SEALING WITH CARBOTECH FOSROC SYNTHETIC RESINS

SUMMARY

A survey is given on the various options to seal water ingress from strata and from concrete structures by injecting different types of resins showing the scope and limits of the individual grouts. The report covers methacrylates and polyurethane hydrogels, one and two component polyurethane resins as well as silicate isocyanate resins. The use of fast reacting two component polyurethane resins has proven to be the most effective method for sealing heavy water intrusions.

1. INTRODUCTION

Water is an essential element in our lives. Without water we could only survive a few days. On a construction site, however, the uncontrolled influx of water rates amongst the most undesirable of factors and in some cases represents a considerable hazard, which can threaten the very existence and function of the construction site.

<table>
<thead>
<tr>
<th>Type of Location</th>
<th>Type of hazard caused by water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salt mine</td>
<td>Flooding through dissolution of the salt</td>
</tr>
<tr>
<td>Roads and gates in mines</td>
<td>Traffic obstruction, additional pumping effort</td>
</tr>
<tr>
<td>Tunnels and Cross cuts</td>
<td>Water and mud slides during driving operations</td>
</tr>
<tr>
<td>Shafts and tunnels</td>
<td>Formation of ice</td>
</tr>
<tr>
<td>Tunnels</td>
<td>Leaking tunnel sealing sheets</td>
</tr>
<tr>
<td>Sluices and dams</td>
<td>Loss of water</td>
</tr>
<tr>
<td>Slopes in loose rock</td>
<td>Earth and mud slides</td>
</tr>
<tr>
<td>Construction pits within Ground water</td>
<td>Hydraulic breach of ground</td>
</tr>
<tr>
<td>Concrete construction sites</td>
<td>Corrosion of steel reinforcement structures</td>
</tr>
<tr>
<td>Bridge</td>
<td>Frost damage, corrosion from industrial salt</td>
</tr>
<tr>
<td>Parking garages</td>
<td>Leaking cracks, paint damage on cars due to water seepage</td>
</tr>
<tr>
<td>Cellars</td>
<td>Creeping damp in walls</td>
</tr>
<tr>
<td>Sewage canals</td>
<td>Beneath ground water level : Infiltration – rise in sewage</td>
</tr>
<tr>
<td></td>
<td>Above ground water: Exfiltration – pollution of ground water</td>
</tr>
</tbody>
</table>

Given the variety of problems it is self evident that a variety of techniques and materials must
be involved in finding the solutions. Sometimes it makes good sense to divert the water influx rather than seal it off, as for example in tunnel drainage. For this purpose CT F has on offer half shell draining pipes called Alpha – and Omega-Drain which are fixed to the rock surface with nails covering the water outlet and leading the water into the general tunnel drainage system before applying shotcrete as support and covered with shotcrete (see fig. 1). By diverting the water the problem of a water build-up as a result of hermetic sealing can be avoided. The back pressure caused by water build-up can endanger the stability of a tunnel. On the other hand, water can also seep into heretofore dry areas, which would then not be water-tight anymore.

It is a widely accepted practice to seal off areas by use of reasonably priced cement grouts. However, there are two serious disadvantages:

- injection cements set relatively slowly, so that running water can erode them
- we are dealing with suspensions of solids, which are restricted to penetrate cracks of not less then 0,3 mm (micro cements not less then 0,15 mm).

Reaction resins show considerably better results because of their enhanced penetration and their fast set properties. They are generally used as two-component systems, this means that a 2-component pump conveys both components separately to the place of injection. There they are combined in a T-piece, passed through a static mixer and are pressed into the formation to be sealed by means of a packer.

2. Methacrylates

With regard to methacrylates we are dealing with a watery solution of monomers, that is, small molecules that combine together. The viscosity of this solution is similar to water, that is, particularly low. This reaction is triggered by hardeners (B-component) and accelerated by activators (additive to the A-component) resulting in a loose network of polymers.

