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Environmentally Friendly Tunnel Sealing and Stabilization With Novel Hybrid Injection System (HIS)

WEBAC®
Our Formula – Your Solution

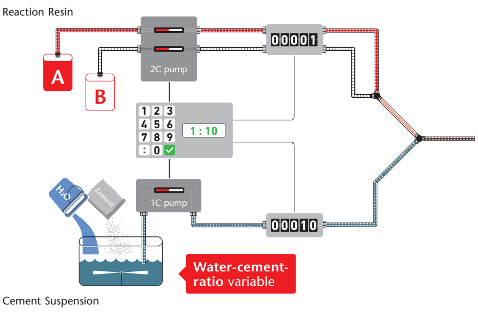
Introduction

HIS is a grouting system of high cement content modified with some reaction resin in a one-shot application. It accelerates cement sticking and hardening. The strength development of cement in early states is activated and the material is not washed out during application. With these benefits the Hybrid Injection System closes the gap between economically pure cement grouting and technical highly effective reaction resin applications.

HIS can be adjusted to different cement types as well as to the broad range of applications done by injection grouting. HIS radically reduces cement spill-out and minimizes elution of organic or inorganic contents and reduces ecotoxicological impact on ground soil and water. As HIS can be used with CEM III types the novel injection system contributes to a lower carbon footprint of injection grouting.

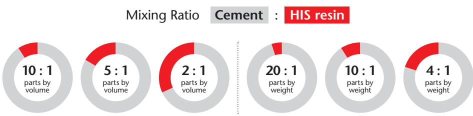
Hybrid Injection System – Working principle

The WEBAC® Hybrid Injection System uses standard techniques with the injection of cement slurries. A second providing line is added for the reaction resin with separate pump and dosage.



The cement used is the one available at the working site; it is adjusted as usual (water-cement-ratio), if necessary, by additives (superplasticizer, dispersion aids, anti-segregation aids, accelerator, retarder) according to the needs of the construction site, the application and the desired performance.

HIS resin is the reactive component for the modification of the cement slurry. It is a 2C material, mixed 1 : 1 by volume, which will be added to the flowing cement slurry. Mixing ratios for the composition slurry/resin are in the range from 30 : 1 up to 2 : 1 by volume.

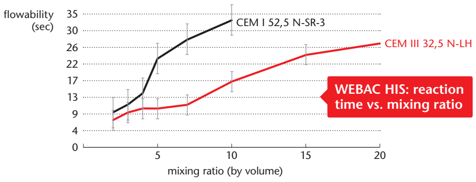


The composite material is homogeneous and comparable in the appearance to other modified cement grouts. The set-up often gives a thixotropic behaviour of the grout, it thickens when the flow is stopped. The material sets to a creamy consistence and is no longer spilled out by water.

Several types of cement have been tested, OPC, CEM II and CEM III types acc. to EN 197-1 as well as different cements directly from working sites from all over the world.

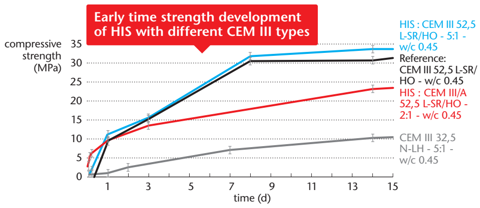
Experimental research: tests & results → Reactivity

With HIS different types of cement are accelerated. Reaction times are dependent on the compatibility and interaction of the used cement and resin, and on the mixing ratio cement : HIS resin. Because of the thixotropic behaviour standard methods to characterise the slurry do not work (efflux time with Marsh funnel, slump flow). This study refers to a laboratory method with visual and tactual estimation of flowability.

