SHORT REPORT

Title

IngiMa - Development of a lime-based cement-free injection technology for historically valuable, gypsum-based masonry

Az.: SWD-10.08.18.7-14.29

Motive/ Initial Position

For the improvement of historical masonry injections are often used. In the past, injections into gypsum masonry often led to serious damage (sometimes complete loss of the original substance). This is due to the material incompatibility of gypsum with cementitious binders (ettringite and / or thaumasite formation). By a suitable material such damage can be avoided.

Scientific scope

The aim of the project was the development of an injection technology for a completely Portland cement clinker free, sulphate-compatible material. As pressing materials fine suspensions are used, which consists of binders, additives and finely ground aggregates if necessary (injection mortar). In special cases gypsum-containing masonry, the injection material must consist of sulphate-compatible substances, which form properties similar to the original substance after setting. In the search for a suitable grouting material, finished products were first examined, modified and re-examined for their sulfate resistance. Based on the results, this approach was rejected as not effective.

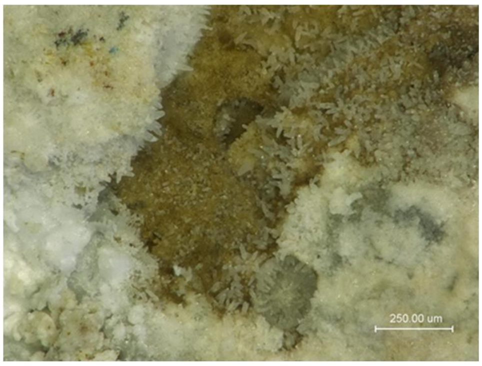


Figure 1. *left unsuitable injection material in the over water storage (Roman cement), right needle-shaped crystals grow throughout the structure*

Activation of pozzolanic materials without Portland cement addition could not be realized in technically relevant periods. As a result, a calcium sulfate based binder was favored for the grout. This was optimized with calcareous filler. Particular attention was paid to the different conditions in the masonry when testing the mortar. Three test and storage conditions were

fixed. Thus, an anchor mortar with dry compressive strengths of up to 20 N/mm^2 and wet compressive strengths of up to 11 N/mm^2 could be formulated.
The bending tensile strength of this mortar was about 3 N/mm^2 after storage over water and after dry storage or drying according to the norm 7-8 N/mm^2.
For an injection mortar with a lower strength, the proportion of lime in the mix was gradually increased. The mortar with 10-20 M.-% lime showed favorable results. Finally, the injection mortar must be adjusted according to the conditions in the surrounding masonry. The masonry moisture and masonry strength are of central importance.
A foam mortar was formulated based on the above formulation. With a suitable foaming agent, stable foam could be prepared and introduced into the fresh mortar. The strengths can be determined by appropriate mortar: foam ratios, in the case tested 1: 1; 1: 0.8 or 1: 0.5 are adapted to the respective purpose. The resulting bulk density severely determines the resulting strength. Conveniently appear mixtures of 1: 0.8 and 1: 0.5. Strengths of 28 d of 5 N/mm^2 and greater could be achieved by setting a bulk density (dry) of approx. 1 g/cm^3.
For applications with low strength requirements (fill cavities), the grout was foamed. The strength of the material can be adjusted via the mortar: foam ratio.

