Test Study on the Expansion Mechanical Properties of Regenerated Anhydrite Rock

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Abstract. Dihydrate gypsum was formed after the anhydrite was immersed in water, and the volume of rock increased significantly. In order to analyze the expansion mechanical properties of Ordovician anhydrite rock, anhydrite rock samples (regenerated anhydrite rock) were obtained by high temperature drying of anhydrite rock samples, and then the rock expansibility were studied. Experiments show that: (1) Rock expansion curve of regenerated anhydrite shows three typical stages: linear rapid increase stage, concave stage and stable stage, and its maximum value of rock expansibility appears at the end of the second stage. (2) The expansion is closely related to the porosity of rock and the comprehensive performance between rock expansion and dissolution, and the average value of force in group B is 2.5964MPa and C is 1.9693MPa. The test scheme and results can provide references for the study of mechanical behavior of gypsum under dry wet cycling.

1. Introduction

As a widely used engineering building material, gypsum has good hydrophilicity and dehydration, and it has different shapes and strengths. It is widely used in cement retarders, building products and model making. Also because of this hydration property, gypsum rock has received much attention. The expansibility of gypsum also has a significant impact on the structural stress of tunnel engineering, which has been extensively studied by scholars at home and abroad. It mainly includes expansive force characteristic test of anhydrite powdery sample [1-3], grinding anhydrite into powdery and carrying out expansive characteristic test of remolded samples, and expansive characteristic test of anhydrite original sample[4-7], that is, making sample based on in-situ rock to study expansive rate and expansive force characteristic of anhydrite, and expansive characteristic research of regenerated anhydrite is drying and dewatering gypsum rock, then the samples were prepared and studied [8-9].

The expansion characteristics of gypsum rock is affected and controlled by the combination of calcium sulfate and water molecules. The anhydrite (i.e. anhydrous calcium sulfate) combines with two water molecules to form calcium sulfate dihydrate, and the volume can increase by 60% theoretically. It is often the object of research on the expansion mechanical properties of gypsum rock. Due to different rock-bearing environment and existing strata, the anhydrite shows great differences in its expansion mechanical properties. The paper uses the Ordovician gypsum rock in Shanxi as the research object, and the rock expansion force of the anhydrite rock were tested according to the
relevant experimental determination method. The expansion force curve of the rock specimen and the microscopic change process of the rock were analyzed and discussed.

2. Introduction to the test process

2.1. Rock sample collection and test specimen production

The rock used in the experiment was taken from the marl stratum of the Upper Majiagou Formation of the Ordovician in the Dugongling Tunnel in Shanxi Province, China (see Figure 1). The test specimen was made by a combination of mechanical and manual ways. First, the rock core was obtained by drilling on the rock blocks. Then, it was cut and smoothed using the stone sawing machine and the stone grinder respectively, and the sample standard meets the requirements of <Method for Determination of Physical and Mechanical Properties of Coal and Rock>. According to the test items and related specifications, the test samples is with a diameter of 50mm and a height of 36mm.

![Figure 1. Rock specimen photo of Dugongling Tunnel.](image)

The anhydrite will turn into dihydrate gypsum rock by absorbing water in the rock test specimen's collection, transportation and production process. To ensure that the anhydrite sample is without dihydrate gypsum, the sample is put into the 220°C drying oven to dehydrate and preserve heat for 48h so that the free water and the combined water in the rock sample are all dried and discharged. Anhydrite obtained in this way is different from the natural anhydrite protolith, so the anhydrite sample is referred to as regenerated anhydrite sample.

2.2. Rock expansion force test

The rock expansion force test is carried out by the pressure balance method and the SCY-2 rock lateral restraint expander (see Figure 2). The SCY-2 rock lateral restraint expander is a digital dial indicator direct reading structure with a precision of 0.001mm.

![Figure 2. Test device and procedure.](image)
Figure 3. Rock test specimen photograph.

The test procedures are as follows: (1) Put the test specimen into the lateral restraint ring, put the permeable stone on the top and bottom of the test specimen, and place the upper pressure head. (2) Rotate the handle on the reaction force frame to make the thimble touch the upper pressure head, inject distilled water and record the initial reading of the dial indicator and the dynamometer. (3) The gypsum rock gains volume as absorbing water. When the threshold value of the dial indicator is exceeded ($1 \times 10^{-3}$ mm), apply rotating force to reset the dial indicator to its initial position, and record the initial reading of the dial indicator and the dynamometer. (4) Cycling like this, terminate the test when the change of the expansion force is less than 0.001 mm per hour. The test specimen is shown in Figure 4 after the test.

