The CMC art on Rock-grouting

The 2000 issue by Odd Tjugum for the propose of understanding

Background

Clearly, grouting of rock is not a completely science, it is also an Art, formed by a complex interacting system which is not easily mathematically modeled.

The resistance to flow of a grout through thinner fractures is however obvious, normal solved by increasing grouting pressure to attain the refusal criteria set i.e grouting until no more grout are taken.

This approach however does not take into account the important roles of additives and admixtures that enhance the rheological aspects.

The purpose of using additives in cement-based grouts is to improve the stability (bleeding) and rheological properties (viscosity, cohesion and internal friction or bond) of the grout in order to enhance the penetrability and flow characteristics.

In order to select and determine critical design and feasibility parameters it is advantageous to perform tests to simulated rocks and assess the operation.

At present, there are no truly reliable small scale or laboratory methods which will accurately determine the injectability limits of rocks.

Injectability tests currently being conducted on a lab scale are usually fundamentally flawed. This as these tests does not allow for grout mixing or injection to be performed in the same manner as is done in the field.

However, these tests may be useful for comparing various grout mix designs against the same criteria but do not accurately determine injectability limits or injectability into site specific rock conditions such as:

- the hole spacing
- the grout type and formulation required
- the performance criteria that are economical or reasonably achievable
- the refusal criteria required to achieve the performance criteria

The art of grouting rock are to fully control some of the factors pertain to the in-situ rocks to be grouted while others pertain to the specific parameters of the grout to be injected.

The rock characteristics

that affects the penetrability of a specific grout into that rock medium:

- **"Particle pick-up"** In most cases, the influence of "particle pick-up" are ignored.

  The presence of contaminants(silt/particles) can become dislodged from the rock matrix and part of the suspension grout thus increasing apparent viscosity, suspended solids content and reducing penetration.

  The same applies for the chemistry of the contaminants and the rock that can affect grout rheology or affect gel and set times.

- **Fissure size and distribution**: contribute to permeability coefficient, pore size and spacing

- **Water content:** dry rocks will absorb some of the water from the grout mix and increase the apparent viscosity

  very wet conditions may cause dilution of the grout, especially if unstable grout mixes are used,

- **Homogeneity**: thinner rock layers require more injection pressure to obtain a desired grout spread, and therefore "choke off" more easily,

  Non-injectable strata may block off layers that are amenable to permeation grouting.

  Density will affect the hydraulic conductivity of the rock

The grout characteristics

that affect the penetrability of that grout into a specific rock medium:

- **The particle size and particle size distribution**
- **Viscosity :** at lower level will reduce the internal friction and enhance penetration

  A balanced stable cement grouts can be formulated to provide an apparent viscosity , compared to conventional neat cement grouts. A slightly higher viscosity will be obtained with the additives.

- **Internal cohesion :** affects the travel distance of the grout.

  The cohesion of the balanced stable grouts is lower than the neat cement grouts due to the deflocculating effect of the superplastizer.

  The slightly higher viscosity values result in a slightly lower injection rate. However, the lower cohesion value theoretically provides a greater radius of grout penetration with the balanced stable grouts for a given fracture aperture.

  Evolutive grouts are characterized by a gradual increase in gel strength and increase in viscosity prior to reaching initial gelation (C= 100 pa) which adversely affects its injectability.

  A properly formulated suspension grout virtually should have non-evolutive gelation characteristics: low viscosity is maintained for at least 50% of its final gelation time to achieve the desired grout spread,

- **Thixotropy :** of a grout is characterized by low viscosity under moderate to high shear conditions and high viscosity under low shear

  As the thixotropic grout travels farther away from the injection point, shear is reduced and its viscosity will increase resulting in a gradual refusal

  The additives in the balanced stable grouts slow the hydration process and thus result in a slower set time. This provide a longer working time and reduce possible costs by discarding grouting materials.

  This also suggest that the neat cement grouts older than 2 hours should be discarded as significant chemical bond or internal friction are beginning to form.

- **Stability/ Bleed**: A difference in stability or bleed between the two types of grout can be very significant.
  Bleed water accumulation that occurs in the grout after refusal has been obtained will result in incomplete filling of the fractures.

  This incomplete filling results in the likelihood of significant secondary permeation after grouting and a subsequent reduction in durability due to the network of flowpaths provided by the bleed channels.

Once the grout cures in the rocks, bleed water separates from the solids, causing anisotropic characteristics in grouted rocks (high residual permeability in the horizontal direction and low residual permeability in the vertical direction)
Unstable grout mixes will easily pressure filtrate or form flocs and hereby increase the effective particle size if the blockage gets dislodged.

- **Pressure filtration:** is the occurrence of mix water within the fluid grout separating from the cement, particularly during a pressure grouting operation.

  The coefficient of pressure filtration is determined based on the API filter press test.

  The pressure filtration characteristics of balanced, stable mixes are clearly superior to the conventional neat cement grouts i.e the neat water cement grouts blows air after only 0,5 to 1 minutes, which indicates that most of the water has been squeezed out.

  Several negative impacts are clearly indicated by a high-pressure filtration value and bleeding.

