THE THERMAL EXPANSION CHARACTERISTICS OF MUDSTONE

by

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Original scientific paper
https://doi.org/10.2298/TSCI180718242M

The location of mudstone rock formations as a repository of radioactive materials has attracted great attention from the international rock mechanics community. In this paper, the strain and thermal expansion coefficient of mudstone during the heating and constant temperature stages are studied through experiments. The results can provide a scientific basis for the design and safety protection of related projects.

Key words: *thermal expansion, mudstone, strain, thermal expansion coefficient*

Introduction

With the advancement of human science and technology and the frequent development of man-made underground activities, more and more rock projects are in high temperature environment, such as deep geological disposal of high-level nuclear waste, development of geothermal resources, mining of ultra-deep mine resources, underground gas, *etc.* The damage mechanism of rock under high temperature is quite different from normal temperature. The international rock mechanics has regarded temperature as an important factor affecting the mechanical properties of rock. Rock engineering problems caused by high temperature environment, such as thermal cracking, deformation instability and collapse of the wall, seriously threaten the operational safety of the project. Therefore, it is of great theoretical and engineering value to study the deformation law of rock under temperature.

In recent years, a lot of research has been carried out in the field of high temperature post-rock physico-mechanical properties. Bauer and Johnson [1] studied the P-wave velocity, tensile-compressive strength, elastic modulus, and permeability change of the westerly and charcoal granites in the late 1970's. Johnson *et al.* [2] studied the relationship between the variation characteristics of granite wave velocity and temperature, and believed that the decrease of wave velocity with temperature is related to the occurrence of cracks in mineral particles at the boundary. In order to numerically simulate the crustal movement process, Heuze [3] summarized and studied the thermal, physical and mechanical properties of granite rocks at high temperatures, and found that there are unusual changes compared with normal temperature. Homand-Etienne *et al.* [4] conducted an in-depth study of the cracks formed by dense granite under thermal action and found that after heat treatment, the rock connectivity increased and new cracks were created. Atkinson *et al.* [5] used acoustic emission to investigate the damage process of rock during heating, and measured the fracture toughness KIC of Westerly granite at

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20-50 °C. Xu *et al.* [6] studied the variation of main mechanical parameters with temperature under uniaxial compression of granite at 20 °C ~ 600 °C. Ma *et al.* [7] used self-made fixtures and environmental chambers to complete the experimental study on the influence of temperature on coal mechanical properties on the MTS810 servo test system, and obtained the strength, elastic modulus and strain of coal rock as a function of temperature law.

In summary, at this stage, the research on the influence of high temperature on the physical and mechanical properties of rock is rich. However, there is still no systematic research results on the thermal expansion and deformation characteristics of rocks under high temperature conditions. In this paper, the effects of temperature, heating time and other factors on the thermal expansion coefficient of mudstone will be studied through experiments, which can provide scientific basis for the design and safety protection of related projects.

Experiment scheme

Fifteen samples were drilled from a mudstone rock mass with a height of 50 mm and a diameter of 20 mm. The two ends were polished smooth and parallel. The experimental equipment uses the MTS 810 servo test system. As the temperature increases, the sample expands when heated, and the height increases accordingly. The upper and lower end faces of the sample are closely attached to the indenter of the MTS experimental system, the upper indenter is fixed, and the displacement of the lower indenter is measured to obtain the height variation of the sample. In order to ensure the stability of the vertical direction during the expansion of the sample, a pressure of 2 kN is applied to the lower end surface of the sample.

The 8 sets of rock samples were heated from 0 °C to 100 °C, 200 °C, 300 °C, 400 °C, 500 °C, 600 °C, 700 °C, 800 °C for a total of eight target temperature levels. During the heating process, the height change of the sample and the current temperature are recorded. When the predetermined temperature is reached, the temperature is kept constant, and the height change of the sample during the constant temperature process is continuously recorded, The sampling frequency is once per second. The formula for calculating the coefficient of thermal expansion is:

$$a_1 = \frac{l_t - l_0}{l_0 \Delta t} \tag{1}$$

where a_1 is the coefficient of thermal expansion, l_0 – the initial height of the sample, l_t – the height of the sample after change, and Δt – the temperature variation.

