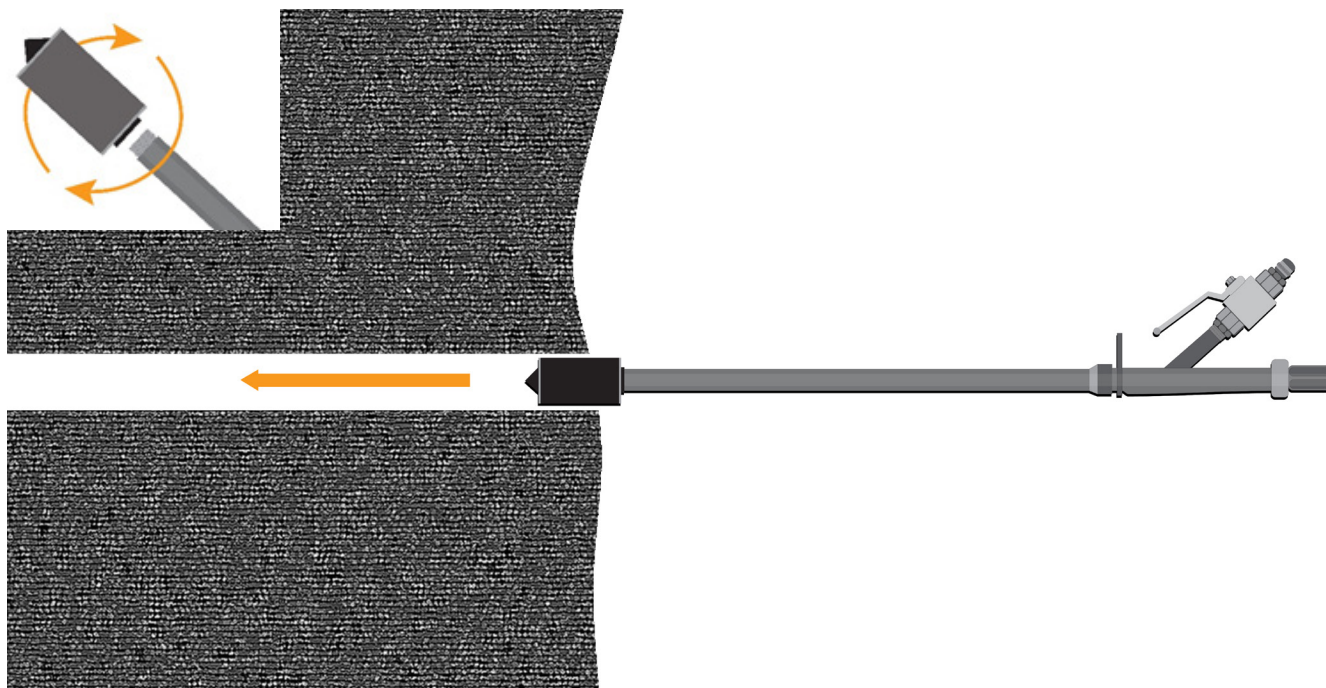
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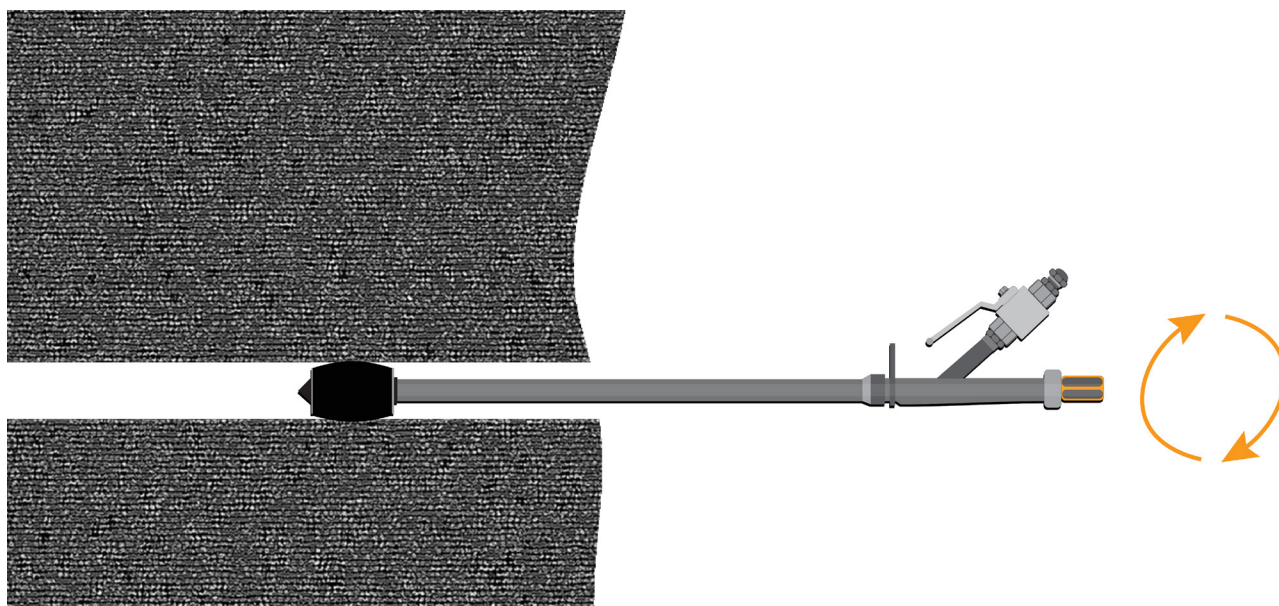
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Installation and Injection of Packer

