FUNGUS: Functional Assessment of Geomechanical and Fluidic Properties of an MgO Drift Seal – 25194

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ABSTRACT

In geological repositories, drift seals are a central aspect of the safety concept. For this reason, they are the subject of numerous research projects. Over a period of 10 years, the STROEFUN-Project has led to the construction of a half dam in the Teutschenthal salt mine. In this research project, the focus was on the contact zone between the sealing element and the surrounding salt formation. To prove the sealing function of the contact zone, a special measuring concept and the associated measuring system were developed. With this measuring system, it is possible to measure the permeability of the contact zone in situ without destroying the sealing element or the host formation. Since this concept provides the possibility to obtain continuous data at different points in time, showing the deceasing permeability of the contact zone, a follow up project was initiated under the acronym FUNGUS.

A main aspect of the FUNGUS-Project is the repetitive collection of data. Using the measuring system mentioned, permeability measurements are carried out at approximately 8-month intervals. This makes it possible to determine the development of the sealing effect of the contact zone over time. Additional site-specific data, like stress state of the surrounding rock salt, convergence of the drift, underground temperatures, and humidity provide the opportunity to transfer the data and knowledge gained to other salt repositories. In the first place, this project will be used to support the licensing process of the closure of the Morsleben Repository (ERAM) and the associated safety case.

In addition to the in situ measurements and testing, cores are taken from the sealing element, the contact zone, and the surrounding rock formation in order to achieve a better understanding of the sealing system. Mechanical and hydraulic measurements in the laboratory are part of the research programme. Furthermore, selected core samples are investigated in more detail by means of computer tomography.

INTRODUCTION

Within the STROEFUN-Project, a test concept for the objective to realise large scale verification of the fluidic functional safety of drift seals required in [1] was developed and the associated measuring system installed and tested successfully. Since the test-setup is non-destructive and the half dam in the Teutschenthal mine is still existing and accessible, further tests and investigations can be done. This situation provides the possibility to test the structure several times and thus generate data to evaluate the behaviour of the sealing structure and the contact zone over a longer period of time. Figure 1 shows a picture of the half dam.

Thus, the follow-up project FUNGUS was established. Furthermore, in order to be able to understand the behaviour of the surrounding salt formation several stress and permeability measurements in boreholes as well as convergence measurements are part of the FUNGUS-Project as well. The convergence and stress measurements provide the basis for making the results from Teutschenthal transferable to other salt mines as well, in this case for the ERAM. Additionally, the permeability measurements in boreholes serve for pointwise verification of the results of the new measuring system.

For the investigations in boreholes, a first drilling campaign was carried out right after the first in situ test series of the half-dam. During this campaign, 17 boreholes were drilled in the sealing structure, the surrounding formation and the contact zone. The obtained cores are used for the laboratory programme, which includes the determination of permeability values depending on the confining pressure, as well as mechanical measurements with the focus on the composite behaviour between the rock salt and the MgO-concrete. Furthermore, some of the samples, essentially from the contact zone, have been examined more closely using computer tomography.

