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BRIEF OVERVIEW OF THE VARIOUS FAMILIES OF GROUTS AND THEIR APPLICATIONS

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1.0 INTRODUCTION

It is difficult to maintain an up-to-date overview of all the grouts presently used on the international market. Better grouts are continuously developed and more formulators are making their appearance. Consequently, it is difficult to clearly define all of the products in the industry.

Major chemical corporations are beginning to licence approved formulators, who in turn, will strive for recognition on the market. These forces will create a bigger market and further diversification into other industries. This implies that the industry will require a classification of the various families of grouts in order to better determine the suitability of a particular product for specific application. We should be ready for fascinating evolutions, more competitive prices, and hopefully, less "black magic".

This topic has been the subject of numerous papers and textbooks. Karol (New Orleans 1982), Caron (Paris 1982), and a number of German, French and American authors havemade valuable contributions to shed light on this issue.

Most authors, however, only focus on their fields of interest: applications in geotechnical, or rehabilitation, or seepage control in civil engineering, oil or mining industry. There has been a limited transfer of technology from one field to the other because of the enormous differences in magnitude, site conditions and consequently the application techniques.

As one can imagine it requires a slightly different approach to seal cracks in concrete as compared to the control of a 12,000 gpm inflow in a deep mine. The installation of a grout curtain in geotechnical applications applies different technology compared to the sealing of the formation above and below the pay zone in an oil well, or jacking up a tunnel.

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DISCLAIMER

The tools the engineer has are:

- His expertise in grouting and engineering background.
- Equipment available or to be designed or modified to carry out a particular job.
- Relevant data available from other sciences, to understand the problem or the situation.
- Products with a variety of characteristics.

This paper concentrates on product selection. The most suitable product for a particular project requires a good understanding of the general chemical and mechanical characteristics of the grout:

- penetrability limits
- viscosity and pumpability limits
- control of set times and factors influencing this characteristic
- long term behaviour and stability
- toxicity
- sensitivity
- behaviour under different pressure regimes
- availability and cost.

The grouts have been classified into four categories for the purpose of this paper. There may be other methods of classification, however, this is only an attempt to help the industry with the selection of the most suitable grout for a given application.

The four categories of grout are:

1. Suspension Grouts
2. Chemical Grouts
3. Hot Melts
4. Precipitation Grouts

2.0 SUSPENSION GROUTS

There have been a number of excellent papers written on this subject, and further research is continuing.

A Suspension Grout consists of:

- The fluid: water or water based liquid.
- The particles: the main component of the grout, not soluble in water, but suspended in a certain concentration.
- The additives:. products to improve or change the characteristics of the grouts, to accomplish particular objectives.

We distinguish 3 categories of suspension grouts:

- Bentonite Grouts
- Cementitious Grouts
- Others (such as clays, silts etc.)

This paper is limited to the discussion of the two first categories.

2.1 Bentonite Grouts

Bentonite is a clay-phyllosilicate of the 2-1 structures, which can absorb up to 16 times (Sodium-montmorillonite) its original volume. It consists of 2 identical plan parallel plates separated by a larger plate. Water is physically bound to these plates, and as a result a stable suspension can be formed. Researchers, such as Jefferies (Stockholm 81 & New Orleans 82) carried out a thorough investigation of the mixing variables (type, time and speed) of bentonite suspensions. It was discovered that the viscosity of the gel gradually increased in time, and that the original mixing speed and remixing after initial hydration has taken place, have a significant impact on the rheological characteristics of the slurry; i.e. the higher the mixing speed (10,000 rpm), the higher the gel strength.

In the field, the viscosity of the slurry is measured with the Marsh Cone.

There are a variety of bentonites on the market, with different characteristics. The slurries contain between 5 and 15% of bentonite for most applications. Examples of applications for Bentonite Grouts are:

- Lubrification (reduction friction losses) in tunnel and pipe jacking.
- Drill mud: to stabilize a drillhole (often in combination with baryte to increase specific gravity).
- Cut-off walls and trenches.

2.2 Cementitious Grouts

These are suspensions of cement in water, prepared in a certain fashion (mixing method), to which other additives are added. We distinguish 3 families of cementitious grouts:

* Unstable Grouts
* Stable Grouts
* Microfine Cements

2.2.1 Unstable Grouts

Typical of these grouts is the segregation of the particles after they have been mixed with the fluid. Bleed water forms on the surface, while the particles settle. The characteristics of the cured grout are seldom uniform throughout the mix.

