DOI 10.1007/s10553-023-01556-y
Chemistry and Technology of Fuels and Oils, Vol. 59, No.3, July, 2023 (Russian Original No.3, May – June, 2023)

INNOVATIVE TECHNOLOGIES OF OIL AND GAS

EXPERIMENTAL STUDY ON DYNAMIC AND STATIC ROCK MECHANICAL PROPERTIES OF TIGHT SANDSTONE GAS RESERVOIR

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The comparative study of dynamic and static rock mechanical properties of tight sandstone is of great significance to deepen the understanding of deep tight gas sandstone geological structure and improve the efficiency of oil and gas development. In this paper, taking the tight gas sandstone of the Sulige Gas Field as an example, experimental research on the difference of dynamic and static elastic parameters under different temperature and pressure conditions was carried out. Furthermore, the mechanism causing the difference of dynamic and static elastic parameters under different measurement conditions is analyzed. The results show that the dynamic Young's modulus measured under reservoir conditions is greater than the static Young's modulus, and there is a good linear correlation between the dynamic and static Young's modulus of rock samples. But the correlation between dynamic and static Poisson's ratio is relatively poor. The existence of microfractures has great influence on the static deformation of rock. It is also found that the dynamic Poisson's ratio of rock decreases with the increase of pressure and temperature. The longitudinal and transverse velocity changes of rock under reservoir conditions are the result of confining pressure and temperature combined in the experiment. In the process of dynamic splitting and crushing of sandstone, the strain rate increases with the increase of impact pressure. The rock has certain rebound effect during unloading. The stress time history curve of sandstone samples is related to the change of impact loading rate and the fracture failure mode. In addition, the accurate evaluation of rock mechanics parameters has a significant impact on fracture prediction.

Keywords: tight sandstone, dynamic and static rock mechanics parameters, Young's modulus, Poisson's ratio.

1. Introductıon

The mechanical properties of rocks are characterized by rock mechanical parameters [1-3]. The commonly used rock mechanics parameters mainly include elastic modulus, Poisson's ratio, shear modulus, volume modulus, tensile strength, etc. These parameters can be divided into static parameters and dynamic parameters according to their physical meaning [4-6]. The elastic parameters obtained by measuring the propagation velocity of ultrasonic wave in rock samples are dynamic parameters. However, static parameters can be obtained by static loading [7, 8].

Tight sandstone reservoirs in the Sulige Gas Field have low natural productivity due to tight lithology, and most of them need

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fracturing to obtain economic productivity. The mechanical parameters of reservoir rock are the basis of fracturing design [9-10]. According to the characteristics of underground engineering, the static elastic parameters of rock should be adopted in practical engineering [11, 12]. However, the static elastic parameters of rock can only be obtained by extracting the core from the ground and testing it in the laboratory, which is time-consuming and costly. In order to obtain the real static elastic parameters under reservoir conditions, it is more expensive to simulate the temperature and pressure conditions under the reservoir, and a lot of core experimental data is often needed to accurately describe the mechanical properties of the reservoir [13-14]. Therefore, in practical engineering applications, dynamic methods (logging and seismic exploration) are generally used to obtain the mechanical properties of reservoirs [15, 16]. The dynamic method can obtain the elastic parameters under real reservoir conditions that are continuous with depth, and it overcomes some disadvantages of the static method. There are differences among rock static and static elastic parameters. By comparing the dynamic elastic modulus calculated by acoustic wave logging with the static elastic modulus analyzed in laboratory, the conversion formula of dynamic and static elastic modulus can be obtained [17, 18]. However, there is a lack of systematic explanation of the microscopic mechanism of the difference between dynamic and static elastic parameters. It is generally believed that there is a good correlation between dynamic Young's modulus and static Young's modulus, the dynamic Young's modulus is 1-10 times of static Young's modulus, and the correlation between dynamic and static Poisson's ratio is relatively poor [19, 20].

In this paper, taking the tight gas sandstone of the Sulige Gas Field as an example, experimental research on the difference of dynamic and static elastic parameters under different temperature and pressure conditions was carried out. Furthermore, the mechanism causing the difference of dynamic and static elastic parameters under different measurement conditions is analyzed. This study is of great significance to deepen the understanding of deep tight gas sandstone geological structure and improve the efficiency of oil and gas development.