The macromolecules are very hydrophilic, that is, when water is available it settles into the structure and a gel is formed. In cases of drying-up, the water would diffuse out of the gel. This leads to swelling or shrinking of the gel in relation to the degree of available moisture. This process is reversible; should the gel have shrunk in the case of dryness, it would swell up to its original volume, when moisture would be available again. The natural moisture level of soils is commonly sufficient to prevent shrinkage of the gel. These systems are manufactured in such a way as to swell slightly in damp surroundings, causing a certain swelling pressure in the structures to be sealed, and this leads to an improved sealing result.

The above applies to methacrylates as well as to the chemically related acrylates, i.e. acrylamides and their resins (methylolacrylamides). These are toxic as monomers and therefore illegal in most countries. The cured gels however, are in no way toxic. Methacrylates as offered by CT F are i.a. utilised in the medical field, e.g. for the manufacture of soft contact lenses. Danger of groundwater contamination only exists when low viscous watery acrylate solutions are exposed to flowing water. This easily leads to mixing and thinning out so that a
part of the monomers would be washed out. The mechanical stability of these gels is very low. In a sandy medium, however, stabilisation is achieved by interaction with the sand matrix.

CT F offers three different systems, which differ from one another in regard to setting time and consistency (degree of the interlacing network). The setting time can be modified, i.e. accelerated or slowed down by variations in concentration of hardening components present.

<table>
<thead>
<tr>
<th>Gel type</th>
<th>Viscosity @ 25°C</th>
<th>Setting time</th>
<th>Expansion Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>CarboCryl Wv</td>
<td>&lt; 10 mPa*s</td>
<td>15&quot; – 4’</td>
<td>70 %</td>
</tr>
<tr>
<td>CarboCryl Hv</td>
<td>&lt; 5 mPa*s</td>
<td>3’ – 10’</td>
<td>20 %</td>
</tr>
<tr>
<td>CarboCryl T</td>
<td>&lt; 5 mPa*s</td>
<td>30’ – 60’</td>
<td></td>
</tr>
</tbody>
</table>

**Advantages of Methacrylate gels are:**

- Watery system
- Water dilutable; pumps can be rinsed with water
- Extremely low viscosity, exceptionally good penetration properties
- Adjustable reaction time from slow to fast
- Reaction is less dependent on temperature
- No side reaction with water
- Excellent adhesion
- Good ground water tolerance

**Disadvantages of Methacrylate gels:**

- Components must be mixed on construction site
- Water sensitive clays are not injectable
- Shrinkage and swelling depends on degree of dampness/moisture
- Minimal mechanical strength

**Areas of use:**

- Sealing of cracks in concrete, amongst others
- Sealing against pressurised water
- Pressure sealing of injection pipes, also multiple applications (T)
- Sealing of damp cellars by means of ballooning or wall injections (Hv)
- Stabilisation of fine sandy soils (Hv)

Acrylates rate as exceptions rather than the rule in this case; other resins offered are polyurethane or related products. There are also polyurethane systems available that achieve similar results to methacrylates, but with better mechanical properties. Also in this case, watery solution of low viscosity are used which react to form hydrophilic, swellable gels. Some of these gels are based on prepolymerised TDI-isocyanate; these must be clearly marked as toxic when delivered. In order to reduce the viscosity of these prepolymer, plasticisers or solvents have to be added some of which are doubtful in regards of hygiene. Other types are based on the much less harmful MDI (declared harmful to health). These ones are available through CarboTech Fosroc.

3. **One-component PU resins**

The following relates entirely to resins, which contain MDI isocyanate as reaction components. The isocyanate group of which every MDI molecule has at least two, reacts with
water under the release of carbon dioxide. The product immediately reacts with a further group of isocyanates so that the molecules link up to form a macromolecular chain (see formula 2)

\[
\text{catalyst} \\
\text{mod. isocyanate} + \text{water} \rightarrow \text{polyurethane/urea} + \text{CO}_2
\]

Formula 2: One Component Polyurethane Resins.