Unstable cement grouts are frequently used in mines to reduce inflows, although stable water repellant grouts in conjunction with chemical grout would provide a much more effective and more economical solution in most cases. The stability of these grouts can be improved by high shear mixing (colloidal mixer) and by adding certain polymers and dispersing agents. An unstable grout (by design) should only be used when segregation and caking is either desired or unimportant.

Possible applications of Unstable Grouts are as follows:

- Stabilization of coarse backfill and rubble.
- Restoration of porous structures (i.e. natural stone walls, masonry) often in conjunction with rebars.
- "Squeeze Jobs" in deep drilling to seal formations.
- Ground anchors, according to some practioners.
- Jet grouting.
- Backfill grouting in mining (associated with dewatering of the grout) when the "cut-and-fill" method is used.

2.2.2 Stable Cementitious Grouts

These are grouts which cure with negligible bleeding and shrinkage. articles remain in suspension when agitation of the mix is interrupeted. These grouts can e c--egorized by their viscosity, particle size, resistance against dilution, resistance against -e: -e filtration, and mechanical strength.

Depending on the type of application, the applicator has to select the ppropriate formulation, mixing sequence, additives, mixing technique, and, if required, pe of fluidifiers and defloculators. This requires a good understanding of the :aracteristics of a number of products.

Mixing:

Regardless of the ingenuity of the formulator, if the mixing is not ppropriate (high shear mixing, not paddle mixing), the results of the entire operation are in opardy. In particular, the "paddle mixing syndrome" is deeply rooted in the mining dustry and often is responsible for questionable performances. Houlsby (1982), Gourlay id Carson (1982), Mueller (1982) and a number of reputable grouting experts agree that e use of a paddle mixer should be limited to rather small and simple applications. The :per by Mueller & Del Val (1989) clarifies these topics further.

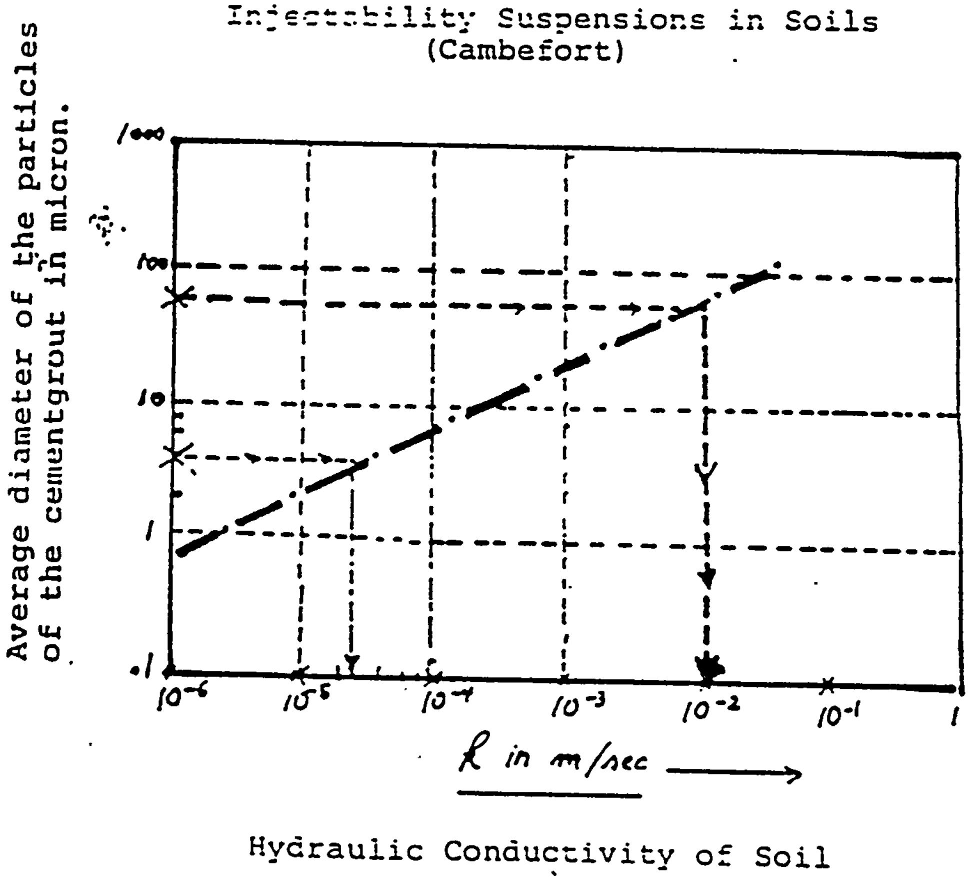
Penetration and Penetrability:

*Soils: A properly balanced grout can penetrate soil provided that the average diameter of the particles in the suspension is smaller than

$$\sqrt{\frac{32\nu k}{g n}}$$

The following graph is useful in determining the injectability of Suspension Grouts in soils.