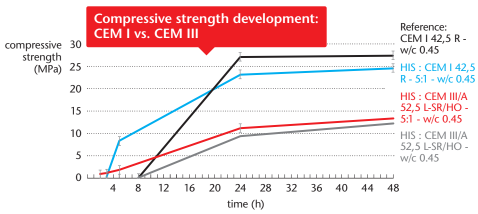


The compressive strength data have been performed using standard bars 40 x 40 x 160 mm³ with an Instron 5960 universal testing machine. For direct comparison all data are generated by 5 : 1 by volume systems (unless stated otherwise). If technically available, a w/c value of appr. 0.5 was chosen. The plotted data refer to 3 measurements minimum (usually 6 ones).

Usually, compressive strength data could be achieved after 2 days earliest. CEM I 42.5 R with the fastest strength development could be measured after 24 h. Slower strengthening cements like CEM I 52.5 N-SR3 need a longer time period to overcome the early strength development of HIS systems.



Bars with HIS compressive strength data can be achieved as early as 30 minutes; with c/r ratio of 2 : 1 by volume a compressive strength of 5 MPa is reached within 2 hours. These fast strength development effects are best achieved by CEM III. HIS with CEM III develop strength very fast up to 5 or 10 MPa. Further strength evolving is slowed down as these cements need longer times to reach final strength, usually.

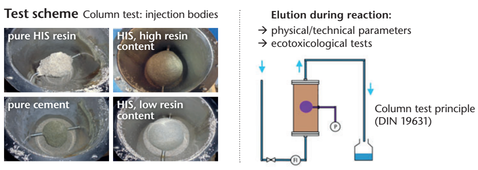


The strength advantage of HIS refers to the application crucial early phase of hardening. In the long range the strength of the cement is the dominant effect. That is why the resin part inside the cement matrix causes a diluting effect to the system and decreases the final compressive strength. The data for tensile bent strength show similar effects – except that HIS samples generally yield a higher bent strength than the pure cement.

Environmental sustainability of the HIS

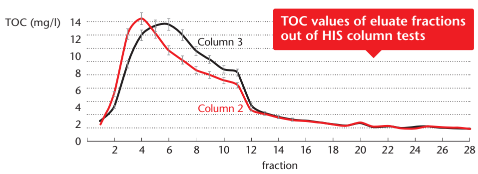
Injection systems, such as HIS, are mostly applicated in contact to ground soil and water. Therefore requirements for environmental sustainability should be fulfilled (Märkl et al. 2017). The testing principles of DIBt (DIBt 2011) represent one of the most challenging concepts in this field. This testing procedure gives realistic information about the critical phase during application, reaction and hardening processes of injection grouting.

Sampling is based on a column test acc. DIN 19631. The principle is shown below. The test material is injected into a column perpendicular to the water flow. During the hardening process water flows around the material sand body and takes elutable components with it into the sampling bottle.



The column test in practise gives injection bodies as shown above. For comparison equal amounts of injection material has been injected into the column: pure HIS resin, pure cement slurry and two mixtures of HIS, c/r ratio 2 : 1 (HIS with high resin content) and 10 : 1 (HIS with low resin content). The data presented in the following are acquired with a column test composed of CEM I 42,5 R (w/c ratio 0.45) with 0.1% superplasticizer and the WEBAC® HIS resin in the mixing ratio 5 : 1 by volume.

The eluates are tested on parameters like pH and TOC. With the graphical visualization below the maximum of TOC is detected for further investigations, especially ecotoxicological tests, special aromatic amines tests, and heavy metal analysis due to the cementitious basis.



Usually, additives are highly eluted out of cementitious grouts during such an early state of consolidation (Märkl and Stephan 2016; Ruckstuhl et al. 2002; Leemann et al. 2011). Even though, with HIS additional organic matter is in the system, only very small amounts (less than 15 mg/l – see diagram above) are mobilized. For comparison: acrylate gels widespread used for curtain injections show TOCmax values from 430 to 1250 mg/l (Wagner 2011).