One-component PU resins generally consist of modified MDI, to which a softener is added in order to reduce the viscosity and to make to foam more flexible. Chemically they are more or less identical with the type of polyurethane, which is used in spray cans for fixing window frames and the like. In order to increase and control the setting time, activators are added prior to processing. (An exception is CarboStop U, which is supplied with an already built-in catalyst). The setting is the result of the reaction with water (“water reactive polyurethane”); 5% water in relation to the resin is sufficient for the setting.

Without back pressure a foaming capacity of up to 40-times is possible, resulting in a light, partly open-cell structured (free rise foaming) product. Closed cell structures often result in rapid shrinkage of the foam due to cooling of the cell gas. When injected into construction sites or rock formations the resin would not be able to foam up freely so most of the cells would be closed.

The procedure is simple as only a single-component pump is required which, however, must be carefully rinsed with cleaning solution (CarboSolv D) after every use because of the water sensitivity of the resin. When injected into a water-bearing construction site, the contact with water causes the liquid resin to foam. The resultant foam pressure drives the resin into even the finest cracks (“self injection”). Because of the partly open-cell nature and low mechanical stability, a permanent sealing effect with one-component-PU is not guaranteed. These products are therefore chiefly suitable for instantly stopping water and provisional sealing. In many cases, however, only a temporary sealing effect is required and for that purpose this product is well suited. The environmental tolerance of these resins has proved to be very good. Because of their medium viscosity and their hydrophobic properties they tend to rather displace water than mix with it as do methacrylates.

Without water contact the resins remain liquid and may be pumped over any given distance, as pipe blockages do not occur. Slow-reacting one-component PU resins (without activators) can also be used for stabilisation in naturally damp or wet sand soils. Hardening is the result of pore water contained between the sand grains. A maximum penetration of 30 cm radius is achieved, with the resin foaming up by a factor 2 – 2,5. The cured PU foam is permanent.

<table>
<thead>
<tr>
<th>Resin type</th>
<th>Viscosity @ 25°C</th>
<th>Setting time</th>
</tr>
</thead>
<tbody>
<tr>
<td>CarboStop W/X</td>
<td>100 mPa*s</td>
<td>30” – 60”</td>
</tr>
<tr>
<td>CarboStop W/Y</td>
<td>120 mPa*s</td>
<td>1’ – 3’</td>
</tr>
<tr>
<td>CarboStop U</td>
<td>425 mPa*s</td>
<td>2’ – 3’</td>
</tr>
</tbody>
</table>
Advantages of one-component PU resins
+ simple processing
+ variable setting according to activator added
+ hydrophobic resin, i.e. displacing water
+ excellent ground water tolerance

Disadvantages of one-component PU resins
- not suited for permanent sealing, because of partially open-cell structured foam
- low mechanical stability
- water sensitive during use

Areas of use
- Blockage of water influx
- Temporary sealing
- Sealing/water stoppage in longer bore holes (in excess of 10m) (Deep injection)
- Sealing of ducts for tie back anchors in diaphragm or sheet pile walls
- Stabilisation of sand

4. Slow reacting two-component PU resin

In concrete construction sites, water can penetrate through shrinkage cracks and, in conjunction with oxygen may cause corrosion of steel reinforcing structures. Seasonal differences in temperature can cause changes in the crack widths. For this reason the German so-called ZTV RISS- Guidelines demand a high permanent elasticity or yield capacity of sealing resins for impermeabilisation of cracks in traffic structures (tunnels, bridges, sluice docks, etc.) [Bundesminister]. With very fine cracks, e.g. 0.1 mm width, a crack extension of 0.1 mm, i.e. from 0.1 to 0.2 mm, is relatively large; CarboTech Fosroc systems are however in a position to deal with crack width changes of up to 100%!