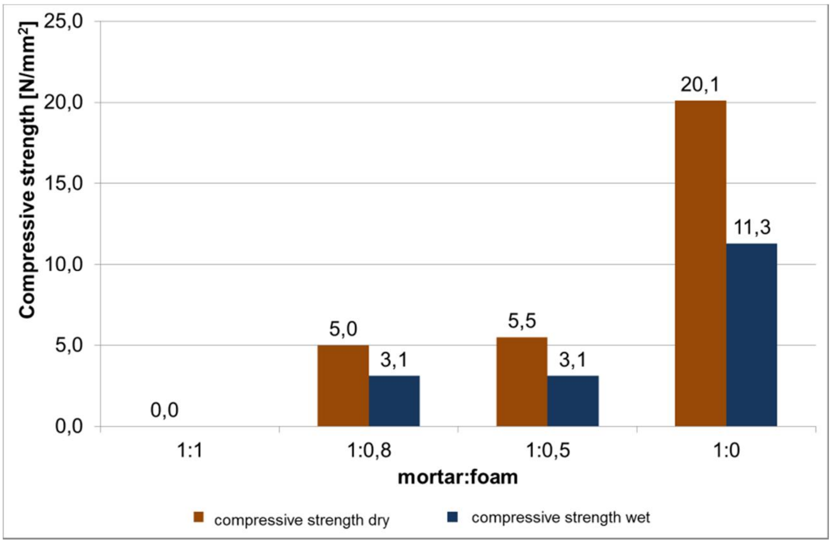
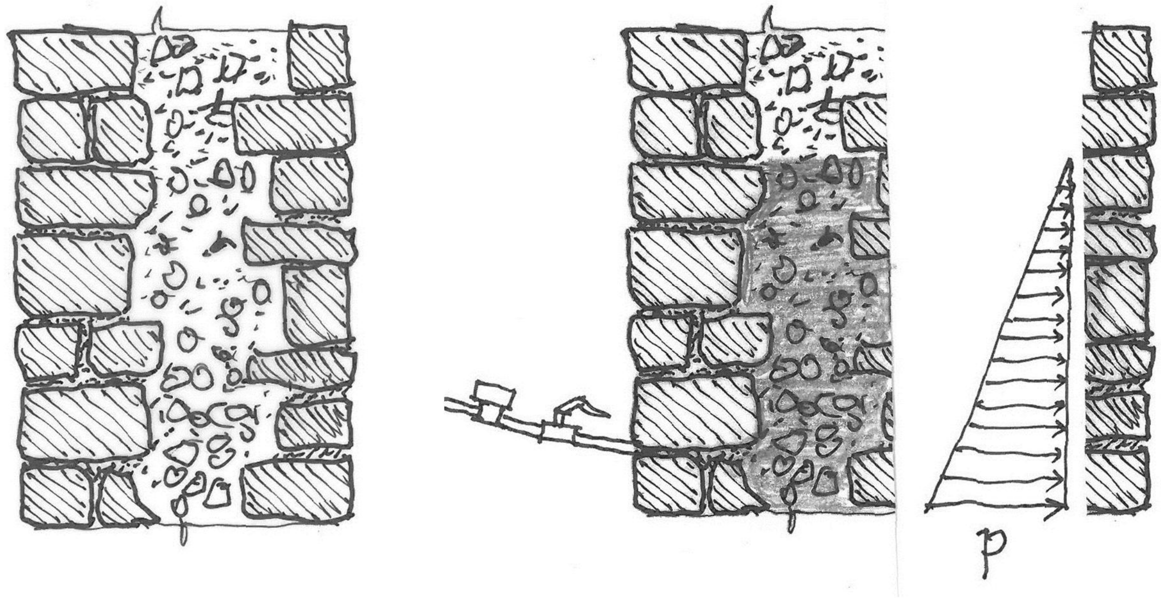


Figure 2. *Compressive strength of the foamed mortar*

By working in the sulphate system it is possible to do without a sulphate compatibility test. The most important relevant parameters are the moisture dependence of the materials, the strength, modulus of elasticity, density / porosity and pumpability / flowability. When injecting, a distinction is made between pure filling and pressing with pressure. The resulting pressure must be checked continuously. It works with low pressures up to $1.5 \cdot 10^5$ Pa. The pressure is controlled by a manometer. The processing time of a batch should be between about 30 minutes and a maximum of one hour. As a rule, work is carried out from the bottom to the top when pressing the masonry, so that pressure builds up solely from the rise in height of the injection material.



a) b)

Figure 3. *Formation of a hydrostatic pressure ("formwork pressure") of the fresh injection material (b) with double-shell masonry with loose filling in the shell space (a)*

The injection material gets into even the smallest cracks and cavities due to the pressure. Only then, when the pressure is a longer time and no longer gradually drops, all cavities and cracks are compressed. Air is a hindrance in the pressing process, if they cannot escape. Therefore, leave ventilation points in the wall. Quality control after injection is extremely important. The properties of the hardened mortar can be tested on the first. Furthermore, the masonry can be analyzed endoscopically or anchors can be drilled over.

Conclusion

In the project, technologies for injections into historic masonry were developed and tested on the model object. According to the aim of the project special injection mortars based on α- and β-calcium sulfate hemihydrate were formulated for the case of gypsum-containing masonry. Lime is used as a filler to adjust the strength to the surrounding original material. The proposed mixtures were tested under real conditions and guidelines for the practice have been delivered. The results provide planners and building material manufacturers with options for the static improvement of calcium sulfate-containing historic masonry structures without any potential for damage. The project identified potentials for further development and practical conversion. The goals of the project were fully achieved.

Key data

Short title: IngiMa - Injection of gypsum-containing historical masonry

Researcher / Project Management:

o. Prof. Dr.-Ing. Wolfram Jäger, TU Dresden
Dipl.-Geol. Thomas Köberle, TU Dresden
Dipl.-Ing. Angela Eckart, Planungs- und Ingenieurbüro für Bauwesen Radebeul
Prof. Dr.-Ing. Wolfram Jäger

Dr.-Ing. Toralf Burkert, Jäger Ingenieure GmbH
Dr.-Ing. Volker Stoll, Planungs- und Ingenieurbüro für Bauwesen Radebeul
Dr.-Ing. Carola Hauschild, Planungs- und Ingenieurbüro für Bauwesen Radebeul

Cooperation partners and Co-financers:

Lhoist
Rue de l´Industrie, 31
B-1400 Nivelles Belgien

DESOI GmbH
Gewerbestr. 16
36148 Kalbach

Jäger Ingenieure GmbH
Wichernstr. 12
01445 Radebeul

Solubel
Flachsstr. 3
91207 Lauf/Neuhof

Knauf Gips GmbH
Am Bahnhof 7
97346 Iphofen

MC Bauchemie
Am Kruppwald 1-8
46238 Bottrop

Mapei
Via Cafierro 22
I-20158 Milano - Italien

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