Result and discussion

Evolution characteristics of mudstone height in warming stage

The fig. 1 shows the change in height in the vertical direction during temperature rise from 0 °C to 80 °C to 800 °C. In the heating phase, the incremental distribution of the sample height at each target temperature is shown in fig. 2.

It can be seen from figs. 1 and 2 that the height of the eight sets of samples all showed an increasing trend with the increase of the heating time in the temperature rising stage. Comparing the temperature rise time of eight temperature levels-sample height curve, it can be found that the height of the eight samples is basically the same as the temperature rise time, which can be divided into two stages: 0~60 seconds stage, the curve shows the concave shape, the sample height. The rate of change is initially slower, and as time increases, the rate of change gradually increases. This is due to the initial temperature rise, the internal temperature of the sample is low, the water inside the rock begins to evaporate, and the mineral particles

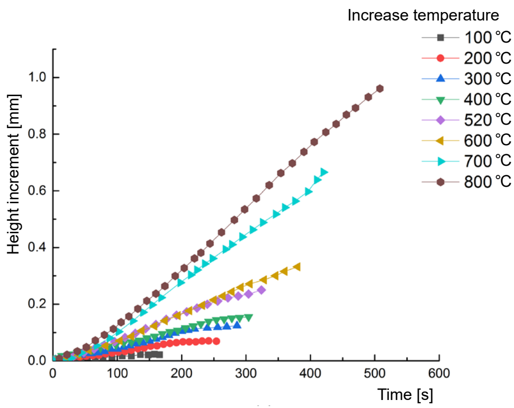

Figure 1. Heating time-height curve

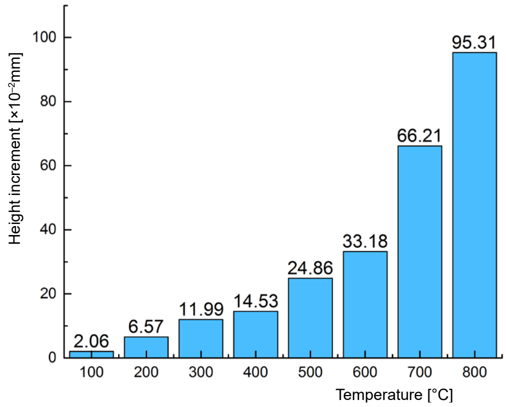

Figure 2. Increase in sample height when warming to target temperature

have not fully expanded. As the heating time increases, the internal water evaporation of the rock approaches the end, the internal expansion rate is basically stable, and the height curve gradually toward linearity.

After heating for 60 seconds, the sample height showed a linear increase with the increase of the heating time, and the rate of change of the sample height was basically constant. When the target temperature of the temperature rise is low (100~600 °C), the slope of the curve corresponding to each temperature increase target temperature is also small, and the values are relatively close, indicating that the rate of sample expansion is small in these cases. When the target temperature is greater than 600 °C, the slope of the corresponding curve increases accordingly, and the larger the target temperature of the temperature rise, the larger the slope, indicating that the sample is expanded at a higher rate.

On the other hand, during the change of the target temperature from 100 °C to 600 °C, the gradient of the height increase duting the warming phase is small. When the target temperature increased from 600 °C to 700 °C, the final increase of the height reaches 0.3303 mm, when the target temperature has increased from 700 °C to 800 °C, increase of the height is 0.2910 mm. It indicates that the increase of the height of the mudstone sample is sensitive in the temperature range of 600 °C ~ 800 °C. Since the coefficient of thermal expansion during heating is large, the possibility of rock damage under sharp deformation conditions is also heigh.

Characteristics of mudstone height with constant temperature

After the target temperature is reached, the temperature is kept constant, and the variation of the mudstone height with time in the constant temperature phase is shown in fig. 3. Under the condition that the constant temperature keeping time is substantially the same, the height increase amount distribution of the constant temperature stage of each target temperature level is as shown in fig. 4.