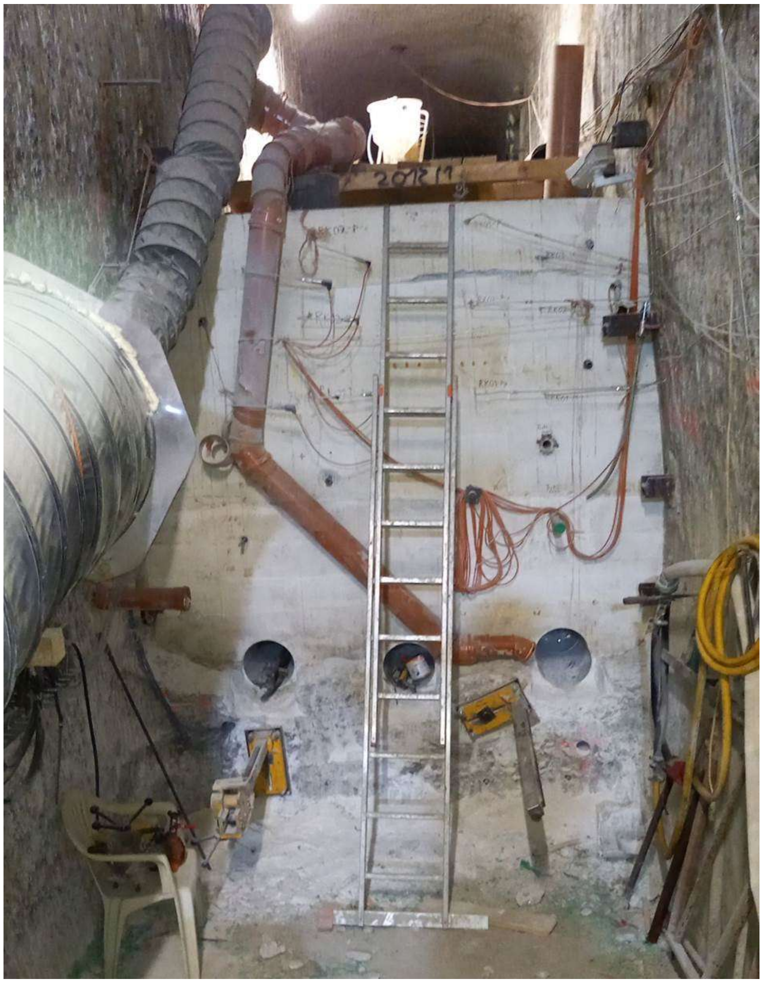

Figure 1 – Front view of the half dam at the end of the STROEFUN-Project [2].

To give an idea about the work done during the first drilling campaign, Figure 2 shows the boreholes drilled during this phase. As the figure shows, the boreholes are penetrating the formation, the sealing structure or both. Figure 2 already implies different lengths, directions and diameters that are attributable to the different reasons for drilling the boreholes. During drilling through the sealing structure, a special challenge represented the installation of mechanical monitoring devices within the concrete element. Two boreholes (B31 and B32) were drilled in order to replace defect devices without damaging neither the measuring system nor the sealing structure itself by the drilling activities.

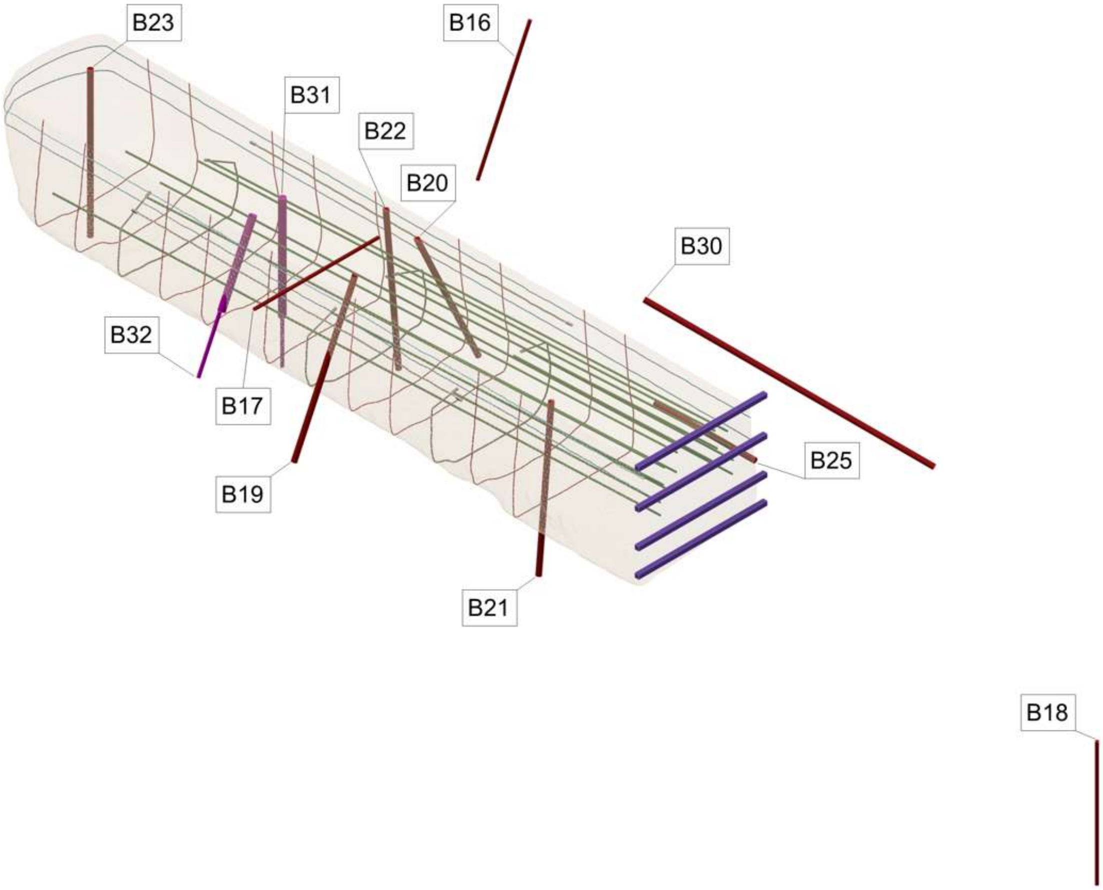

Figure 2 – Display of the boreholes drilled during the first drilling campaign of the FUNGUS-Project.

