Research of safety-relevant natural and structural factors influencing the load-bearing capacity of rock stabilization with chemical grouts

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ABSTRACT: Geotechnical structures are subject to environmental and structural factors depending on formation water or the rock fracture degree. These factors inevitably affect the load-bearing capacity of the structure and in consequence the stability. Due to increasingly dense development, space constraints and the relocation of buildings to the underground, the subsoil improvement is playing an increasingly important role, as this often means that the subsoil has to adapt to the necessary requirements of the structure and not vice versa. The research focuses on the stabilization of rock with different high performance chemical grouts. For this purpose, the rock mechanical testing program on grouted rock was extended by special tests to investigate the material behavior of the chemical grout and its bonding with the surrounding rock in detail. The results of the research work are of safety-relevant importance and should therefore already be considered in the design phase of a construction project.

Keywords: Rock stabilization, chemical grout, formation water, rock fracture.

1 INTRODUCTION

When planning rock stabilizations designers and the contractors can choose from a wide range of chemical grouts, such as acrylate, aminoplastic or resin grouts (Hornich & Stadler 2009). The resin grouts in particular provide a waterproof and mechanical improvement (Gu et al. 2020, Spagnoli 2018), making them suitable for rock stabilization.

In addition to the choice of the chemical grout, the geometrical aspects depending on the rock fracture degree, as well as the interaction between the rock stabilization and the environment influence the load-bearing capacity. Further influences on rock stabilization can result from the construction process and the associated different load phases.

In particular, environmental influences such as water contact are investigated in the study at hand. The safety-relevant aspects of the research are intended to increase the awareness of the designer of a rock stabilization with chemical grouts. In order to consider structural and environmental factors, which can significantly change the load-bearing capacity of the rock stabilization, already in the design phase of a construction project.

2 ROCK SUPPORT WITH CHEMICAL GROUTS

This research work focuses on rock support with chemical grouts. The research is based on laboratory tests carried out on two different materials. The first material was a fractured sandstone stabilized with resin 01 and the second was an artificially produced conglomerate of chalk gravel and resin. The artificially produced conglomerate was made with two different resin-based grouts. The resins 01 and 02 differ in their deformation behavior and load-bearing capacity. The mechanical parameters of the materials are shown in Table 1 and represent the reference values for the intact material. These reference values will be referred to in the comparative considerations of this research work. The values in the table were determined experimentally.

Figure 1. Grouted Sandstone 67,5° (left) and artificial produced conglomerate (right).

Table 1. Mechanical parameters of intact sandstone and artificial produced conglomerate.

Mechanical parameters		Sandstone (intact)	Conglomerate	Conglomerate
Grout	[-]	-	resin 01	resin 02
Density	[kN/m³]	26	18	18
Young's modulus	[GPa]	19	1.8	0.2
Poisson's ratio	[-]	0.1	0.25	0.25
UCS	[MPa]	210	9.3	1.6

2.1 Influence of rock fracture

The influence of the fracture geometry was investigated using predefined joint orientations $\beta = 0°$, 45°, 67.5° and 90°. In addition, the fracture widths were varied from approx. 2 and 6 mm. The cylindrical specimens were cut to a height-to-diameter ratio of $h/d = 2$, thus meeting the specifications for test specimens according to (Mutschler 2004). A result after grouting with resin 01 into a 2 mm wide fracture of $\beta = 67.5°$ is shown in Figure 1 (left). After grouting, the specimens were stored at room temperature for 7 days before testing.

The UCS was determined in a triaxial instrument for rock. A total of five specimens were made for each fracture width. Three intact specimens were examined as reference values. A value of 0.1 mm/min was selected as strain rate for all specimens. In addition to measuring the axial load and continuously recording the vertical strain by means of a conductive displacement transducer, the radial deformation of the specimens was measured using a measuring chain.

The results of the uniaxial compression tests are shown in Figure 2. The plot shows the maximum vertical stresses at failure of the specimen in relation to the intact sandstone, separated by fracture widths of 2 mm and 6 mm. For visualization purposes, the measuring points were connected linearly. The lowest load bearing capacity or the greatest reduction in strength to 10% of the intact material occurs at a joint orientation of 45° and 67.5°. According to the sliding plane of weakness model Figure 2 (right) and assuming a friction angle φ of 30°, the lowest strength values will be reached for β = 60°. This shows a good agreement with the measured values. Numerical calculations by Boley et al. (2020) also show this characteristic curve for rock stabilization with chemical grouts.