Injectability Suspensions in Soils
(Cambefort)



*Rock: The penetrability of regular cementitious grouts is limited to fissures wider than 160 micron (Littlejohn 1975). It is common practice, especially in the mining industry, to use extremely high grouting pressures, thereby fracturing of the rock, and increasing the hydraulic conductivity of the formation, defeating the purpose of the operation.

Brief Review of Some Additives:

1. Stabilizing Agents and Fillers:

- Bentonite:
  - Reduces bleeding.
  - Buffers against dilution and caking provided prehydrated slurry is used (time consuming).

- Silicafume
  - Good Stabilizing Agent:
  - Reduces bleeding
  - Prevents caking
  - Reduces permeability of cured grout. Some pozzolanic characteristics
  - Excellent as thixotropic agent making grout more water repellant.
  - Is becoming expensive.

- Cementfume (Microfine Kilndust):
  - Good thixotropic and stabilizing agent.
  - Good water repellant characteristics and buffer against dilution.
  - Increased viscosity, reduces penetrability and pumpability.

- Clays (dry) (especially after being used for other purposes - waste product):
  - Enhanced penetrability.
  - Water repellant.
  - Inexpensive filler.

- Slag and Limestone Dust.
  - Inert filler to be used in conjunction with other additives.
  - Poor resistance against caking.

- Flyash (types C and F):
  - Inert filler but some types of flyash have pozzolanic characteristics.
  - Characteristic strongly dependent from plant to plant (type of coal): some flyash has excellent water repellant characteristics.
  - Poor resistance against caking.
  - Poor stabilizing effect (most flyashes) - requires other additives.

- Trass (clay phyllosiiicates 1-1 structures - natural pozzolan):
  - Excellent pozzolanic characteristics.
  - Some stabilizing characteristics.
  - Good waterrepellant characteristics.

2. "Magic" Liquids and Powders:

Accelerators:
- Calcium Chloride
- Sodium Silicate
- Organic Accelerators

Retarders:
- Calcium Lignosulphonate
- Sugar

Fluidifier:
- Superplasticisers
- Detergents
- Naphtalenes
- Calcinmlignosulphonate

Expanders:
- Aluminum Powder
- Saturated Brine

Some Applications of Stable Cementitious Grouts:

- Curtain grouting in rock or granular material.
- "Flash Set" (2 components) grouting in mining (replacing wooden cribs).
- Backfill grouting behind tunnels, liners, foundation bases.
- Slope protection grouting in geotextile mattresses.
- "Cement Foam" grouting for compressible low density backfill in mining operations.
- Slabjacking, mudjacking and compaction grouting.
- Stabilization of tunnel face or back in unstable granular soil condition.
- Rootpiles.
- Ground modification technique for foundation construction in unstable soil conditions.
- Structural repairwork and renovation in concrete or masonry structures.
- Encapsulation heavy metals in soils: treatment of sludges.

2.2.3 Microfine Cements
(AVXCCM, MC500, MC100, CEMENTFUME)

To enhance the penetrability of cement based suspension grouts, finer ined, cementitious grouts were developed and commercialized. MC-500 is a Japanese [illegible] introduced in the early eighties. Fifty percent of the particles are smaller than 4 ron and the Blaine finess = 8000 cm^2/gram. An unstable grout is formed with sfactory penetrability into sands with a hydraulic conductivity over 8 10^{-4} cm/sec.

A colloidal mixer is required for preparing the suspension and a dispersing nt such as naphtalenesulphonate should be added.

Microfine cementfume has been introduced for the same type of applications 500 has been used. Like with MC100, a sodium hydroxide solution is used as the [illegible] of the particles in the suspension. These products have been successfully used in a [illegible] of soilgrouting projects.

Typical applications are:

- All types of soil grouting projects.
- Structural repairwork.

3.0 CHEMICAL GROUTS

3.1 Sodium Silicate Based Grouts

These are the chemical grouts most commonly used for soil and rock grouting. Their popularity grew as a result of the pioneering work being carried out by researchers like Dr. Peruchon with Rhone Poulenq. There are numerous studies published on some of the uncountable case histories (particularly in Western Europe), mechanical characteristics and long term behaviour of grouted soils, especially since the Nurenberg catastrophy rocked the grouting industry.