In the following sections, the development of the permeability of the half dam at the contact between the MgO-concrete structure and the surrounding salt formation is shown. Additionally, pictures taken with the computer tomography can be found in this paper as well. All the current findings are summarised in the end, including an intermediate conclusion and a brief outlook.

EVALUATION OF THE TESTS OF THE HALF-DAM TEUTSCHENTHAL

In the past, the determination of the permeability of a sealing structure was often carried out in connection with boreholes influencing the concrete element or the surrounding formation. With the test setup presented by Bauermeister et al. [2] and in the final report of the STROEFUN III-Project [3], this influence on the sealing element can be excluded.

Before the concreting of the sealing structure, inflatable hoses were installed at the contour of the drift. These hoses are referred to as test chambers (TC), see Figure 3. These test chambers are either used for pressurisation or for pressure monitoring. If a chamber is pressurised, it is referred to as a pressure chamber (PC). If it is used for monitoring purposes, it is referred to as a monitoring chamber (MC).

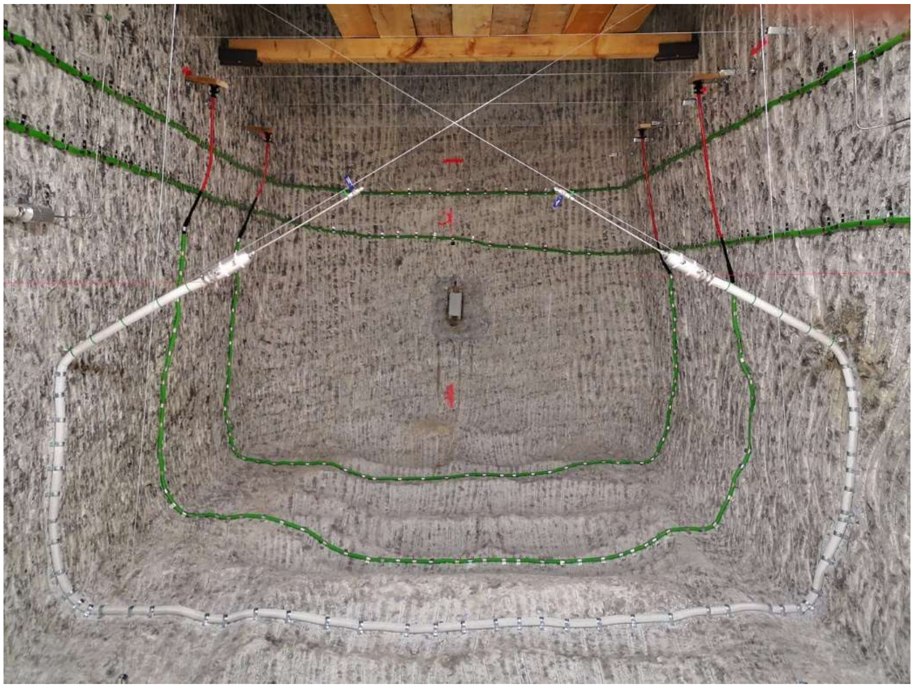

Figure 3 - Installed test chamber 3 (white hose).

Due to the half-dam structure besides the TCs two horizontal test chambers (HC) are necessary to characterise the hydraulic system completely, in order to catch all outflows when summing up inflows and outflows on different pathways, correctly. An outline of the installation can be found in Figure 4. During the concreting of the dam, the TCs and HCs are pressurised. By relieving the pressure after the setting of the concrete, cavities are created for later testing.