It can be seen from fig. 3 that in the constant temperature stage, as the time increases, the heights of the eight sets of samples all show a linear increase first, and then tend to be stable. Influenced by the warming phase, the heating rate determines the expansion rate of the mudstone, and the constant temperature in the constant temperature phase determines the final expansion of the mudstone sample at this temperature level. Therefore, in the initial stage of the constant temperature stage, the rate of change of the height of the mudstone sample is large, and the expansion deformation of the medium inside the sample cannot be completed instanta-

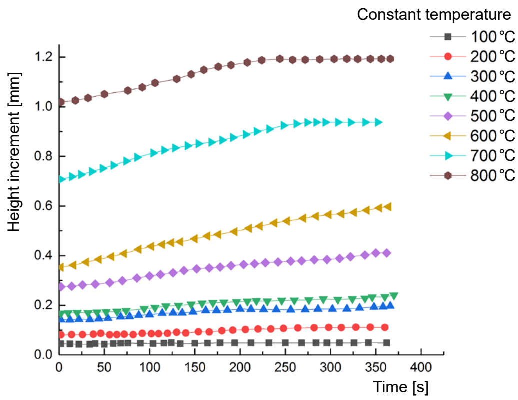

Figure 3. The process of incremental change of mudstone height in constant temperature stage

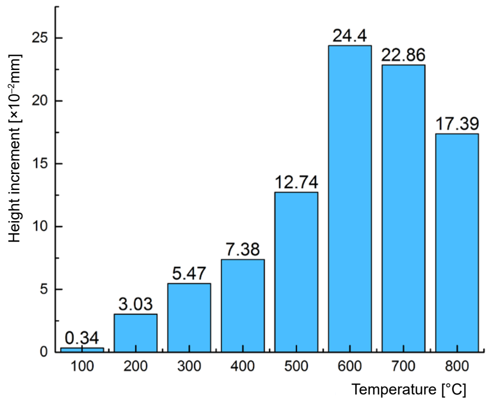

Figure 4. Height increase diagram of mudstone in constant temperature stage

neously. After maintaining the constant temperature for a certain period of time, the sample is fully expanded and its height increment is stable, such as fig. 4 shows.

Comparing the temperature variation of each target temperature level and the whole process of constant temperature, it can be found that under the set target temperature levels, the ratio of the height increase in the constant temperature stage to the total height increase is: 14.17%, 31.56 %, 31.33%, 33.68%, 33.88%, 42.38%, 25.67%, 14.53%. It can be seen that for each target temperature level, the height increment in the constant temperature phase is generally less than 40% of the total process height increment; the height increment in the warming phase plays a leading role.

As show in fig. 5, it can be seen that, in the early stage of the constant temperature stage, the height increase of the mudstone and the holding time are approximately linear. The higher the holding temperature, the greater the slope of the curve, indicating that the rate at which the sample is growing is increasing. When the holding temperature is low, the slope of the curve increases slowly with the increase of the holding temperature and after 400 °C, the slope of the curve increases rapidly, as shown in fig. 5. This shows that the higher the holding temperature during the same holding time, the greater the rate at which the sample expands. The reason for the phenomenon may be: when the holding temperature is low, the moisture in the mudstone sample is more, and the absorbed heat is mainly used to evaporate the moisture in the sample, so the expansion phenomenon is not obvious; in the case where the holding temperature is high underneath, the moisture in the mudstone sample completely evaporates, and the sample particles produce a relatively obvious expansion. At this time, the size of the mudstone sample itself increases, and the height of the sample increases greatly.

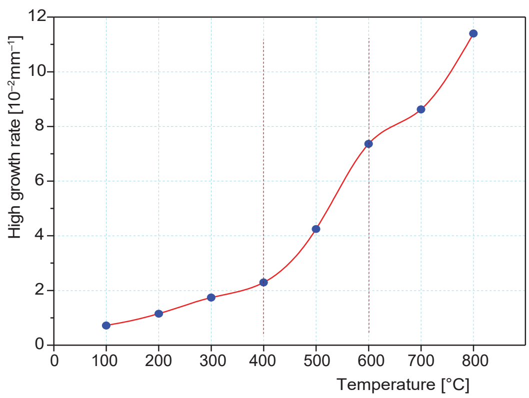

Figure 5. High linear growth rate curve of sample under constant temperature conditions