3.1.1 The Classic Sodium Silicate Solutions

This is a 2 component grout:

- The A-component is a diluted sodium silicate solution. The original solution is characterized by its density (in degrees Baume). The most commonly used solution is the 38° Baume solution. Water is added "to taste", and determines whether a weak or hard gel will be formed.

- For the B-component, a number of products have been used. Products such as: $CaCl_2$ (unpractical "Joosten "procede").
  Formamide
  Acids such as H_2SO_4, H_3PO_4
  Ethylacetate

  are no longer in use because of the handling problems, and the unpredictable behaviour of the gels (fast deterioration). Rhone Poulenq developed the hardeners of the 600 series (sixties) and later the 1000 series (early eighties), to solve some of the inconveniences experienced with other hardeners.

The "Durcisseurs" from Rhone Poulenq are a mixture of diacidesters, ethyl glutaric, adipic and succinic acids.

There have been serious problems with these sodium silicate grouts. Although their viscosity is low, resulting in ample penetrability, the long term stability is debatable. The more hardener used in the gel, the higher the degree of neutralization and hence the better the durability, however, the pump time will become shorter unless some of the more special types of hardeners are used which produce prolonged gel times.

The viscosity starts to increase as soon as the two components are mixed, until the gel is formed (evolutive reaction pattern).

If diluted by groundwater flow, it is possible that the product may not cure completely and cause environmental problems. As a result, it should not be used when there is a chance for this to occur. Some countries are becoming very strict about the use of sodium silicates in soil grouting.

Sodium silicates are still successfully used in conjunction with cementgrouts in "flash set" applications.

3.1.2 Non Alkaline Silica Sol

This is a Japanese product created to eliminate some of the environmental concerns with the classic zodium silicate systems. Basically, the alkali has been removed and the solution has the same ph as the groundwater. An inorganic hardener is used. The Japanese claim excellent gel stability, and a complete and easily controllable gel time. This product, so far, has been of little practical use to the international grouting industry.

3.1.3 Silacsol

This recently developed silicate based grout has been used by some of the major French and Italian contractors over the last few years. The A component is an activated silica liquor and the B component is an inorganic hardener. A crystalline end product is obtained which remains stable in time. The typical syneresis (formation of free water after the grout has gelled), as encountered with the classical sodium silicates is not evident. Because of its stability, this product does not pose an environmental problem. The viscosity does not increase noticeably until 80% of the gel time has lapsed. The product is used for the typical tunnelling and cut off wall applications, soil and rock grouting. This product shouldn't be used when there is a risk for considerable dilution.

3.1.4 Terraset (Celtite)

This is a three component silicate grout producing a permanent gel. An unsoluble stiff silica gel is formed when hardener and the silicate solution are mixed. This set time can be cut down by adding an accelerator. The more the mix is diluted, the longer the gel time. The reaction is an evolutive gelation. The product should preferrably be injected with a two component positive displacement grout pump. It is used for soil and rock grouting to prevent seepage of in cut off walls.

3.2 Acrylamide, Acrylate Grouts

(Products such as AM9, AV100, Rockagil, Siprogel, PAM, Terrastic, AC-400, Injectite 80 etc.)

AM9 has been called "the ideal grout" for seepage control. It has a viscosity comparable to water and can be adjusted to meet particular job requirements. At present, AV-100, manufactured in Japan is used instead, because the manufacturer of AM9 is only producing for a selected and very limited number of end-users.

Acrylamide based grouts consist of a mixture of two organic monomers:

- acrylamide
- cross linker (usually 5%)

These powders are usually diluted to a 10% concentration in water. The more cross linker added, the stiffer the gel; the higher the concentration of the monomers, the higher the gel strength.

Acrylamide solutions (A component) are activated with products like T.E.A. (thriethanolamine).

The second component contains the catalyst (diluted in water), which is usually amoniumpersulphate. On the second component, other additives are added to either influence gel strengths or to make the grout more compatible with the groundwater chemistry.

The gel time is influenced by the following factors:

- Concentration of catalyst (AP) or initiator.
- Temperature of rock or soil (very significant influence).
- Concentration of the activator.
- Soil water chemistry.
- But not by the concentration of acrylamide in the solution, as long as it is above 3%.

The A component should not be exposed to sunlight or metal. Fresh concrete or cementgrout acts as a positive catalyst and gel times are seriously reduced when acrylamide grout makes contact with it.

Gel times are controllable within narrow limits between a few seconds and 24 hours.

The grouts are neurotoxic and should be handled with utmost care. When diluted beyond the 3% concentration limit, there is no gelation possible, and they become an environmental hazard.