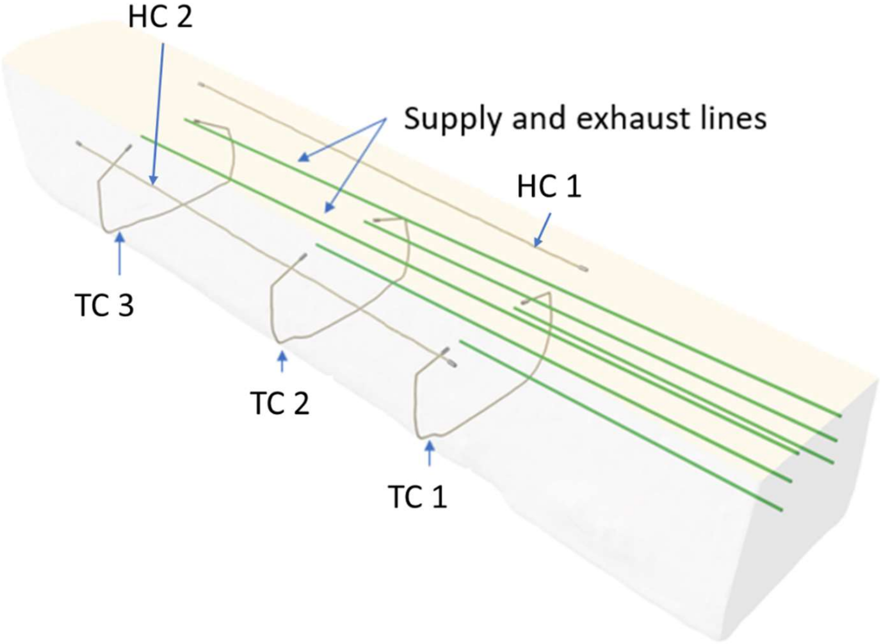

Figure 4 - Illustration of the installation of the test chambers.

During the test series with the new measuring system, one of the test chambers (TC) is pressurised with air and the pressure decrease is measured as well. This TC is referred to as pressure chamber (PC). In the other two TCs, then referred to as monitoring chambers (MC), the pressure response is measured. This procedure yields the permeabilities of the contact zone at three regions along the dam their Geomeans. After the construction of the half-dam in the STROEFUN III-Project a first test series has been carried out to verify the functionality of the installed measuring system. The results from June 2022 constitute the initial values. After the end of the STROEFUN III-Project and before the start of the FUNGUS-Project an interim test has been conducted to provide continuous information about the permeability development of the system in situ. Right after the start of the FUNGUS-Project, in October 2023, a third test series was carried out. Due to delays in the overall course of the project, the fourth measurement had to be postponed to September 2024. In Table 1 the values for the determined integral permeability of the half-dam can be found constituting a measure to characterise the decreasing permeability of the contact zone. It has to be noted that the values found under TC1 imply that TC1 has been pressurised and based on the reaction in the other two TCs the integral permeability has been determined by parameter identification for a numerical model of the sealing element. The same applies to the data noted in the other columns. Whereas the negligible pressure reactions in the HCs show that the main pathway is situated in the floor.

Table 1 - Development of the integral permeability of the half-dam with time.

k_{int} ($A_{half\ dam}$)	TC1	TC2	TC3	Geomeans
June 2022	1.1E-16	2.3E-16	3.0E-16	2.0E-16
February 2023	5.9E-17	1.5E-16	1.9E-16	1.2E-16
October 2023	5.7E-17	9.2E-17	1.2E-16	8.5E-17
September 2024	7.1E-18	6.9E-17	7.6E-17	3.3E-17

The values in Table 1 already show a clear trend. In all cases, a reduction of the permeability was observed. To show this trend even more clearly, a graphical illustration of the measured values can be found in Figure 5. It suggests a linear decrease of the logarithmical scaled permeability of the individual group of measurements with time. Only the value belonging to the measurement of MC1 in October 2023 falls out a little, potentially indicating the last phase before the permeability reduction related to pressure build-up in the range of a zero effective hydraulic pressure (i.e. the fluid pressure criterion is fulfilled [4]). However, it needs to be clarified that the permeability values in Table 1 are values for this specific concrete structure and cannot be compared directly with results from measurements in drift seals. Even though the contact zone only describes an area with a thickness of 2 mm, it has a significantly greater influence on the half-dam described in this paper than in a full drift seal.

In order to be able to better assess the influence of the contact zone on the integral permeability of the dam and to be able to better classify the contact zone individually, the permeability of the contact zone was determined. Here, as with the integral permeability of the half-dam, a decrease of the permeability was observed. The permeability of the contact zone itself decreased from the range of 1.1E-14 m² to 2.0E-15 m² in June 2022 to the range of 2.2E-15 m² to 1.0E-16 m² in September 2024.