As the holding temperature increases, the height increase of the mudstone increases gradually. The higher the holding temperature, the greater the increase of the height increase value. However, after 600 °C, the increase in the height of the mudstone begins to decrease, and the higher the holding temperature, the greater the decrease. This shows that in the case of heat preservation, the height of the mudstone will still increase. This is because the heat transfer takes time. After a period of heat transfer, heat can be transferred from the surface of the test piece to the inside of the test piece. The higher the holding temperature, the more heat transferred to the inside of the test piece, the more water inside the test piece evaporates, the more dry the test piece, so that the heat absorbed by the test piece is mainly used for its own expansion, therefore, the higher the holding temperature high, the increase in the value of time height increases. The higher temperature will make the mudstone more dry. Therefore, more pores will be generated in the sample. As the holding temperature is further increased, the self-expansion of the mudstone will gradually fill the pores, making the interior more dense. Therefore, in the case where the holding temperature is further increased, the increase in the height of the test piece may decrease, and the higher the holding temperature, the larger the decrease.

Change law of thermal expansion coefficient of mudstone in warming stage

It can be seen from fig. 6 that as the temperature increases, the thermal expansion coefficient curve of the mudstone heating time can be divided into two stages. The first stage is the initial stage of heating, and the thermal expansion coefficient curve of the heating time is concave. As the heating time increases, the thermal expansion coefficient changes rapidly. This is mainly because the initial temperature is low, and the energy provided by the initial heating is mainly used for the test. Transfer heat in the sample. The second-stage curve is basically linearly rising, and the thermal expansion coefficient is proportional to the heating time. The slope of the curve remains basically unchanged, indicating that the growth rate of the thermal expansion coefficient is constant.

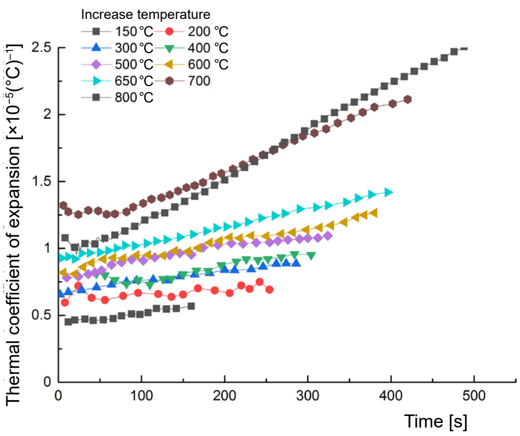

Figure 6. Curve of thermal expansion coefficient of mudstone in warming stage

During the heating process, the variation characteristics of the thermal expansion coefficient of mudstone in different heating stages show significant differences. Theoretically, under the same rock sample and heating rate conditions, the change of thermal expansion coefficient of each sample before reaching a certain target temperature level should be basically consistent. However, due to the use of on-site mudstone samples, after the sample preparation process such as drilling, cutting, grinding, and the heterogeneity of the rock mass itself, the error of the test process is unavoidable. Therefore, the temperature rise process curve, fig. 7, with representative maximum target temperature level is selected for analysis to reveal the evolution characteristics of mudstone thermal expansion coefficient at different heating stages.

It can be seen from fig. 7 that, with the increase of temperature, the thermal expansion coefficient of mudstone shows a non-linear growth trend. According to the characteristics of the thermal expansion coefficient curve, it can be divided into three typical stages: In the first stage,

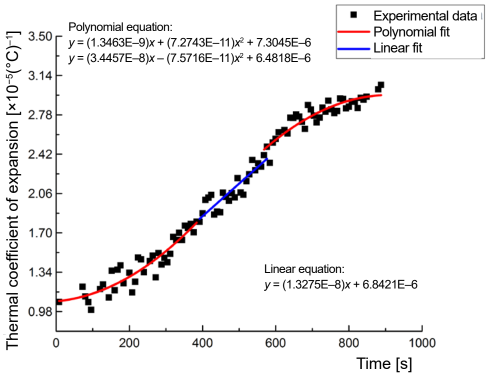

Figure 7. Fitting curve of thermal expansion coefficient of mudstone heating time