1. Select the appropriate packer and the correct length of the injection tool with the designated connection unit (high pressure or low pressure). Attach the packer to the inner tube of the injection tool and insert it into the cleaned borehole to the intended depth.



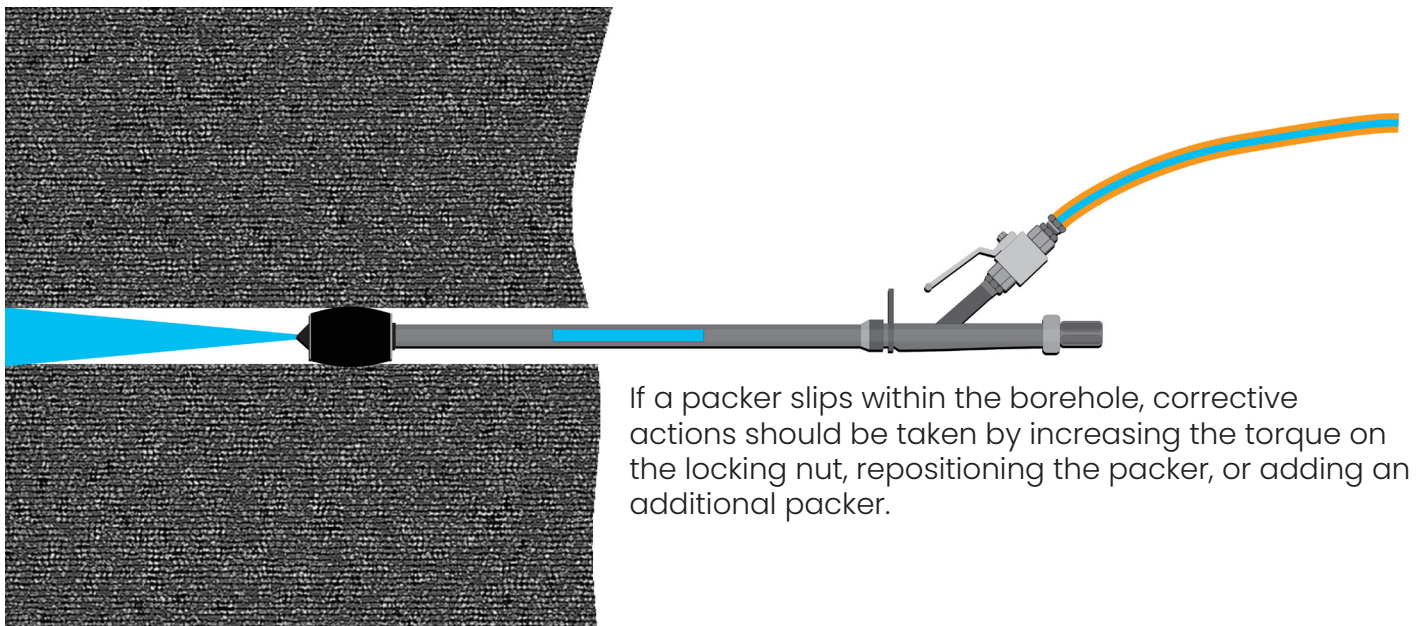
2. Tighten the locking nut to expand and anchor the packer, with a minimum recommended torque of 100-120 Nm. If necessary, check the torque just before starting the injection process.