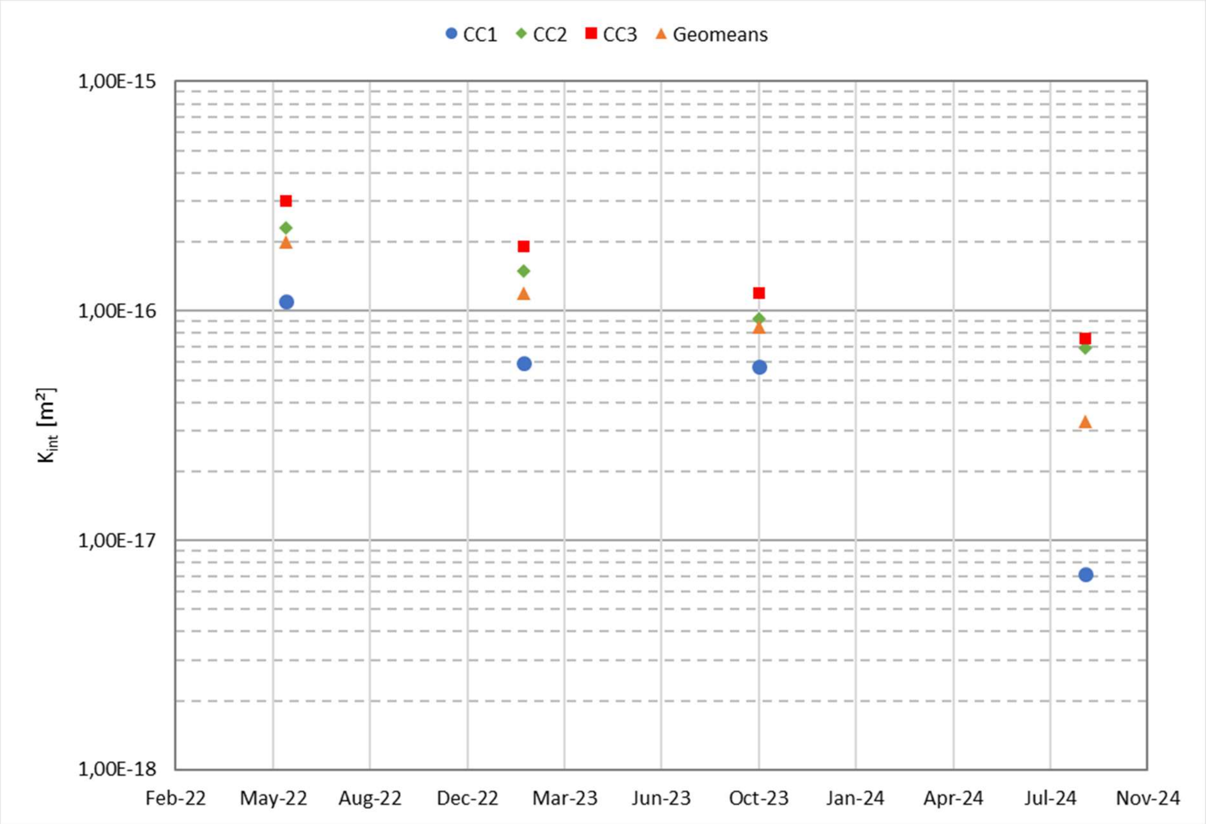

Figure 5 – Graphical display of the development of the integral permeability of the half-dam with time.

EXAMINATION OF DRILL CORES USING COMPUTER TOMOGRAPHY

The drill cores extracted during the drilling campaign were mainly used for quality assurance (QA) measures in the laboratory. Some drill cores, however, included the contact zone between the construction material and the salt formation. A few of these core samples were selected for examination by using computer tomography (CT) in order to get a deeper insight into the structure of the contact zone. The contact zone is assumed to be the mechanically and hydraulically weakest spot, which is the reason to focus on this region.

Figure 6 shows a drill core from the borehole B20, which penetrates through the half-dam and ends in the wall of the drift. Figure 7 shows a section of this core sample investigated by CT. The tight contact zone at the wall has exemplarily visually confirmed what was already concluded from the results of the negligible pressure build-up in the HCs during the in situ test series.

Figure 6 – Core sample of the contact area between concrete and formation obtained from borehole B20.