Resins according to ZTV RISS are of hydrophobic nature and very slow setting. This enables them to displace water from the porous surface as they penetrate into the crack structure beneath. An acceleration of the resins leads to a more fine-celled pore structure and therewith to a decrease of adhesion. Without water the resins will not foam. With water the resultant foam has a structure with large bubbles. (see formula 3)

\[
\text{isocyanate} + \text{polyol} \rightarrow \text{polyurethane} \\
\text{isocyanate} + \text{water} \rightarrow \text{polyurea} + \text{CO}_2
\]

Formula 3: Slow and Fast setting Two Component Polyurethane Resins

For this application, wall packers are fitted diagonally into the cracks to be repaired, spaced at distances of half the thickness of the concrete section. The resin is mixed either prior to injection and pumped by means of a one-component pump, or injected via a special two-component pump with a special steel static mixer. If the probability exists that too much resin will flow out of the cracks during injection, the cracks can be dammed up prior to injection.
These resins are suitable for sealing dry and damp cracks as well as cracks dripping with water. In the case of high water influx it is advisable to pre-inject with a one-component resin such as CarboStop U according to ZTV RISS guidelines. Alternatively it is possible to seal with a Bevedol-Bevedan System (see following chapter). These resins, however, are relatively brittle. To ensure that this sealing remains functional in winter temperature conditions, a low glass temperature for the hardened resin is necessary. This temperature indicates the point at which the resin becomes brittle. On the other hand, the elasticity of the resin is challenged right then when low temperatures cause contraction of the concrete and therewith a widening of the cracks.

CTF offers three systems:

- **CrackSeal H** has passed the criteria of the German ZTV RISS. Its adhesive strength has achieved 1 MPa, at the same time withstanding between 40 and 100% crack-dilation. Hardened and set in a damp crack, its solidification temperature is measured at – 40°C.
- **CrackSeal M** is a reasonably priced, more rapid acting version with similar characteristics.
- **CrackSeal NV** has a longer processing time and lower viscosity, and in contrast to the others it is not injected in a mix ratio of 1 : 1 Vol.T, but rather in a mix ratio of 2,5: 1 Vol.T.

<table>
<thead>
<tr>
<th>Resin type</th>
<th>Mix viscosity @ 25°C</th>
<th>Curing Time</th>
<th>Glass temperature</th>
<th>Shore Hardness</th>
<th>Tensile Strength</th>
<th>Resistance to Tearing elongation</th>
</tr>
</thead>
<tbody>
<tr>
<td>CrackSeal H</td>
<td>~ 180 mPa*s</td>
<td>15 h</td>
<td>-15°C</td>
<td>A 53</td>
<td>4 MPa</td>
<td>150 %</td>
</tr>
<tr>
<td>CrackSeal M</td>
<td>~ 185 mPa*s</td>
<td>7 h</td>
<td>-15°C</td>
<td>A 55</td>
<td>6 MPa</td>
<td>120 %</td>
</tr>
<tr>
<td>CrackSeal NV</td>
<td>~ 90 mPa*s</td>
<td>20 h</td>
<td>-6°C</td>
<td>A 50</td>
<td>2 MPa</td>
<td>110 %</td>
</tr>
</tbody>
</table>

**Advantages of slow 2K-PU-resins:**

+ highly hydrophobic, displaces water
+ penetrates into the finest cracks, because of slow setting
+ permanently compact and elastic, even at low temperatures
+ high elasticity properties within the crack
+ excellent adhesive stability (“extendible joining”)
+ excellent ground water tolerance

**Disadvantages of slow 2K-PU-resins:**

- slow setting
- not applicable under pressurised water conditions.

**Areas of use:**

- Renovation of shrinkage- and other cracks in concrete structures
- Prevention of corrosion in reinforced concrete supported structures

5. **Fast setting two-component PU-resins**

Fast setting two-component polyurethane resins present the most effective injection method against water influx, especially if pressure is involved. It was CarboTech Fosroc who developed this method. Over the past twenty years this method was, on many occasions responsible for successfully sealing water leaks when all hope had been abandoned. The
Bevedol-Bevedan resin systems WF, WFA or WT harden according to type and temperatures between -20 and 90 °C. Nevertheless they foam at contact with water.