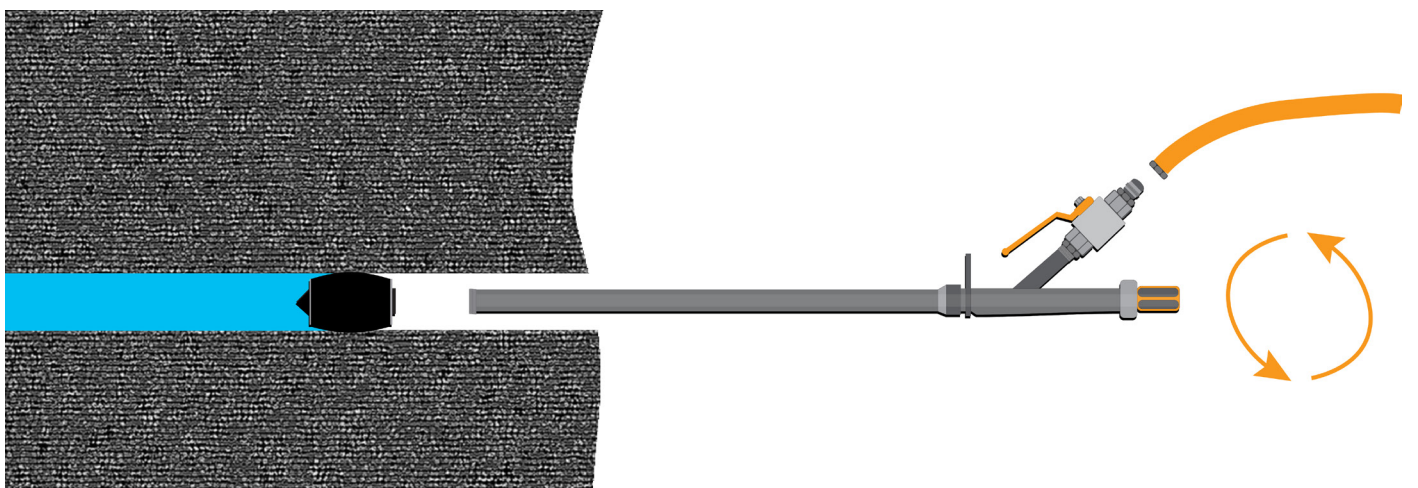
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It is not recommended to start the injection unless the injection tool is secured to the rock surface with a suitable wire or chain. At high injection pressures, the packer may be ejected from the hole, potentially causing injury or damage.

3. When connecting the grout hose, make sure to first pump grout until the hose is completely filled. This step is essential to avoid the risk of compressing trapped air in the borehole.



4. As soon as possible after stopping the pump (for a PSU packer), loosen the locking nut and remove the injection tool for immediate thorough cleaning and lubrication. If injection is performed using a PMU packer, the proper timing for grout stiffening must be determined to avoid grout loss due to premature removal while still allowing for packer cleaning and reuse.



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Health and Safety (HSE)

HSE aspects of grouting in tunnels are an important topic, mostly beyond the scope of this brochure. Some key risk areas include the handling of cement and protection against cement dust, potentially hazardous chemical grouting products, personnel movement around the worksite, and personal protective equipment.

The most significant risk factor is the high pump pressure that forces the grout through the injection hose and packer into the ground. It is important to remember that a pressure of 100 bar is equivalent to the pressure of a 1000-meter water column.

This entire subject requires a comprehensive risk analysis for each individual case, and past experience has shown that:

- All hoses, couplings, connections, and packer components must be rated for the maximum pump pressure.
- Packers can suddenly lose their anchorage in the borehole and be ejected at high speed. Therefore, packers must be secured to the rock surface with an anchored wire or chain.
- Grout is injected under pressure into cracks and joints in the rock mass, which can cause shifts and dislodgment of rock slabs from the excavated tunnel's surface, roof, and walls. For this reason, personnel movement must be restricted while grouting is in progress.
- To prevent accidental sudden pressure loss and hazardous grout jetting, all operators must be trained in the necessary equipment handling procedures, especially regarding the connection and disconnection of hoses, opening and closing of valves, and changing of grout hose connections.

Packers and tools are manufactured under strict quality control to ensure they can be used safely within the specified limits of our products. However, the overall HSE risk assessment and management of site operations remain the responsibility of the end user.



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