  If a grout mix is susceptible to pressure filtration (i.e. water is 'squeezed' from the grout) a rapid increase in viscosity occurs under pressure and reduces penetrability into smaller pores (as pore channels are smaller, particles tend to "dry pack" and block further flow of grout),

  The rheology of the neat cement grouts is not stable during the pressure injection process and results in self- thickening (sedimentation).

  An other negative impact are also that a significant amounts of water are being injected into the formation being attributed to "grout take".

  The balanced stable grouts sustain a longer pumping distance with no sedimentation or dry packing occurring.

- **The mixing sequence:** the process by which the grout are produced:

  Some additives need to be incorporated in the grout mix at a specific stage in order to provide the desired impact on the fluid characteristics of the grout.

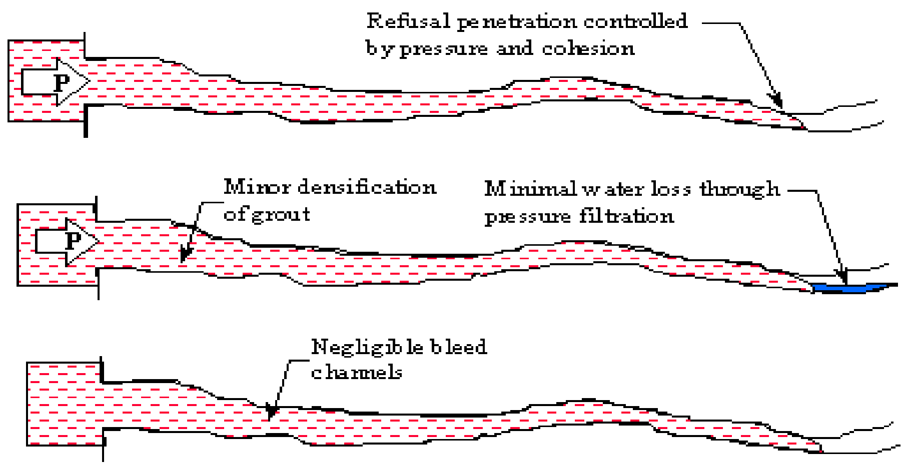
  It is imperative that a high shear mixer is used to ensure complete mixing and that each particle is individually wetted to obtain an optimum stabile suspension.

- **Compressive strength:**

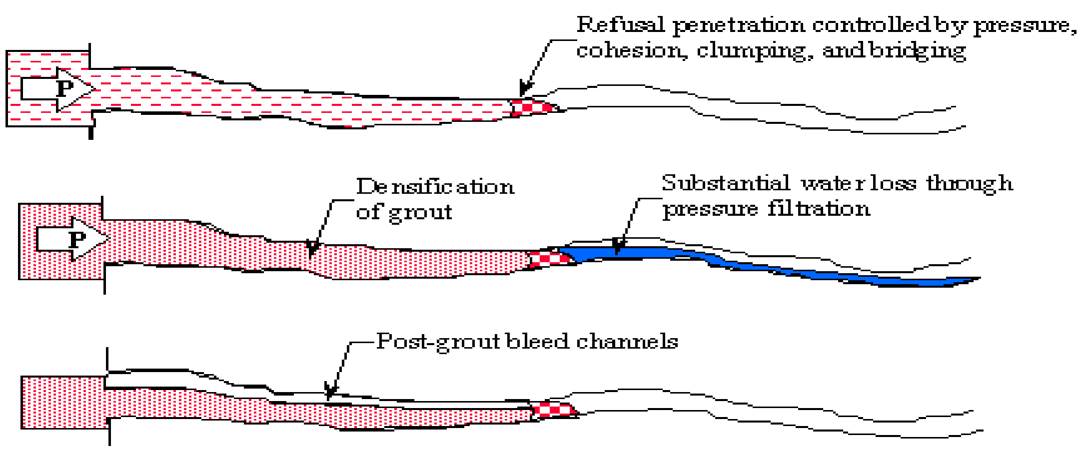
  A balanced stable grout has a lower compressive strength than the neat cement grouts.

The CMC art on Rock-grouting
The 2000 issue by Odd Tjugum for the propose of understanding

Grouting theory - balanced, stable grouts



Grouting theory - neat cement grouts



CMC-*INJECTION BASED UPON "NONE FLUIDLOSS"PRINCIPLES*
SHORT SUMMAY ON HEADLINES OF TECHNIQUE AND MATERIALS

General
The fluidloss technique combines the use of fluidloss additives, ultra rapid setting cement and high speed and pressure pumping.

Goals
Low cost due to reduced down-time compered to normal standard injection principles.