For a joint orientation of 45° and 67.5°, no significant differences in load-bearing capacity were found with respect to the fracture width of 2 mm and 6 mm. This is in contrast to the joint orientation of 0° and 90°. At a fracture width of 2 mm, about 65% to 75% of the load bearing capacity of the intact sandstone can be achieved with the resin-based rock stabilization.

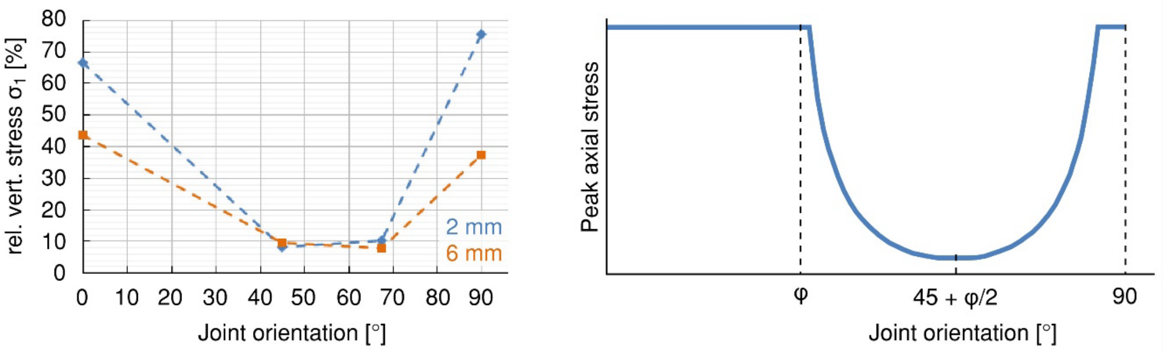

Figure 2. Relative vertical stress of grouted sandstone (left) and sliding plane of weakness model according to (Jaeger et al. 2007) (right).

2.2 *Influence of environment*

Water and temperature effects were considered as environmental factors influencing rock stabilization. For this purpose, the UCS of the artificially produced conglomerate was determined at room temperature and dry storage and shown as a reference value in Figure 3. Furthermore, the environmental and storage conditions of the specimens were adjusted and the specimens were water-stored at 10 °C. Figure 3 shows the corresponding UCS values.

It can be clearly seen that there is an environmental influence on the load bearing capacity. In the case of water contact, generally lower values are determined than under standard laboratory conditions. A reduction in temperature by 10 °C tends to reduce strength, although this influence is of secondary importance. Therefore, the detailed reproduction of the in-situ conditions during the laboratory tests is of great importance. A direct comparison of resins 01 and 02 reveals significant differences with regard to the effects of water. While the reduction in load-bearing capacity of the artificially produced conglomerate with resin 01 is within an acceptable range, the conglomerate with resin 02 loses almost its entire load-bearing capacity on contact with water.

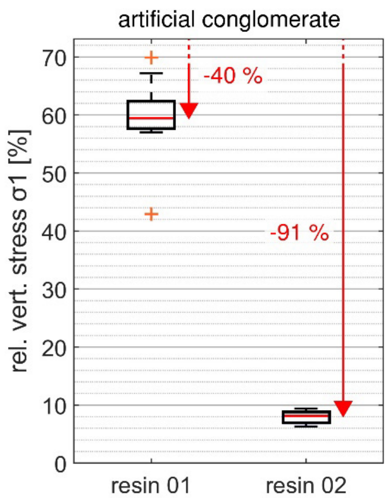

Figure 3. Relative vertical stress of artificially produced conglomerate (contact with water, 10 °C).

To evaluate the curing time of the resin 01, oscillatory rheology tests were carried out. The resin was mixed, deaerated and after 10 min installed between the plate/plate measuring device. A Peltier temperature device was used to keep the temperature constant during the test. Figure 4 shows the graphs of the moment curve of the resins 01 and Table 2 shows the characteristic ranges of the material behavior. In general, the measured moment represents a physical parameter, which depends on the selected measuring system and can be converted into the rheological parameter shear stress (Mezger 2018). The change of state proceeds from fluid behavior, where no bonding between resin and gravel exists, to gelation/curing, and finally to solid behavior, where a firm adhesive bond between the gravel enables a force transmission.

Table 2 shows the corresponding times or time intervals. It can be clearly seen that an increase in ambient temperature leads to a decrease in curing time of about 40%. The laboratory results agree well with the Arrhenius equation for the temperature dependence of reaction rates.

Table 2. Characteristic ranges of the material behavior of resin 01.