the curve is concave, which is expressed in the form of a quadratic curve for the accelerated growth phase; at this stage, as the temperature increases, the rate of change of the thermal expansion coefficient of mudstone increases and the growth rate increases; it indicates that the expansion deformation inside the rock sample is not uniform at the initial stage of temperature rise; at this time, the internal temperature of the rock sample is less than the performance temperature, and the internal expansion deformation is small. In the second stage, the curve shows a linear growth, which is a stable growth stage and can be expressed as a linear equation; at this stage, as the temperature increases, the rate of change of the thermal expansion coefficient of the mudstone remains stable; it shows that although there is still a temperature difference between the surface and the inside of the sample, the temperature difference remains basically the same, the heat exchange process is stable, and the heating rate of the internal and surface is basically the same; at this time, the growth rate of the thermal expansion coefficient of the mudstone sample is basically not change. In the third stage, the curve is concave, which is a deceleration growth phase and can be expressed as a quadratic curve; at this stage, the growth rate of the thermal expansion coefficient decreases, indicating that the thermal expansion coefficient of the mudstone increases slowly or even approaches the limit after reaching a certain temperature.

The variation law of thermal expansion coefficient of mudstone after stabilization with temperature

Take the thermal expansion coefficient of each sample after the deformation is stable for a certain period of time, and plot the thermal expansion coefficient-temperature curve of the mudstone as shown in fig. 8.

It can be seen from fig. 8 that when the target temperature is 100~500 °C, the thermal expansion coefficient increases from $1.21\cdot10^{-5}$/°C to $1.60\cdot10^{-5}$/°C, and the increase is small. When the target temperature is 500~700°C the coefficient of thermal expansion increases from $1.60\cdot10^{-5}$/°C to $2.79\cdot10^{-5}$/°C, and the growth rate is larger. When the target temperature is in the range of 700~800 °C, the thermal expansion coefficient increases from $2.79\cdot10^{-5}$/°C to $2.89\cdot10^{-5}$/°C, the increase is small. Among them, when the temperature is 650~700 °C, the coefficient of thermal expansion increases the most, reaching 35.6%. The sensitive temperature range indicating a significant influence on the thermal expansion coefficient of the stable stage mudstone is 500-700 °C.

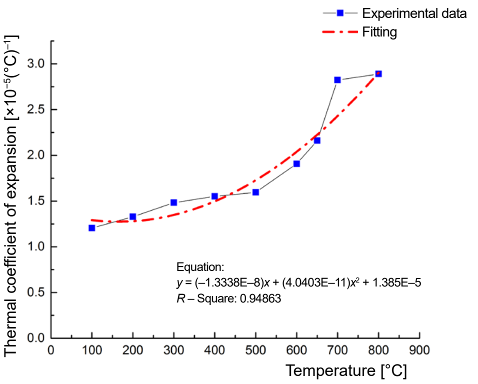

Figure 8. Curve of thermal expansion coefficient of mudstone after stabilization with temperature

Conclusion

In our work, the strain and thermal expansion coefficient of mudstone during the heating and constant temperature stages was investigated based on the experiments. It is shown that the height increment of the constant temperature stage is generally less than 40% of the whole process height increment, and the height increment of the mudstone sample in the heating stage plays a leading role. The increase in the height of the mudstone sample during the warming phase is sensitive to the temperature range of 600 °C to 800 °C. With the increase of temperature, the thermal expansion coefficient of mudstone shows a non-linear growth trend. According to the characteristics of the thermal expansion coefficient curve, the growth process of the thermal expansion coefficient of mudstone can be divided into three typical stages: accelerated growth phase, linear growth phase, and deceleration growth phase. With the increase of temperature, the thermal expansion coefficient of mudstone samples showed a significant increase trend. Among them, the sensitive temperature range which has a significant influence on the thermal expansion coefficient of the stable stage mudstone is 500~700 °C. When the temperature is 650~700 °C, the increase of the coefficient of thermal expansion reaches a peak value of 35.6%.

Acknowledgment

This work is supported by the National Natural Science Foundation of China (Nos. 51674250); Major Program of National Natural Science Foundation of China (Nos. 51734009); China Postdoctoral Science Foundation (No. 2019M652018); Independent Innovation Project for Double First-level Construction (China University of Mining and Technology) (No. 27183004).

Nomenclature

a_1 – the coefficient of thermal expansion, [(°C)-1]
l_0 – the initial height of the sample, [m]
l_t – the height of the sample after change, [m]
Δt – the temperature variation, [°C]

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Paper submitted: July 18, 2018
Paper revised: September 23, 2018
Paper accepted: January 21, 2019