These systems are related to the resins that have, for decades, been developed to become an indispensable state-of-the-art method in European coal mines with their particularly difficult mining conditions [Maurer, 1977]. Polyurethane foam when injected into the crack structure of rock formations or coal, is in a position to adapt to volume changes due to rock movements and at the same time preserve the cohesion of the rock formations. This procedure is likewise successful in tunnel construction during cross-cutting of faults or slopes covered by loose rock. Its uncomplicated technique and rapid hardening makes it particularly suitable in cases of production break down.

The procedure is as follows:
The two components polyol and isocyanate are pumped separately into the bore hole, mixed by a static mixer and injected into the rock face through packers. The bore holes are, depending on the procedure, between 0.5 and 5 m deep. This means, in all probability, that linings that must be sealed, e.g. shaft and tunnel linings, will be drilled. The resin flows back from the rock area into the open space and seals off any water escape routes.

If required to seal off an underground cavity against water, the following picture presents itself after core drilling. Whilst foaming material can be found deep in the rock formations, the density towards the shaft or tunnel wall increases; close to the wall the resin is very hard and completely impervious to water. This means, that the watertight interior layer is protected against any influences of formation movements by the surrounding foam-buffer. The sealing is permanent, as has been proven by repair work done according to this method.

Two main factors are responsible for this phenomenon:
1. With every injection procedure there is a pressure drop from the pump to the foremost injection line. There the pressure has decreased to the pressure in environment. The foaming rate depends on the pressure, as the carbon dioxide causing the foaming process can only expand as far as the surrounding pressure will allow it; consequently the hardened foam becomes more compact in the vicinity of the borehole.

2. The extent of foaming and foam pressure also depends on the amount of water present to influence the reaction between both components polyol or isocyanate. The mixture initially injected into the water bearing formation makes the most intensive contact with water, causing it to foam up rapidly and strongly, thereby displacing water and simultaneously penetrating finer cracks (self-injection). At the same time this foam provides a protective layer for the resin stream; this encounters less water and as a result foams up less. During the injection process the resin hardens to a more compact and stable and ultimately fully water tight material. In this way, a permanent sealing as well as a flexible stabilisation of rock formations may be achieved in one single operation.

This method is applicable not only for water leaks during heading operations in mines or in construction pits (e.g. sheet or slot piles) but also for renovation of tunnels and shafts [Cornely]. In extreme cases even brick walls can be treated this way. As a rule the effect of this method is limited to short distances in rock formations, the rapid reaction of two-component systems does not allow a long open time of the resin, which is why injection is generally limited to a radius of 5 – 8 m.
A similar principle applies to our silicate resin process. Instead of polyols reacting with isocyanate, watery solutions of sodium silicate (silicate-isocyanate-resins) are applied. Firstly a foaming silicate resin (Geofoam) is injected (free foaming factor approx. 25), which stops the water flow. A non-foaming silicate resin (Wilkit T or Geoflex, an elasticised version) is post-injected into this foam structure.

\[
\text{catalyst} \\
\text{isocyanate} + \text{water} \rightarrow \text{polyurea} + \text{CO}_2 + \text{polyisocyanurate} \\
\text{aqueous sodium silicate} + \text{CO}_2 \rightarrow (\text{SiO}_2)_x + \text{soda} + \text{water}
\]

Formula 4 : Silicate Isocyanate Resin

With the help of these resins it is possible to carry out injection even against flowing and pressurised water. The experienced operator/injector will however, avoid water influx wherever possible. A construction pit in which a balance has been achieved with the ground water will be easier to seal than a site which has been pumped dry and into which there is a constant flow of water. Naturally the work must be carried out by divers in such and other similar cases. In the case of tunnelling, water-bearing cracks should, if possible, be blocked provisionally with mechanical means in order to achieve a minimisation of water influx.