Technique of injection
Start with relatively high viscosity grout, corresponding to w/c-ratio at 1.0-1.5.
Injection of 1-4 holes at the same time.
Apply high pumping pressure from the start, which require high pumping capacity
Injection to be stopped at an in advance decided and agreed :

- Total quantity of grout per holes
  Or
- When reaching an upper pumping pressure

Benefits

- Injection of fine and coarser cracks at the same time
- Reduced time consumption for each round of injection
- No(or very little) down-time waiting for cement to set
- Immediately start of drilling/driving tunnel operations
- Reduced/cutting amount of rounds of injection
- Cutting total costs

Basic principles of standard injection
Long holes for injection will contain a combination of fine, narrow and coarser type of cracks
Standard injection start with a low viscosity grout, w/c-ratio 2-3. Only the coarser cracks will be grouted because of a "filter cake" that will be produced as a bridge over the finer cracks.

As the pumping pressure increases, the finer cracks are lost, that means impossible to inject. This kind of filter cakes can even block the drilled holes completely, only metres from the packers.
The need for extra rounds of injection will thus be required as the control holes show no effect of the last injection.

To solve this problem, the packers must alternatively be placed stepwise, beginning metres from the bottom of the borehole, only. Consequently stepwise waterloss measurements will be required as theses results normally are used for evaluating the exact starting mix (w/c-ratio).

Basic principles of new technique
Fluid-loss additives are here the most important ingredience followed by ultra rapid setting cement.
The result is a grout without water separation.

Filter-loss testing

- Ca 0.5 l of the grout are pressurised at 50 bar in a testcylinder, containing a 45 micrometer filter in the bottom
- Expelled quantity of water is measured after 2 ,5 and 30 minutes
- Thickness of filtercake produced inside the cylinder are measured, in mm, and consistency described, soft, hard etc.
- Fluidity of grout above filtercake to be described
- Viscosity at 600, 300, 200 and 100 rpm are measured in seconds

By standard cement grout without additives, even micro-cements, can show total loss of water, and thus producing heavy filtercakes with no grout of ant kind above.

Introducing/adding special fluid-loss additives, the loss of water can be regulated down to only a minimum, controlled by producing a filter cake over the finer cracks. As a consequence the pressurising of the grout does not influence on the flowability/viscosity of the grout elsewhere in the midler and coarser cracks.

This explains the new technique.

Finer cracks are sealed off by a thin filtercake and with no influence on the performance of the narrower/coarser cracks that normally are more effective injected by a corresponding thick cement grout at high pressure.

Use of ultra rapid setting cement, cuts down time waiting for cement to set, likewise it also naturally shows up low and reduced time for any water separation. Consequently the cracks will be completely filled.

Sealing off finer cracks implies that these cracks will remain completely isolated in the rock, without influence on the proceeding water loss measurements.

The CMC – truck on grouting

- .**General**
- The fluidloss technique combines the use of fluidloss additives, ultra rapid setting cement and high speed and pressure pumping.
- .**Goals**
- Low cost due to reduced down-time compered to normal standard injection principles.

Technique of injection

- .Start with relatively high viscosity grout, corresponding to w/c-ratio at 1.0-1.5.
- .Injection of 1-4 holes at the same time.
- .Apply high pumping pressure from the start, which require high pumping capacity
- .Injection to be stopped at an in advance decided and agreed :
  - Total quantity of grout per holes
  - Or
  - When reaching an upper pumping pressure

Benefits

– .Injection of fine and coarser cracks at the same time
– .Reduced time consumption for each round of injection
– .No(or very little) down-time waiting for cement to set
– .Immediately start of drilling/driving tunnel operations
– .Reduced/cutting amount of rounds of injection
– .Cutting total costs

Basic principles of standard injection

– Long holes for injection will contain a combination of fine, narrow and coarser type of cracks

– Standard injection start with a low viscosity grout, w/c-ratio 2-3. Only the coarser cracks will be grouted because of a "filter cake" that will be produced as a bridge over the finer cracks.

– As the pumping pressure increases, the finer cracks are lost, that means impossible to inject. This kind of filter cakes can even block the

Basic principles of new technique

– Fluid-loss additives are here the most important ingredience followed by ultra rapid setting cement. The result is a grout without water separation.

Filter-loss testing

- .Ca 0.5 l of the grout are pressurised at 50 bar in a testcylinder, containing a 45 micrometer filter in the bottom
- .Expelled quantity of water is measured after 2 ,5 and 30 minutes
- .Thickness of filtercake produced inside the cylinder are measured, in mm, and consistency described, soft, hard etc.
- .Fluidity of grout above filtercake to be described
- .Viscosity at 600, 300, 200 and 100 rpm are

The CMC – truck on grouting

- By standard cement grout without additives, even micro-cements, can show total loss of water, and thus producing heavy filtercakes with no grout of ant kind above.
- Introducing/adding special fluid-loss additives, the loss of water can be regulated down to only a minimum, controlled by producing a filter cake over the finer cracks.
- As a consequence the pressurising of the grout does not influence on the flowability/viscosity of the grout elsewhere in the midler and coarser cracks.

This explains the new technique.

- .Finer cracks are sealed off by a thin filtercake and with no influence on the performance of the narrower/coarser cracks that normally are more effective injected by a corresponding thick cement grout at high pressure.
- .Use of ultra rapid setting cement, cuts down time waiting for cement to set, likewise it also naturally shows up low and reduced time for any water separation. Consequently the cracks will be completely filled.
- .Sealing off finer cracks implies that these