2. Materials and methods

The experimental cores are tight gas reservoir rock samples of the Sulige Gas Field, with average porosity of 8% and average permeability of 0.5 mD, which is typical tight sandstone (**Figure 1**). The samples were processed into standard cylindrical samples with diameter of 2.5 cm and length of 5 cm, which met the requirements of measuring ultrasonic propagation velocity and static mechanical parameters of rock samples. The measuring instrument is the "Petrophysical Parameter Test System". The device can produce a maximum confining pressure and pore pressure of 70 MPa and a maximum temperature of 150°C. In addition, the equipment can provide a maximum axial pressure of $9 \cdot 10^5$ N. The measurement accuracy of strain is 0.0001 mm.

In this paper, a 50 mm diameter variable section rod was installed as the loading equipment in SHPB test. Four kinds of loading impact pressure were used to drive the impact rod, and dynamic splitting tensile tests were carried out at different loading rates. SHPB test device is the core equipment for dynamic splitting tensile test of rock. During the test, the specimen is sandwiched radially between the incident rod and the transmission rod. The RMT-150B rock mechanics test system was used to carry out

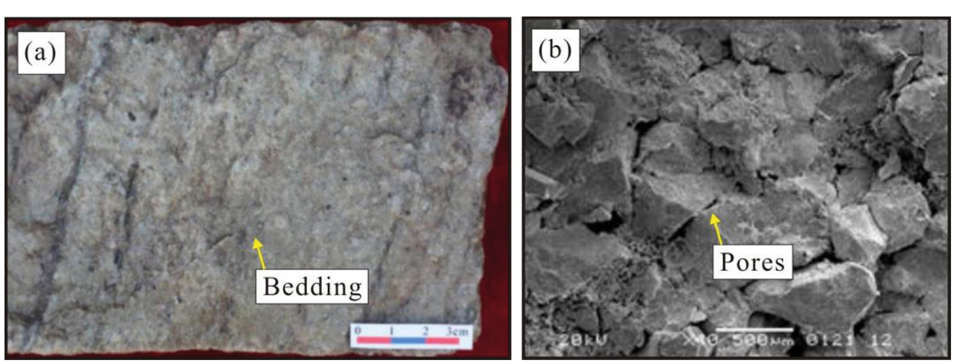

Fig. 1. Photos of the testing sandstone samples. a) Core photograph, 3,713 m, Well X1; b) Microscopic thin section image, 3726 m, Well X2

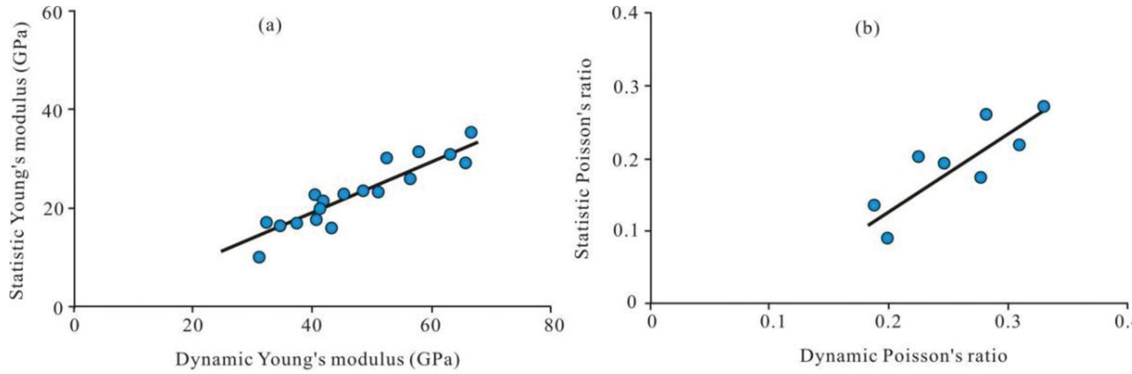

Fig. 2. Relationship between dynamic and static rock mechanics parameters of the tested samples. a) Dynamic and static Young's modulus; b) Dynamic and static Poisson's ratio

static splitting tensile test. Three sandstone specimens were selected from each type and radial loading was carried out by direct connection loading.