The ecotoxicological tests cover a broad range of biological indicators. All these tests only show slight effects with algae or daphnia and no effects with the other biological tests for the samples with the maximum organic load and no effects with in the decay phase. The results are summarized here:

Test specification & results of ecotoxicological parameters

Ecotox. Parameters	Standard	Results with		References	
		TOCmax	TOCbase	lowest level	limit acc. DIBt
Scenedesmus chlorophyll fluorescene test /algae)	DIN 38412-33	GA = 6 – 8	GA = 1	GA = 1	GA = 8
daphnia	DIN 38412	GD = 6 – 8	GD = 1	GD = 1	GD = 8
luminescent bacteria inhibition test	DIN EN ISO 11348-2	Glb = 1 – 2	Glb = 1	Glb = 1	Glb = 1
umu test	DIN 35415-3	GEU = 1.5	not detected	GEU = 1.5	–
zebrafish egg test	DIN EN ISO 15088	GEI = 1	not detected	GEI = 1	GEI = 6

Heavy metals contents in the eluates have been determined by means of AAS and ICP methods. Besides chromium they are significant below LAWA no effect levels (LAWA 2017; all values by far meet the requirements of the Drinking Water Ordinance (TrinkwV) (BRD 2016).

Further studies with earthworm species (Enchytraeus albidus) cover the impact of pure eluates out of dynamic surface leaching tests (DSLT acc. DIN CEN/TS 16637-2 (2014) (Nebel and Spanka 2013). They definitely confirm the low effects on higher grades of biological species (Märkl et al. 2017).

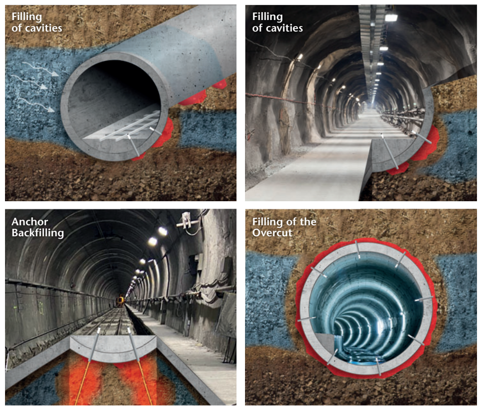
HIS gives best results with CEM II or CEM III types (EN 197-1). OPC is the highly carbon dioxide sensitive part in cement. As OPC content stands for 65 to 79% with CEM II/B or 20 to 34% with CEM III/B only and blast furnace slag is added the carbon footprint is up to 3 times better than for pure OPC. Strength, especially early state strength, is achieved by the addition of HIS resin. HIS resin is classified according to EN 15804 for its contribution to the system carbon footprint. Lower material usage due to faster reaction and less wash-out and waste additionally contributes to an environmentally friendly application with HIS.

Local authorities ask for evidence for environmental sustainability. With HIS, both, the cementitious part and the reaction resin part of the system are clearly successful tested and proved as highly environmentally friendly.

Conclusion

The Hybrid Injection System HIS combines the mechanical strength of cement and the fast curing properties of reaction resins. The resin only takes a small part and uses the cement types at the working site.

HIS compared to pure cement yields in faster reaction and early state development of strength parameters, especially with CEM III types. Hence HIS meets the crucial point in injection grouting.



With these characteristics HIS covers a broad range of applications of both material types as stopping water, filling, consolidation and sealing of the overcut and annular gap behind tubbing constructions, tunnel face stabilization and pre-injection in excavations with TBM.

Early strength features lead to an effective application with less waste of material and short times of work progress interruptions. This is highly advantageous for contractors, applicators and the environment. Better technical results with CEM III additionally relieve the economical and ecological balance. These cements are cheaper; they are composed of distinctly less portions of high temperature calcinated OPC clinker and hence feature a significant lower carbon footprint for injection applications in tunnelling and mining. This is the benefit of HIS.

Further investigations are oriented at tailor-made mechanical properties as well as adjustments of special reaction and injection profiles.

Acknowledgements

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