If handled with care, these products are an excellent tool in the hands of the professional grouter. Therefore, it is recommended to dissolve the monomers under controlled circumstances in the shop and ship the concentrated solutions to the site.

Products like AV100 already contain the cross linking agent.

Acrylamide gels are weak and subject to extrusion from wider cracks under elevated pressures.

When the manufacturer ceased production of AM9, products like AC400, Rockagil BT & BT2, etc. were developed.

The AC400 and the AV120 Durigel are polyacrylamides using the same catalyst and activators as the monoacrylamide systems. Because polyacrylamides are less toxic, they are sometimes preferred over the less expensive monoacrylamide solutions. The applications for these products are basically the same as for the monoacrylamides.

Rhone Poulenc formulated a number of acrylamide combinations such as the Rockagil family and siprogel. The first series of products could be considered acrylic/formaldehyde grouts, and are mainly used in Europe instead of monoacrylamides, which are unofficially banned in most European countries. Rockagil uses the same activator and catalysts as the monoacrylamide. It is generally applied for minor seepage control and non accessible sewer grouting projects.

Siprogel is a sodium silicate/acrylamide combination which results in a flexible strong gel. The reaction is controllable within narrow limits.

P.A.M. is a polyacrylamide mainly used for surface stabilization and revegetation. Glyoxal and ammonium hydroxide are used to create a stable gel with low phytotoxicity.

Typical Applications:

- Sewer grouting in non-accessible sewers.
- Grouting matrix porosity in concrete and rock.
- Fine sand modification (low mechanical strength and low hydraulic conductivity).
- Seepage control, especially finer cracks, or passive cracks under low hydrostatic pressure.
- Erosion control and revegetation.

3.3 Water Reactive Polyurethanes

Polyurethane prepolymers have one thing in common, they react with ground) water to create a foam or a gel which is either hydrophobic or hydrophyllic.

They are "one component" products using "the enemy", the water as a reaction partner to create a finished product. The first generation of prepolymers was manufactured in Japan by companies such as Takenaka (Tacss products), Dai Ichi Kogyo Seyaku co (polygrouts) in the late sixties.

These products were introduced in the European market in the seventies. No other type of products has changed the grouting industry in such a fundamental way. Some projects that used to take months could suddenly be done in a matter of days. Soon the prepolymers were considered the "Deus ex machina" for any type of seepage problem. A new technology emerged but applicators learned the hard way what the limits of the prepolymers were.

It became clear that the hydrophobic polyurethanes were not a replacement for the AM9, but were catering to a different market segment. The hydrophyllic polyurethanes were more suitable to fill the gap left by the AM9.

Water-reactive prepolymers are high molecular grouting materials. They are primarily produced by mixing a polyol with an excessive amount of polyisocyanate to form a low prepolymeric compound, containing some free OCN groups. The injection resin is composed of this prepolymer, plasticiser, diluter, surface stabilizer and the amine catalyst.

The mechanism of reaction among the isocyanate, polyol and other components is rather complicated. In simple terms the following happens:

- The reaction between the isocyanate and the polyol yields a prepolyurethane.

- The reaction of polyisocyanate with water liberates carbon dioxide and urea derivatives.

- The reaction of polyisocyanate with ureido develops molecular links and high molecular formation.

These reactions occur because of the existence of the free OCN groups in the grout, which can react with the compounds containing active hydrogen atoms, such as hydroxy, water, amino and ureido. The hydrogen atoms move to link up with the nitrogen atoms of the polyisocyanate and from high molecular polymers.

3.3.1 Hydrophobic "Rigid" One Component Prepolymers for Blocking Water Inflows and Soilgrouting

Water Cutoff: Tacss 20, Aquapreps 15, Deci 16, SK1, MME Universal, Rhone Poulenq P.U., Mountaingrout, Adhesive Engineering 4058, Resicast GH67, BASF & BAYER Formulations etc.

Soil Stabilization: Tacss 25, Aquapreps 05, Deci 161, SK3, MME Ultrafine etc.

These products react with the in-situ water and expand during the exothermic reaction, releasing carbon dioxide. They are totally inert and stable after reaction, but have no flexibility.

The water cutoff series has been developed for major water cutoff and seepage control. They are most suitable for the fairly crude applications when water has to be stopped, but not necessarily to the last drop.

Products within the same family differ due to:

- viscosity
- mixability with water
- reactivity at elevated pressures
- toxicity (solvent content)
- cellular structure of the free foam and hydraulic conductivity of grouted soils.