3. Results and analysıs

Relationship between dynamic and static rock mechanics parameters. All the measured samples were 100% saturated with brine. Dynamic and static Young's modulus and dynamic and static Poisson's ratio were respectively measured under the same measurement conditions. The measurement results are shown in **Figure 2**. It can be seen from Figure 2 that the dynamic Young's modulus measured under reservoir conditions is greater than the static Young's modulus, and there is a good linear correlation between the dynamic and static Young's modulus of rock samples. Most of the measured dynamic Poisson's ratios are greater than static Poisson's ratios under reservoir conditions, but there is no obvious correlation between dynamic and static Poisson's ratios. The distribution range of static Poisson's ratio is wide (0.1-0.27), while the dynamic Poisson's ratio is concentrated (0.2-0.35).

It can be seen from the relation between dynamic and static parameters that most of the static moduli are smaller than their dynamic moduli. The main reason for the difference between dynamic and static parameters of rock is the anisotropy and heterogeneity of rock caused by microfissure and pore in rock. The existence of microfissure has great influence on the static deformation of rock, but ultrasonic wave can travel around these microfissure. Thus, rocks exhibit different properties under static and dynamic loads [21-23]. However, with the increase of depth, the confining pressure on the rock increases, and the microfissure gradually closes, and the difference between dynamic and static elastic parameters of the rock decreases. Static mechanical parameters are mainly used in oilfield, but the cost of measuring static parameters is high [24-26]. Therefore, the static parameters of the sample can be obtained through the dynamic and static relationship of rock mechanics parameters after the dynamic parameters are obtained from the long source distance acoustic logging data [27, 28].

It is also found that the dynamic Poisson's ratio of rock decreases with the increase of pressure and temperature. Under the same pressure, the higher the temperature of the measured rock sample, the smaller the dynamic Poisson's ratio of rock. At the same temperature, the larger the pressure of the measured rock sample is, the smaller the dynamic Poisson's ratio is. This is consistent with the change law of P and S wave velocity with temperature and pressure [29, 30].

Change of P and S wave velocity under confining pressure. The P- and S-wave velocities of the samples were measured under reservoir conditions. The test samples were saturated with salt water in tight sandstone reservoirs. The test results are shown in **Figure 3**. Under a constant temperature, the P and S-wave velocities increase with the increase of pressure and decrease with the increase of temperature.

As can be seen from Figure 3, the longitudinal and transverse wave velocity changes of rock under reservoir conditions are the result of the combined action of confining pressure and temperature applied in the experiment. Under the action of temperature and pressure, the rock wave velocity can be used as a function of temperature and pressure. The change of temperature and pressure has significant influence on wave velocity [31, 32]. Its main performance is that the rock wave velocity increases with the increase of pressure. The reason is that when the pressure increases, the microfissure in the inner part of the sample closes,

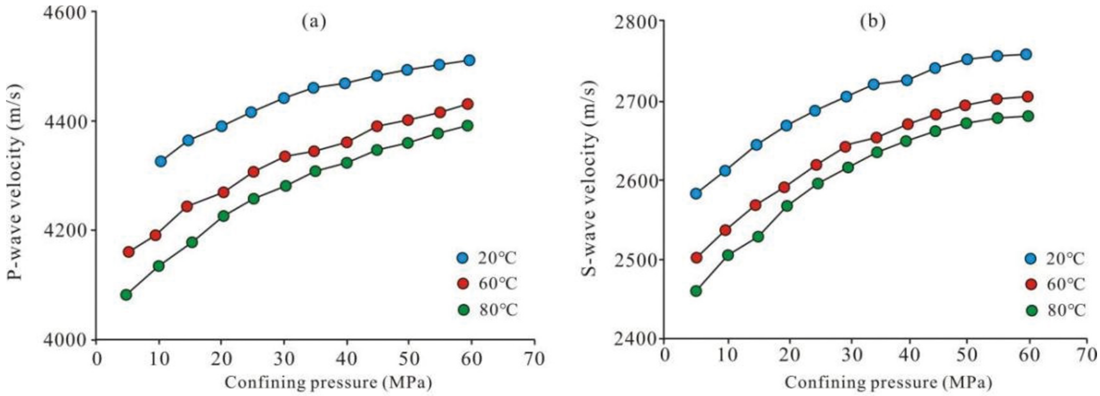

Fig. 3. Change characteristics of P-wave and S-wave velocity under different temperature conditions. a) P-wave velocity; b) S-wave velocity

the propagation path of sound wave becomes shorter, and the wave velocity increases. The rock wave velocity decreases with the increase of temperature. The reason is that the thermal expansion coefficient of rocks, minerals, colloidal compounds and pore fluid is different [33, 34]. The increase of temperature will increase the development of reservoir micro-fractures, which will lead to longer acoustic propagation path and lower wave velocity [35, 36].