Resin 01	10 °C	20 °C	10 °C → 20 °C
Fluid behavior	< 13.5 h	< 7.5 h	-44%
Gelation/curing	13.5 h - 18.1 h	7.5 h - 10.5 h	-44% - -42%
Solid behavior	> 18.1 h	> 10.5 h	-42%

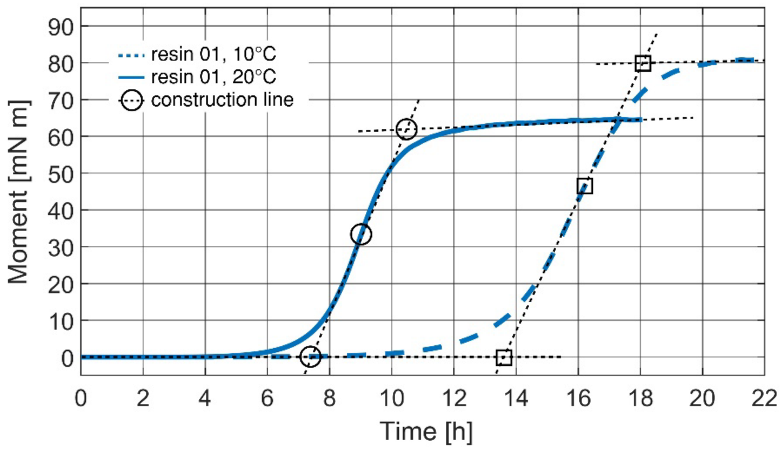

Figure 4. Time-moment curves of resin 01 at 10°C and 20°C.

3 CONCLUSIONS

Based on the results of the experimental research work it is clear that for rock stabilization with chemical grouts the environmental and structural factors need to be considered. The choice of the resin is of great importance, since even supposedly identical groups of chemical grouts, show completely different load-bearing behavior as a result of environmental influences. These safety-relevant aspects have to be taken into account in the laboratory tests, as well as in the design of a rock stabilization with chemical grouts. Consequently, the focus of the designer and contractor should exceed the typical application limits, for example the viscosity, and take into account the environmental influences. Essentially, the findings of the present research work can be summarized as follows:

- The greatest reduction in strength to 10% of the intact material occurs at joint orientations of 45° and 67.5°, regardless of fracture width.
- For a joint orientation of 0° or 90°, a load-bearing capacity of 65% to 75% of the intact sandstone can be achieved. This applies to a fracture width of 2 mm. For a fracture width of 4 mm, the values are about 40% of the intact sandstone.

- Water influence on rock stabilization with chemical grouts is significant. The influences of temperature variation are present, but of secondary importance.
- The supposedly identical group of chemical grouts of the resins reacts completely different to water contact. Resin 01 continues to have a load-bearing capacity, whereas resin 02 is characterized by a strength reduction of approximately 90%.
- Based on the oscillatory rheology tests it could be shown that the resin 01 has a solid behavior and initial strength after 18.1 hours at 10 °C. If the Temperature is increased by 10 °C, the reaction rate doubles and the rock stabilization can be subjected to mechanical loads after 10.5 hours.

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REFERENCES

Boley, C., Forouzandeh, Y., Pratter, P. 2020. Improvement and Stabilization of fissured rock by acrylate gels and polyurethane resins. In: *Proceedings of the 54th US Rock Mechanics/Geomechanics Symposium*, ARMA, Colorado, USA, 28 June-1 July 2020.

Gu, Y., Zhao, J. Johnson, J. A. 2020. Polymer networks: From plastics and gels to porous frameworks. In: *Angew Chem* 59 (13), pp.5022–5049. DOI: 10.1002/anie.201902900

Hornich, W. & Stadler, G. 2009. Injektionen. In: *Grundbau-Taschenbuch, Teil 2: Geotechnische Verfahren*, Witt, K. J. (ed), pp. 159-198. Ernst & Sohn: Berlin.

Jaeger, J. C., Cook, N. G. W., Zimmerman, R. W. 2007. *Fundamentals of Rock Mechanics* 4. Wiley-Blackwell Publishing: Malden.

Mezger, T. G. 2018. *Applied rheology: With joe flow on the rheology road* 2, pp. 89-100. Anton Paar: Graz.

Mutschler, T. 2004. Neufassung der Empfehlung Nr. 1 des Arbeitskreises „Versuchstechnik Fels“ der Deutschen Gesellschaft für Geotechnik e. V.: Einaxiale Druckversuche an zylindrischen Gesteinsprüfkörpern, In: *Bautechnik* 81 (10), pp. 825-834. Ernst & Sohn: Berlin.

Spagnoli, G. 2018. A review of soil improvement with non-conventional grouts. In: *Int J Geotech Eng* 15 (3), pp. 273-287. DOI: 10.1080/19386362.2018.1484603