In order to start the reaction, there is a minimum enthalpy required, which is higher, as the pressure is higher. This means that, if the enthalpy is too low (temperature low) the reaction does not start unless the products are mixed thoroughly with the ...r. Some researchers have come up with a reaction-diagram for some of the products (a "reaction-line" below which the reaction takes place, and above this line reaction does not occur). Some of the more recently developed prepolymers react regardless of pressure and groundwater temperature (such as MME Universal).

The reaction pattern is different for every pressure-temperature situation, which makes the control of the reaction sometimes rather difficult. For example:

- where there are small and large cracks, the heat build-up in larger cracks is higher than in smaller cracks.

- when the cracks start to plug up, the carbon dioxide will build up additional pressure, again altering the pressure regime (in completely closed environment, the reaction pressure can build to is over 400 psi [2.7 Mpa]).

A way to control the reaction times is by using the products as a two ...ponent grout, with water or brine being the second component, separately introduced nto the manifold. By using the header-pipe as resident-pipe, and selecting an induction period, a little longer than the resident time, for a given pressure, it is much easier to control an inflow. This is a fairly sensitive operation as the flow pattern is continually changing during the grouting operation.

Some Typical Applications:

- Curtain grouting in rock and soils, under a continuous water flow, or when there is a chance of dilution of the grout.
- Tunnel grouting to control inflows or for ground control purposes.
- Sealing water and groundbreaks ("renard") through joints in Icanda walls (subways, tunnels, parkades etc.).
- Stopping piping and internal erosion of soils in coffer dams, sheetpile structures, retaining walls etc.
- Water seepage control in leaking mine shafts and underground workings.
- Sealing dike breaks.
- Structural repairwork in brick or natural stone structures, in conjunction with cement grouting.
- Underwater seepage control (divers).
- Controlling potential water inflows prior to blasting: grouting prepolymers in conjunction with cementitious grout to speed up the advance rate of a drift.
- Quick tieback anchors for pipelines, shoring etc.
- Grouting joints in accessible sewers.

3.3.2 Hydrophobic "Flexible" Prepolymers

(such as Flex 44, MME Flex, Mountain Grout Flex)

These products remain flexible in time and are "formstable". They usually have a high viscosity. The foam contains a certain percentage of open cells, and grout has to cure under pressure to form an effective seal.

Applications:

- Sealing seriously leaking expansion joints.
- Sealing seriously leaking active cracks.

3.3.3 Hydrophyllic One Component Polyurethane Grouts such as products manufactured by:

- 3M (US)
- Spetec (Belgium)
- Dai Ichi Kogyo Seyaku Co (Japan)
- Togo (Japan)
- De Neef (Belgium)
- Denys (Belgium)

etc.

and distributed under a variety of trade names such as CR grouts & Scotchseal, AV-Grouts, Superseal, Polygrout, MME Multigrout, Penegrout, Strata Tech Series, etc.

These products are grouted in conjunction with water and form a hydrophyllic gel or a hydrophyllic foam (depending on mixing ratio).

A hydrophyllic gel is not very stable in time. The degree of stability varies from product to product. The cured gels continue to physically absorb water in certain or uncontrolled quantities depending on the type. The hydraulic conductivity of the cured g . increases and the grouts lose their bond and some of their strength. Some products

ot survive the accelerated aging test. When the grouts absorb water after gelation, they
t a swell pressure which sometimes cannot be sustained by the structure.

Care is recommend when selecting these products for an application. When products are mechanically confined, the post-swelling is rather a positive characteristic e a tighter "gasket" is created.

Some Typical Applications:

- Sealing cracks in leaking underground structures (grout not subject to wet/dry cycles).
- Soil grouting in small scale projects (only certain types suitable).
- Cutoff grouting in rock with very high hydraulic conductivity.
- Grouting joints in non-accessible sewers.
- Grouting injectotubes in confined joints.

3.4 Polyurethane Elastomers (2 Component Grouts)

These products consist of 2 components:

- The polyol (usually a polyether polyol) on which a catalyst is added to select the gel time.

- The isocyanate: preferably .... M.D.I. (Diphenylmethanediisocyanate) type since T.D.I. (Toluene Diisocyanate) poses severe health hazards at ambient temperature.

The first generation of polyurethane elastomers have been used in Germany ince the early sixties under the name "polytixon". The polytixon products are T.D.I. based; oils are used to lower the viscosity.

Since 1984, a new generation of polyurethane elastomers has been duced to the grouting industry resulting in considerable improvement of the ehabilitation and seepage control grouting.