Variation law of tensile stress strength and strain rate. Figure 4 shows the variation curve of the mean strain rate of sandstone samples in M3 group with time in the splitting tensile test. It can be seen from Figure 4 that in the process of dynamic splitting and crushing of sandstone, the strain rate of specimens increases with the increase of impact pressure. However, in the static splitting tensile test, the strain rate of the specimen is very small, which can be neglected [37, 38]. When the impact pressure is small, the strain rate fluctuation is small, the strain rate curve is relatively flat, and there is a long section of constant strain rate. With the increase of the burst pressure, the strain rate fluctuation also increases, but there is still an approximate constant strain variability plateau in the strain rate curve. The negative value of strain rate appears in the late stage, which indicates that the rock has a certain rebound effect during unloading [39, 40].

It can be seen from **Figure 5** that the stress time-history curve of each sandstone specimen is related to the change of impact loading rate and the splitting failure mode of the specimen. The strength of dynamic tensile stress increases with the increase of impact, and the time to reach the peak stress decreases, which shows strong sensitivity. This is mainly because, under the impact load, the microcracks in the specimen failed to crack through in time, resulting in the phenomenon of deformation lag [41, 42]. With the increase of the impact pressure, this phenomenon becomes more and more obvious, thus increasing the tensile stress strength of the specimen. The dynamic tensile stress strength of M4 group sandstone samples is 93% higher than the static tensile stress strength.

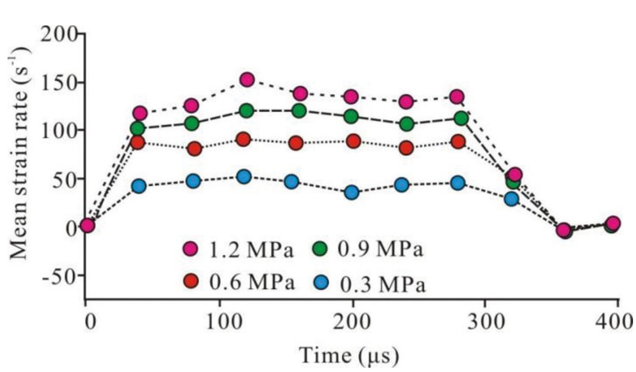

Fig. 4. Variation of mean strain rate of the M3 group of samples under different time and tensile strength conditions

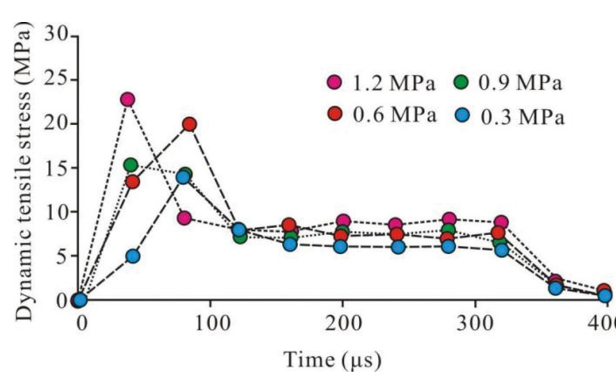

Fig. 5. Changes of dynamic tensile stress of the M4 group of samples under different time and tensile strength conditions

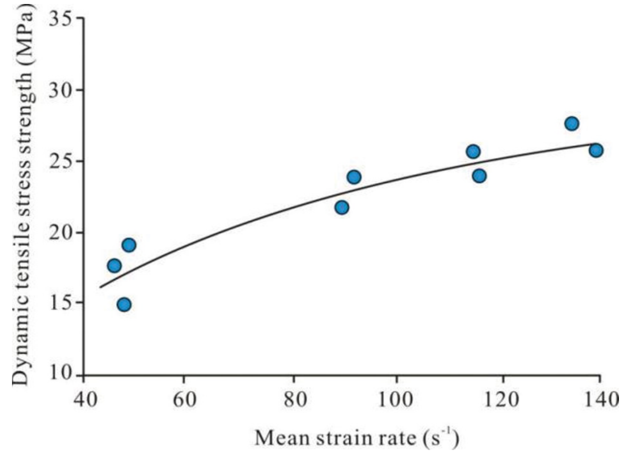

Fig. 6. Relationship between dynamic tensile stress strength and mean strain rate of the sandstone samples

In the splitting tensile test, the dynamic tensile stress intensity and corresponding average strain rate data of sandstone samples are shown in **Figure 6**. There is a power relation between dynamic tensile strength and average strain rate of sandstone. It can be seen that the dynamic tensile strength of sandstone specimens is more sensitive to the strain rate response than the dynamic compression strength.