3. Analysis of test results

In the rock expansion force test, six rock samples in the B and C groups were tested. The expansion stress-time curve is shown in Figure 4 and Figure 5.

![Figure 4. Swelling stress curve of sample B.](image)

![Figure 5. Swelling stress curve of sample C.](image)

(1) From the overall analysis of the expansion stress-time full-path curve, the expansion stress of the regenerated anhydrite rock sample can be divided into three stages (see Figure 6):

- The linear rapid increase phase (OA phase in Figure 6). The increase of the expansion stress in this phase is generally linear with the immersion time, and the expansion force increases rapidly with the immersion time.

The dry density and wave velocity test results of the standard specimens of rock B and C are shown in Table 1. The dry density of rock C is 0.03 g/cm³ smaller than rock B and the wave velocity is 205.33 m/s smaller. This shows the compactness of rock B is higher than rock C and the porosity of rock C is larger than rock B. By comparing their curves, it can be found that sample C showed a more significant concave shape than sample B in the initial stage (Figure 4). It shows that at this stage, due to the internal pores of the rock sample and under lateral control, the volume expansion of the specimen is first directed into the inner pore space of the rock specimen, and part of the expansion force is released. After the internal pores of the rock sample is full, the expansion developed rapidly in the axial direction.
Table 1. List of test results.

| NO. | Quality before drying/g | Quality after drying/g | Density after drying/(g/cm³) | Longitudinal wave velocity (m/s) |
|-----|-------------------------|------------------------|-------------------------------|---------------------------------|
| B   | 450.52                  | 449.91                 | 2.29                          | 4297.41                         |
| C   | 444.09                  | 443.78                 | 2.26                          | 4095.08                         |

2. The concave phase (AB phase in Figure 6). The expansion stress increment at this stage becomes slower with the immersion time and reaches the maximum expansion stress value. At the same time, the duration of this stage is also closely related to the internal porosity of the rock (see Table 2). For the B sample with lower porosity, the period generally lasts for about 400 minutes and reaches the maximum expansion stress value, while for the C rock sample with higher porosity, it will last for more than 2000 minutes before reaching the maximum value.

3. The steady phase (BC phase in Figure 6). At this stage, the expansion stress decreases with the immersion time and tends to be stable. At the beginning of this stage, the expansion stress of the sample dropped from the maximum value, indicating that during the water absorbing process of the sample, the calcium ions and sulfate ions in the test specimen were dissolved in water, and some minerals also got dissolved (see Figure 7), which causes slack in the expansion of the sample and a decrease in the expansion stress test data.

The dividing points' values of test curves of the 2 groups of 6 rock samples in each stage are listed in Table 2.

Figure 6. Threes stage division of B1 specimen

Figure 7. Immersion photos of regenerated anhydrite rock samples.

(2) Maximum expansion force and final expansion force

According to the data of the expansion stress-time whole path curve, the relationship between the maximum expansion force and the final expansion force of the B and C samples can be known (as
listed in Table 3): The final expansion stress and maximum expansion's average difference of the three samples in Group B in stress (referred to as "dissolution stress release value") is 0.105 MPa, which is 4.04% of the average value of the maximum expansion stress. The average difference between the final expansion stress and the maximum expansion stress of the three rock samples in Group C is 0.0325 MPa, which is 1.65% of the average value of the maximum expansion stress.

Table 2. Dividing point of swelling force curve.

| Sample | Boundary point of full expansion stress-time curve |
|--------|-----------------------------------------------|
|        | Point A | Point B | Point C |
| B1     | Time/min | 415     | 921.5   | 4592   |
|        | Stress/MPa | 1.7968  | 2.4358  | 2.3489 |
| B2     | Time/min | 417     | 920     | 4594   |
|        | Stress/MPa | 2.483   | 3.1038  | 2.8916 |
| B3     | Time/min | 263     | 923     | 4590   |
|        | Stress/MPa | 1.5227  | 2.2496  | 2.2708 |
| C1     | Time/min | 380     | 2060    | 4050   |
|        | Stress/MPa | 1.215   | 2.1806  | 2.117  |
| C2     | Time/min | 904     | 3145    | 4045   |
|        | Stress/MPa | 1.4219  | 1.7880  | 1.7827 |
| C3     | Time/min | 574.5   | 2667.5  | 4047.5 |
|        | Stress/MPa | 1.4     | 1.9394  | 1.9108 |