3.4.1 Hydrophobic Polyurethane Elastomers:
(Resicast GH40 & 65, MME Polycast Std. and L.V.)

In cured form these grouts are totally inert and hydrophobic, and they :main flexible in time.

The set time can be adjusted within narrow limits. These products have an xcellent penetrability in cracks and are more suitable than the classic epoxy grouts for tructural repairwork in concrete.

For most applications, the excellent characteristics of epoxies are not equired. As long as the tensile strength and the bond of the urethane to the concrete is greater than the tensile strength of the concrete, it is sufficient to adequately seal cracks in concrete. The major reasons for structural grouting are:

- Seal the cracks against penetration of air, water or steam.
- Protect the rebars against corrosion.

Contrary to what is accepted by most authorities in the U.S., a good bond of the grout on both sides of the joint is required to obtain a proper seal. "Flush-grouting" of cracks with water or even diluted HCl may be required prior to grouting. (When HCl is used, flush with water to remove acid completely).

Only a few applications do require the injection of a rigid epoxy into fissures in concrete. Epoxies have far superior characteristics than concrete, but are not able to follow any deformations, and as a result, new cracks adjacent to the old ones often occur. Most applications become allergic to epoxy in time, and a number of amine hardeners are not "user friendly".

More and more multiple grouting is used under rather high pressures to saturate porous concrete or rock, or to fill fine fissures. The longer a borehole is exposed to a given pressure, the higher the spread out radius of the grout. In order to obtain an :onomical" take, it is advantageous to expose a number of boreholes simultaneously to the same injection pressure.

The adjustability of set times of 2 component polyurethane elastomers is a major advantage over epoxies. Polyurethane grouts (M.D.I. based) are less harmful to the applicators than epoxies.

Some Possible Applications of Hydrophobic Grouts:

- Sealing cracks and joints in concrete and masonry.
- Structural repairwork by saturating honeycombed concrete, matrix porosity in rock and wooden beams (restoration).
- Injectotube applications (contactgrouting)
- Sealing techniques around bulkheads.

3.4.2 Water Compatible Hydrophobic Grouts such as (MME Polycast Wtr.)

The products displace water in cracks and cure without reacting with the water, to form an elastic hydrophobic strong gel, with excellent adhesion to the medium. The gel is not affected by wet/dry cycles and is stable in time.

This product is suitable for grouting into waterbearing formations, cracks or joints (not running), and for grouting into injectotubes filled with water to create a "gasket" between two structures. Also suitable for repairwork of wet cracks in concrete pavement. These products have a good bond to wet and dry concrete.

3.4.3 Hydrophyllic Polyurethane Elastomers (Dowel CSR Sealring, MME Polycast Exp.)

These grouts swell out after they have cured in contact with water. They are injected in a dry joint or opening. In contact with water at a later stage, they swell out in a predictable way to form a tight gasket.

The CSR sealring has been used extensively for "picketage rings" in shafts and for sealing around flood bulkheads. The product is totally hydrophyllic, and when given space to swell, its mechanical characteristics decrease resulting in seepage. Most sealrings had to be regrouted to tighten up the original grout barrier.

The MME Polycast Exp. is only partly hydrophyllic. A predetermined (custom tailored formulation) amount of expansion will occur if given the room to expand. As a result, a tight seal can be created by properly designing the required expansion.

Typical Applications:

- Picketage rings shafts.
- Sealing around flood bulkheads.
- Prefabrications of "swellseals" of any size or dimension for joint sealing or prefab applications.
- Injectotube grouting (tunnels, parkades, swimming pools, etc.).

3.5 Two Component Polyurethane Foam Grouts for Mining Applications (Rockgrip, ICI-Foam, Bevidol/Bevidam)

The result of the reaction between a polyol (R-OH) and an isocyanate (R1-NCO) is the creation of a polyurethane foam.

Depending on the type of polyol, blowing agents, catalysts, a wide variety of foams with different characteristics is formed:

- density
- cellular structure
- compressive strength
- reaction pattern (cream time - tack free time)
- water absorption

The isocyanate has a high affinity for water which has a tendency to "steal" the isocyanate leaving not enough isocyanate for the polyol to form a complete reaction.

These products are mainly injected to stabilize loose and cracked rock. They are extensively used in European, South African and to a lesser extent, in American coalmines. There are a number of types dealing with various ground conditions:

- slow setting for deep grouting
- fast setting
- wet conditions

The applications are very crude, and are mostly carried out with small 2 component TURMAG pumps. In case this foam catches fire the gases liberated are lethal. In spite of some tragic accidents in various mines in the U.K., South Africa, U.S., France & Belgium, killing large numbers of miners, these products are still applied. Only in U.K. and in some regions of France, the product is banned.