Influence of rock mechanical parameters on fracturing. The sandstone in the study area belongs to low permeability reservoir, which can be put into production by fracturing. The reservoir is mainly sand-mudstone thin interbedded, and the heterogeneity of reservoir makes the difference of rock mechanical parameters. By analyzing rock mechanical parameters of sandstone in the study area, it can be seen that the elastic modulus of mudstone is nearly 1/2 of that of sandstone, and Poisson is larger than sandstone. Moreover, the difference of mechanical parameters between different reservoirs is different. In fracturing construction, the rock properties of reservoir medium directly affect the fracturing effect, restricting the fracturing scale and the thickness of the interval. If there is a large difference in rock mechanical parameters between the fractured layer and the upper and lower intervals, the artificial fracture is not easy to press the channeling interval, and the thickness of the interval required for fracturing can be appropriately reduced. If there is little difference in rock mechanical parameters between the fracture zone and the upper and lower spacers, the spacer is easily channeled, resulting in flooding and casing deformation during water injection. Then, it is necessary

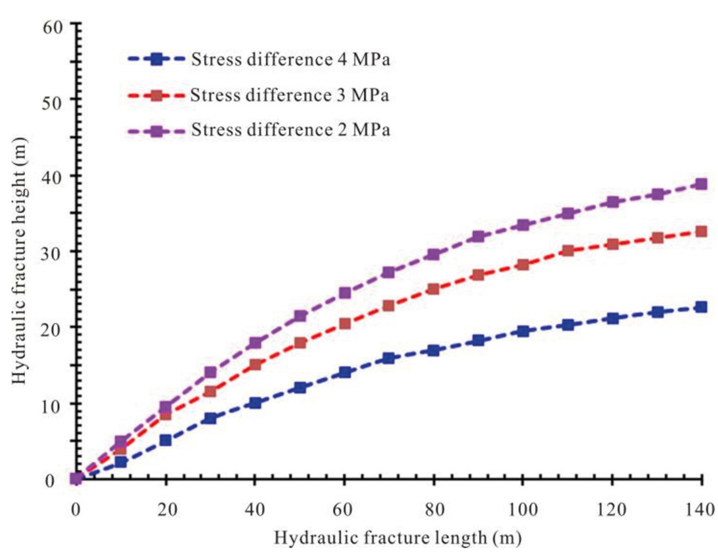

Fig. 7. Influence of rock mechanical parameters on hydraulic fracture

to determine the reasonable fracturing parameters and the larger thickness of the interval, control the fracturing scale, so as to avoid the pressure channel of the interval. It is worth emphasizing that the selected parameter samples are intact. However, due to the existence of various weak structural planes in the actual stratum, such as structural fractures distributed through the bed, interbedded fractures spread along the bedding or lithologic interface, it will affect the rock mechanics parameters of the reservoir.

This effect can greatly reduce the rock strength and deformation resistance of the reservoir. Therefore, when determining the water injection pressure and fracturing scale of a region, it is not only necessary to refer to the static mechanical parameters of the reservoir rock, but also according to the development of natural fractures in different oil fields and different blocks, so as to avoid the casing damage caused by mud water and unnecessary losses. In addition, the rock mechanics parameters in the range of borehole depth are a function of stress. The mechanical properties of the reservoir medium are anisotropic. As a result, hydraulic fracturing can affect the results of in-situ stress measurements (**Figure 7**).

4. Conclusions

In this paper, taking the tight gas sandstone of the Sulige Gas Field as an example, experimental research on the difference of dynamic and static elastic parameters under different temperature and pressure conditions was carried out. Furthermore, the mechanism causing the difference of dynamic and static elastic parameters under different measurement conditions is analyzed.

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The rock has certain rebound effect during unloading. The stress time history curve of sandstone samples is related to the change of impact loading rate and the fracture failure mode. In addition, the accurate evaluation of rock mechanics parameters has a significant impact on fracture prediction.

Acknowledgements

This work was not supported by any funds. And the authors want to show sincere thanks to all the techniques who have helped this research and all the authors of the references.

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