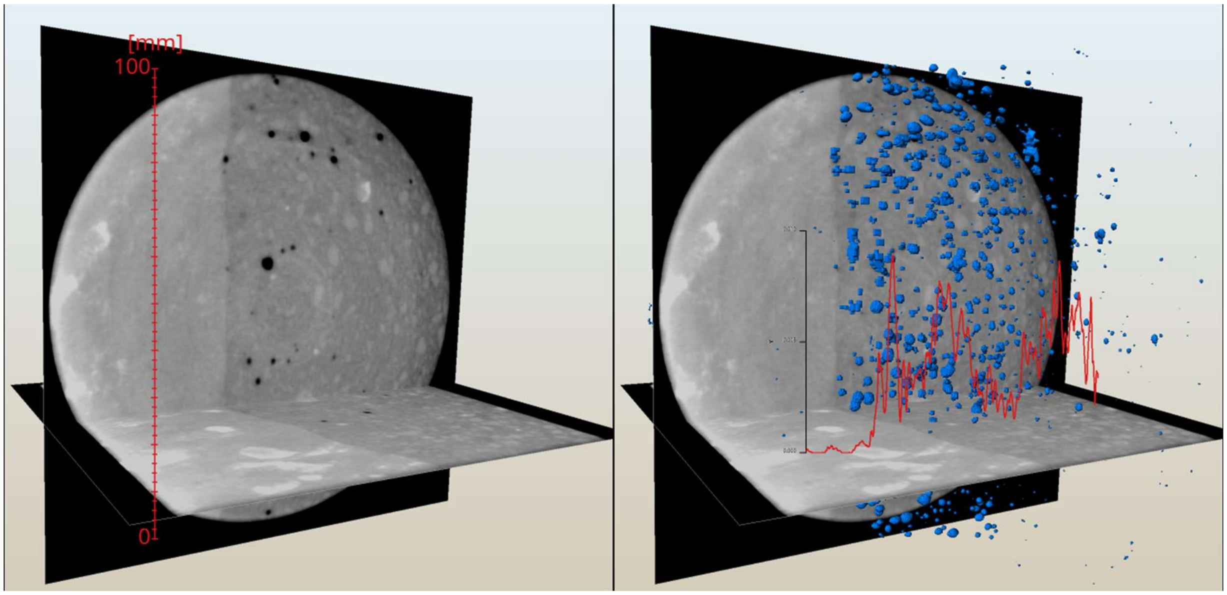

Figure 7 - CT image of the red marked section (Figure 6) of core sample from borehole B20 (left). CT image pointing out the air filled pores in a 3D system (blue) and the derived porosity profile (right). Voxel size of 44.9 µm.

In contrast to the contact zone at the wall, where the majority of the core samples showed tight bonding of the contact zone, the bonding quality of the contact zone in the floor varies, evidently. Figure 8 shows a photo of the contact zone at the floor from a core sample of B31. This borehole was drilled vertically trough the half dam into the floor of the drift. Regarding Figure 8 a good bond between salt and concrete can already be assumed, since no gaps can be seen. Furthermore, the breakage of the core took place in the salt section and not at interface, suggesting a tight mechanical contact. The salt aggregate can be clearly identified in the MgO-concrete. Furthermore a fairly homogeneous distribution of the aggregate can also be observed. Figure 9 displays the associated CT images of the core sample from borehole B31.