Typical Applications: (Other than insulation applications)

- Stabilization of unstable rock in mines.
- Sealing pervious formations in front of flood bulkheads.
- Sealing gaps and joints around ventilation doors.
- filling damaged "air-caissons" (locks).
- Pipeline applications: (installation river crossing, erosion blocks, etc.).

3.6 Epoxy Grouting (Low Viscosity Injection Resins)

In most cases during the reaction of bisphenol A or F resin with an aliphatic or cycloaliphatic amine, amide or amine adduct or a mixture of these products, a rigid epoxy gel is created. The finished product has far superior characteristics than concrete. Only in a few cases, these superior qualities are required.

Four categories of systems could be distinguished:

- The normal low viscosity injection resins.
- The low viscosity water repellant injection resins.
- The very low viscosity injection resins (short chains - more brittle).
- The epoxy-urethane combined resins with higher flexibility and lower strength.

Typical Applications are:

- Concrete repairwork for bridges.
- Concrete and brick structural repairwork.

Buildings	Tunnels	Dams
Parkades	Mines	Purification Stations

- Structural repairwork of chemically deteriorated concrete.
- Stopping capillar moisture-movement in old building structures.
- Filling cracks with the injecta perm system.

3.7 Phenoplast Grouts (Mariflex Series)

Soilgrouting (Resorcinol):

These type of resins are only sporadically used for soilgrouting and have only historical importance.

Phenoplasts are polycondensates resulting from the reaction of a phenol with an aldehyde using an acidic catalyst. These grouts are very sensitive to the ground conditions (ph) and temperature.

The degree of dilution plays an important role. Moreover, these products are rather toxic and cause environmental problems. Most of the applications have taken place in France.

Rockgrouting (Mariflex Series):

These are foaming grouts used for the stabilization of rock. They consist of 2 components:

Resin: A diluted mixture of phormo-phenolic resins in water.

Catalyst: A mixture of strong, mainly sulphonic acids diluted in water.

Depending on the type, a very light or dense rigid foam is formed. There is also a type for spray applications which hardly foams. These products are extenseively used in the European coal mines, and have also been installed in a shaft application in a potash mine in Western Canada.

The foam is inert and resistant to very high temperatures and does not burn.

Applications:

- Ground control applications in coal mines.
- Fire barriers and ventilation dams in mines.
- Surface sealing (methane gas) of main galleries in mines.
- Sealing cable passages for fireproofing purposes in the building and civil engineering industry.

3.8 Aminoplast Grouts (Urea Formaldehyde, Igloneige, Isoschaum)

Aminoplasts require an acid environment to complete the reaction between the urea and the formaldehyde. They are only sporadically used for soil grouting. The infamous urea formaldehyde foam is still used in coal mines to create methane, fire and air barriers. Urea formaldehyde has been banned in Canda.

3.9 Lignosulphonates

These grouts are only of historical importance:

They consist of lignosulphonates and a hexavalent chromium compound. In an acid environment a weak gel is produced. These grouts are sensitive and grouted soils are subject to creep and consolidation phenomena.

The products are highly toxic (contain dichromate salts) and should not be used any longer.

4.0 HOT MELTS

Hot Bitumen and Hot Sulphur:

Hot bitumen have been used in the early twenties to stop inflows below dams. In the early eighties they made their come back in a very impressive way. With the advancement of technology they can be grouted in almost the same fashion as classic grouts.

Major inflows below dams were controlled with hot bitumen and the product was considered for use to be grouted in deep holes (950m). With the help of oil field and deep drilling experts, the details were established to heat up the drillhole with steam and carry out a grouting program to stop a major inflow in a potash mine.

Applications: Stopping major inflows through rock formations.

5.0 PRECIPITATION GROUTING

This is one of the newest grouting procedures sucessfully used to control a huge inflow in a potash mine in Canada.

By introducing a saturated $Ca\ Cl_2$ solution, into fast flowing saturated brine, Na Cl and gypsum crystals are produced reducing the aperture. Sodium Sulphate is used in conjunction with $Ca\ Cl_2$ to enhance the precipitation. As the crystals grow, the aperture is choked regardless of its size, and the velocity and pressure regime of the inflow. These grouts are not closure grouts, and other chemical grouts are required to seal the inflow if possible from a rock mechanical standpoint.

Applications: Controlling major inflows in salt and potash mines.