From the relationship between the maximum expansion force and the final expansion force of Group B and Group C, it can be inferred that:

① The rock sample's volume expansion and dissolution phenomenon occurs simultaneously during the water immersion process. In the early stage of the sample immersion, the volume expansion behavior of the rock sample has a far greater impact on the expansion force than the dissolution phenomenon. As a result, the expansion force increases continuously in the test. In the late stage, the volume expansion behavior of the rock sample gradually slowed down while the dissolution phenomenon developed continuously, so that the dissolution of the rock sample has a greater impact than the expansion. As a result, the expansion stress decreases during a certain phase in the test; it also indicates that the dissolution period of the sample is longer than the expansion period.

② In the process of water immersion, the rock sample's expansion and dissolution both has a certain limit. That is, the maximum expansion stress value and the maximum "dissolution stress release value", and the maximum expansion stress value and "dissolution stress release value" obtained in the test both are not the maximum value in the real sense, but a value under comprehensive interaction of the two, and the real value should be greater than the test value.

③ The maximum expansion stress value and the "dissolution stress release value" of the rock samples of Group B and Group C are closely related to the internal porosity of the rock sample (Table 1): the smaller the porosity, the higher the density, and the larger the maximum expansion stress value. At the same time, the "dissolution stress release value" is also larger; It also shows that the internal pores of the rock sample provide deformation space for the expansion of the rock and eases the extrusion to the outside space. For the plaster rock, the porosity of the rock is mostly affected by the degree of dissolution of the dissolution material. The greater the porosity, the more the dissolution material is lost, and the less the dissolution-apt material is retained in the rock. At the same time, the "dissolution stress release value" is also smaller in the test.
Table 3. Maximum and end value of swelling stress(unit:MPa).

| Sample | Maximum | Final value | Difference |
|--------|---------|-------------|------------|
|        | Test value | Average value | Test value | Average value | Test value | Average value |
| B1     | 2.4358     | 2.3489      | 0.0869     |
| B2     | 3.1038     | 2.8916      | 0.2122     | 0.105       |
| B3     | 2.2496     | 2.2337      | 0.0159     |
| C1     | 2.1806     | 2.117       | 0.0636     |
| C2     | 1.788      | 1.7827      | 0.0053     | 0.0325      |
| C3     | 1.9394     | 1.9108      | 0.0286     |

4. Discussion

In this paper, the anhydrite sample (regenerated gypsum rock sample) were obtained by high-temperature dehydration of gypsum rock specimens. Based on the rock test standard, the expansion mechanical properties of gypsum rock were tested. The characteristics of the sample acquisition route made it different from the anhydrite protolith expansion mechanics test, mainly in the following ways:

(1) The microstructure of the rock specimen itself is different. By high temperature, the regenerated anhydrite specimens are removed of the two water molecules combined with the calcium sulfate molecules, so that the space occupied by the combined water inside the rock sample is vacated. Whether this part of space is in the anhydrite protolith (assuming the protolith's initial state to be anhydrite) or in the previous conversion process from anhydrite to dihydrate gypsum is unknown. If it derives from the former, the microscopic difference between the regenerated anhydrite and the anhydrite protolith is small, while if it is from the latter, the difference is greater.

(2) Whether there is the microstructure difference between the regenerated gypsum rock and the anhydrite protolith, the test method is essentially different from the test of the expansion mechanical property of the anhydrite protolith. The test carried out in this paper is more similar to the rock's loading and unloading test. The test result indicates the expansion mechanical property of gypsum rock converted again from anhydrous calcium sulfate to calcium sulfate dihydrate, which is the mechanical behavior under the dry-wet cycle.

5. Conclusion

(1) The rock expansion force curve of the sample under immersion can be divided into three stages: the linear rapid increase stage, the concave stage and the steady stage; the maximum value of rock expansion force occurs at the end of the second stage, both the maximum and the final value of expansion force are closely related to the internal porosity of the rock.

(2) The test value of the expansion force of regenerated anhydrite rock is a result of the comprehensive interaction between rock expansion and dissolution when meeting water. The average expansion force of group B is 2.5964MPa, and the average expansion force of group C is 1.9693MPa.

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