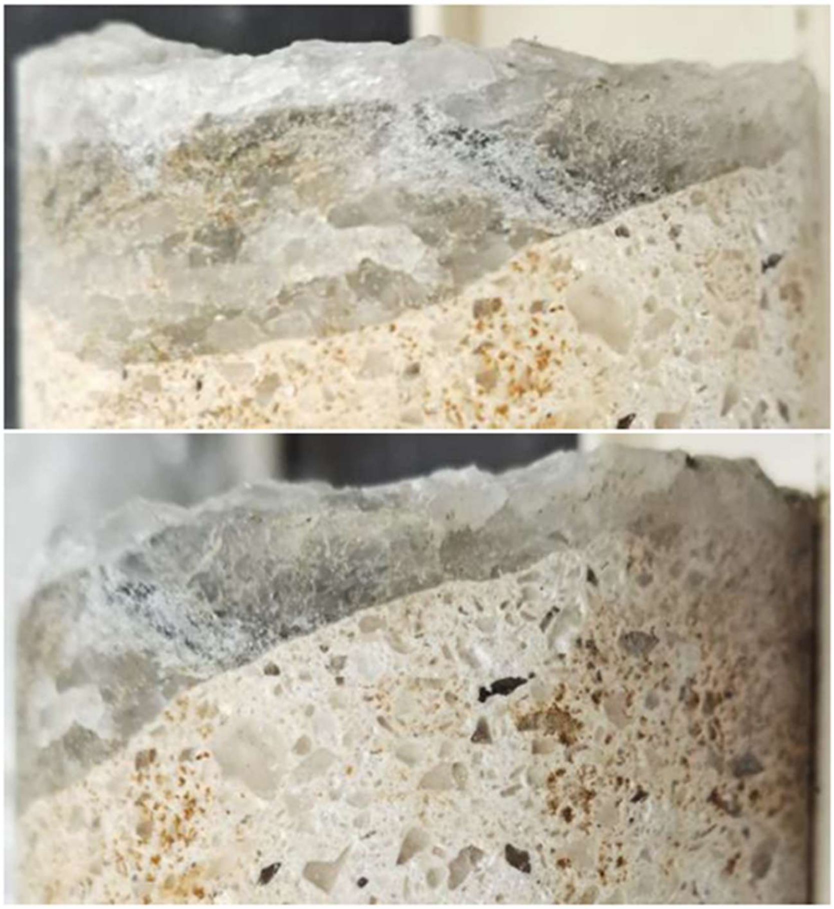

Figure 8 – Core sample of the contact area between concrete and formation obtained from borehole B31.

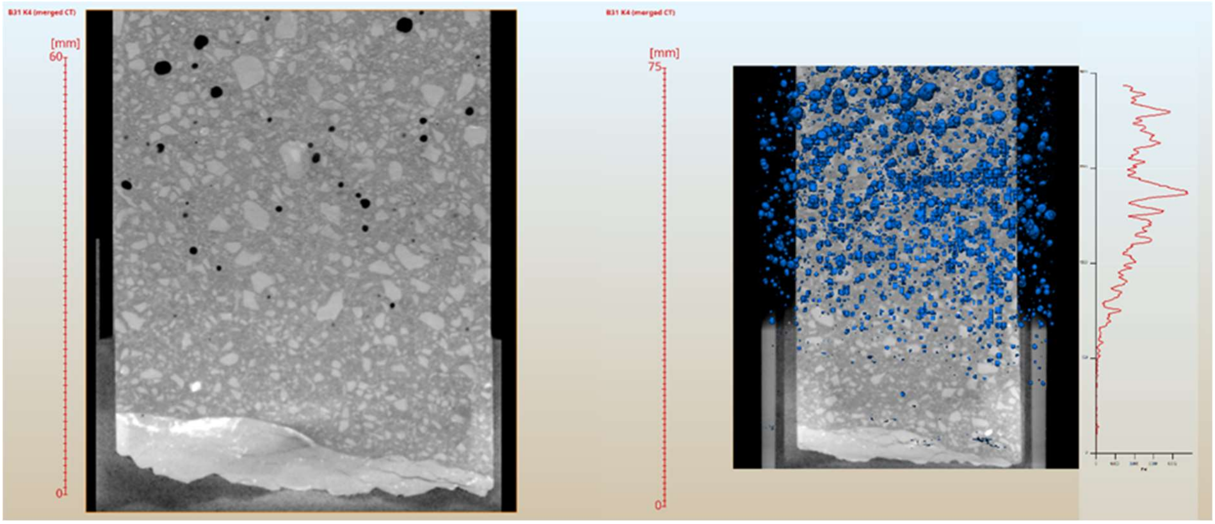

Figure 9 - CT image of the core sample displayed in Figure 8 (left). – CT image of the core sample displayed in Figure 8 pointing out the air filled pores in a 3D system (blue) and the derived porosity profile (right). Voxel size of 23.7 µm.

Figure 9 (left) shows the CT image in general, the top being the MgO-concrete and just a bit of the salt at the bottom. The darker the colors in the figure, the lower the density. As the concrete is dry after hydration, the black dots are identified to be air filed pores. Figure 9 (right) shows the distribution of the air-filled pores in a 3D system and the porosity profile. As it can be seen in both figures, no air filled pores can be identified at the interface. Furthermore, no cavities or gaps between the salt and the concrete are observed. Again it may be concluded that the bond between the salt and the MgO-concrete is quite good. As it was already mentioned before, the core broke near the contact zone in the salt. Some fractures and fissures can be identified on the far bottom of the CT images. The width of these fissure is below 0.1 mm. Supposedly, these fissures are a result of the breakage of the core in this region.

The second core, penetrating the contact zone on the floor of the drift, suitable to take CT images was obtained from the borehole B23. The B23 was drilled slightly slanted as it can be surmised based on Figure 2. Either during drilling or when retrieving the core from the borehole, the core broke at the contact zone between concrete and salt formation. However, the fracture does not follow the interface (Figure 10) but runs through salt and concrete. This might be an indicator that the connection between the MgO-concrete and the salt formation is of a good and strong quality. Although the drill core is not quite ideal, CT images were taken which can be found in the Figure 11.