For the sealing of larger cavities (diam >70 mm) it is advisable to introduce semi-permeable fabric hoses into the cavity and fill them with foaming resin [Mehesch, H. et al.]. After inflating the hose and filling the void by the foaming process, a part of the resin passes the fabric structure thus glueing the hose the void walls and filling the adjacent cracks. With high water influx it may happen that the liquid resin will be floated out. In this case the resin WT is used instead of WF or WFA [Cornely, W. et al.]. This resin tends to become pasty immediately after mixing and therefore cannot be rinsed out easily. During sealing work carried out on construction pits during the building of the new government premises in Berlin this resin proved to be most successful.

With the help of PUR systems and in excess of 20 years of sealing experience we have succeeded in remedying almost all difficult sealing cases.

<table>
<thead>
<tr>
<th>Resin: Bevedan applied with:</th>
<th>Mix Viscosity @ 25°C</th>
<th>Stetting time</th>
<th>Compressive Strength (SF=1)</th>
<th>Shore-Hardness</th>
<th>Adhesive Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bevedol WF</td>
<td>~ 250 mPa*s</td>
<td>35“–90”</td>
<td>60 – 80 MPa</td>
<td>D 85</td>
<td>2,4 MPa (moist)</td>
</tr>
<tr>
<td>Bevedol WFA</td>
<td>~ 250 mPa*s</td>
<td>15“ – 50“</td>
<td>60 – 80 MPa</td>
<td>D 85</td>
<td>7 MPa (dry)</td>
</tr>
<tr>
<td>Bevedol WT</td>
<td>&gt;100 000 mPa*s</td>
<td>35“– 90”</td>
<td>60 – 80 MPa</td>
<td>D 85</td>
<td>5 MPa (dry)</td>
</tr>
<tr>
<td>Bevedol WX</td>
<td>~ 250 mPa*s</td>
<td>2’ – 40’</td>
<td>60 – 80 MPa</td>
<td>D 85</td>
<td></td>
</tr>
</tbody>
</table>

**Advantages of fast reacting 2K-PU-resins:**

+ adjustable viscosity process
+ rapid to very rapid mixing
+ self injection
+ stabilisation effect, high stability
+ excellent ground water tolerance
Disadvantage of rapid 2K-PU-resins:
- limited extent because of quick reaction time
- minimal elasticity

Areas of use:
- Renovation of wet shafts and tunnels
- Sealing of pressure water influx
- Fixing mud slides
- Penetration of fault zones, as precautionary or remedial action
- Stabilisation of wet and damp rock

6. Sewer Repair

In principle, the same techniques and injection methods can be applied to the renovation of sewage canals; however this is only valid for accessible pipes. Non-accessible pipes require other methods for which purpose CarboTech Fosroc offers a string of different silicate resins. The methods encompass injection-, spatula and impregnation processes, which partly require highly specialised processing equipment.

At this point I would like to present just one of the simpler procedures, namely the placing of partial liners for the restoration of cracks e.g. in pipes. In this case the pipe in situ is covered with a fibreglass-reinforced synthetic. This is done as follows: A fibre glass mat is cut to size and soaked with a slow setting silicate resin (CarboLith PL). The mat is then wrapped around a pneumatically inflatable rubber packer with a polyethylene foil separating packer and mat. The slack packer is brought to the restoration point and inflated there with approx. 1 bar. After 20 – 30 minutes the resin will have hardened to the extent that the packer can be withdrawn in a slack state. This technique is widely used. [RSV-Merkblatt]

7. Conclusion

CarboTech injection resins, especially its PU grouts, offer a wide range of working tools to fight almost any case of water intrusion in the construction and in the mining industry, from simple, easy to use resins to sophisticated grouts, from low viscous aqueous solutions to pasty grouts, from sealing damp structures as cellar walls to great water inrushes under pressure.

8. Literature