Figure 10 – Core sample of the contact zone between concrete and formation obtained from borehole B23.

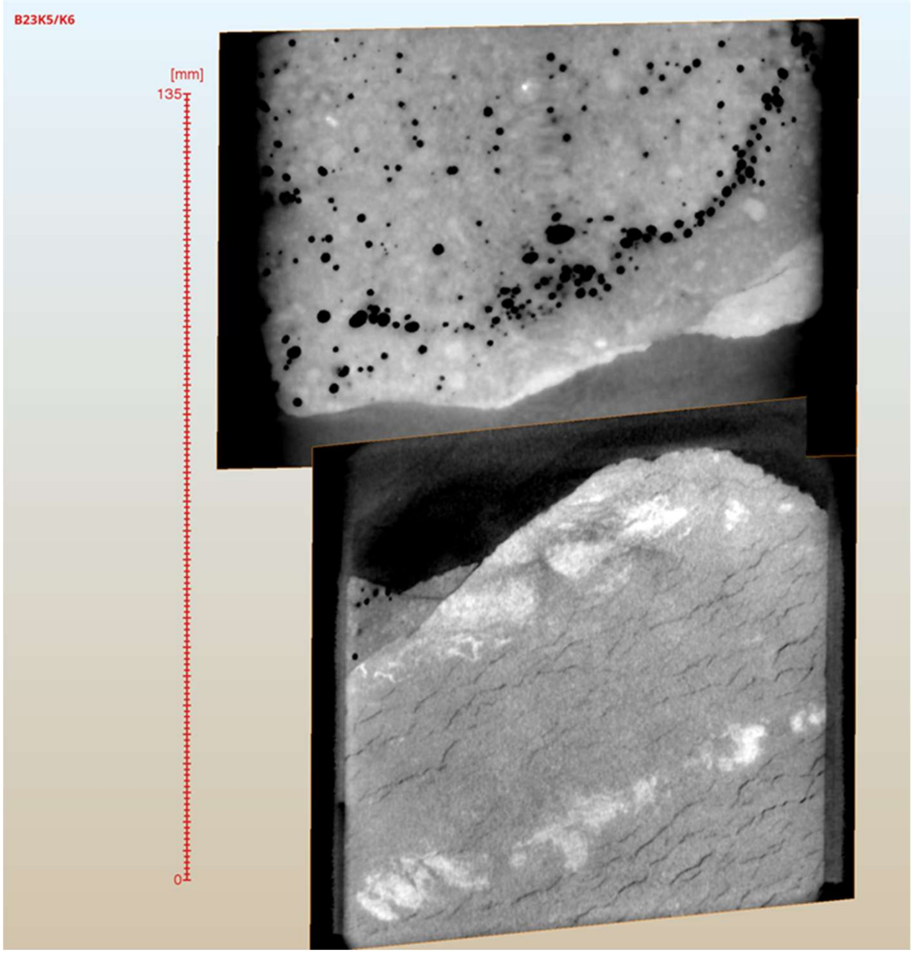

Figure 11 – CT image of the core samples displayed in Figure 10.

In Figure 10 and Figure 11, air filled pores can be identified in the core sample from borehole B23. However, they are not directly located at the interface between salt and MgO-concrete. Fine cracks can be seen in the salt, which run towards the concrete. The origin of these fissures is difficult to name, they could be caused either by the excavation of the drift or by the breakage of the core sample. Although the latter explanation seems to be more plausible it has to be taken into account that the contact zone in the floor seems to be the main pathway with respect to the results of the hydraulic measurements in situ.

Based on the CT images shown and analysed so far, it can be concluded that the connection and the associated sealing effect at the lateral walls can be considered good in general. Unexpectedly, the contact zone in the floor of the drift differs from the contact zone at the wall and varies evidently in its structure. For potential explanations of this issue further investigations and laboratory tests will be carried out within the FUNGUS-Project.

CONCLUSIONS AND OUTLOOK

This paper gives an interim update of the FUNGUS-Project showing results achieved so far. Within the FUNGUS-Project it is planned to continue the in-situ permeability measurements as described in this paper. Apart from this, a second drilling campaign will be carried out. Therefore, further drill cores will be available for additional laboratory investigations. Furthermore, further investigations regarding the different bond of the contact zone at the walls and the floor are planned.

In addition, a main topic of the FUNGUS-Project are investigations and tests regarding the used MgO-concrete. In combination with the bonding question mechanical tests will be carried out as well as the properties of the concrete suspension will be determined in detail.

ACKNOWLEDGEMENT

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