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Prediction of Tensile Strength in Tight Sandstone Based on Well Logging Data

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Abstract: The tensile strength of tight sandstone reservoirs has a direct impact on crack initiation, hydraulic fracture propagation, and the connectivity between hydraulic fractures and natural fractures during hydraulic fracturing processes. To overcome the limitations of experimental testing methods and field hydraulic fracturing techniques, this study conducted Brazilian tensile strength tests to obtain tensile strength data for 16 sets of tight sandstone samples. By comparing these experimental results with well logging data, a predictive model for the tensile strength of tight sandstone was established based on geophysical well logging data, with a correlation coefficient exceeding 0.92. The research findings indicate a positive correlation between tensile strength and sample density. This study provides support for fracture design, assesses fracturability, and aids in the selection of optimal drilling locations for hydraulic fracturing operations.

Keywords: Tight sandstone, Tensile strength, Well logging data, Hydraulic fracturing, Predictive model.

1. Introduction

Tensile strength is a crucial parameter in rock mechanics. During the process of rock failure, the failure of the tensile zone typically occurs first, while the compressive strength of the rock is usually much higher than its tensile strength. For tight sandstone reservoirs, hydraulic fracturing is often required to maintain stable and high production rates from individual wells. The tensile strength of the rock directly influences the initiation and propagation of hydraulic fractures, as well as the connectivity between hydraulic fractures and natural fractures. Therefore, accurate prediction of the tensile strength of tight sandstone is vital for assessing initiation pressures, evaluating fracture complexity, and determining the volume of fracture network reconstruction in hydraulic fracturing operations.

Currently, the main methods for evaluating rock tensile strength include experimental testing and field hydraulic fracturing techniques. However, these methods cannot fully reflect the influence of formation factors on rock strength parameters, nor can they provide continuous profiles of rock tensile strength. Continuous profiles of tensile strength are essential for the design and optimization of hydraulic fracturing operations. Unfortunately, there is a lack of research on quantitative evaluation of reservoir tensile strength based on well logging data.

Therefore, this study focuses on tight sandstone in Block SU53 of the Ordos Basin. By combining experimental results from Brazilian tensile tests and sonic testing under confining pressure with geophysical well logging data, a predictive model for the tensile strength of tight sandstone is established. This predictive model provides a foundation for fracture design, assesses fracturability, and aids in the selection of optimal drilling locations for hydraulic fracturing operations. Through this model, a more accurate assessment of reservoir tensile strength can be achieved, providing reliable guidance for the optimization and design of hydraulic fracturing operations.

2. Tensile Strength Determination Based on Brazilian Test

The experimental samples used in this study are tight sandstone cores obtained from the Shanxi Formation and Shihetazi Formation in the Ordos Basin. The sample collection range includes the central and western parts of the Yishan Slope, as well as the Tianhuan Depression. The burial depths of these cores range from 2910 to 3347 meters. To ensure the accuracy of the experimental results, we selected full-diameter core samples and processed them using a cutting machine to obtain 16 groups of core samples with a diameter of approximately 25mm. In the process of sample selection, we considered the diversity and representativeness of the geological conditions as much as possible to obtain comprehensive research results. The Ordos Basin, as one of China's important sedimentary basins, is characterized by widespread distribution and rich research value of the Shanxi Formation and Shihetazi Formation. Additionally, the rock characteristics in the central and western parts of the Yishan Slope and the Tianhuan Depression are representative and can reflect the rock mechanical properties of this region.

To ensure the reliability and repeatability of the experiments, full-diameter core samples were used. This choice helps preserve the original structure and properties of the rocks, reduces external interference, and provides more accurate experimental data. By using a cutting machine to process the cores, the consistency of the core sample dimensions was ensured, which is crucial for the subsequent experimental steps and data analysis.

Figure 1. Standard Rock Core Sample

The Brazilian test was utilized to measure the compressive strength of the rock samples, and the tensile strength of the Brazilian disc-shaped specimens can be calculated using the following formula.

$$S_t = \frac{2P}{\pi DL} \tag{1}$$

Based on this formula, the tensile strength of the tight sandstone was calculated, and the experimental test results are shown in Table 1. The distribution range of tensile strength in the study area was found to be 2.73 to 8.35 MPa, with an average value of 5.13 MPa.

Table 1. Results of Brazilian Disc Splitting Test

Serial Number	Serial Number (mm)	Thickness (mm)	Failure Load (N)	Tensile Strength (MPa)
1	25.3	11.6	2247	5.258
2	25.1	12.4	3423	7.332
		…		
15	25.2	12.5	3337	6.856
16	25.1	11.7	2874	4.913

3. Tensile Strength Prediction Model for Tight Sandstone

Experimental testing and field hydraulic fracturing are currently common methods used to determine rock tensile strength. However, these methods have limitations such as high testing costs, time-consuming procedures, and the ability to provide tensile strength values only at specific well depths without continuous profile information. Therefore, there is a need to explore methods for predicting rock tensile strength using geophysical well logging data. However, research in this field is relatively limited, and currently, only a few scholars have proposed methods for calculating sandstone tensile strength using well logging data. These methods involve multiple empirical formulas and require complex calculation processes. When predicting rock tensile strength using geophysical well logging data, several challenges need to be overcome. Firstly, conventional well logging data only provide a few parameters such as compressional wave velocity, while shear wave velocity usually needs to be obtained through experimental data fitting or the use of empirical formulas, which introduces some uncertainties. To reduce the probability of errors, it is preferable to directly establish the relationship between geophysical well logging data and tensile strength, rather than relying on indirectly obtained parameters.

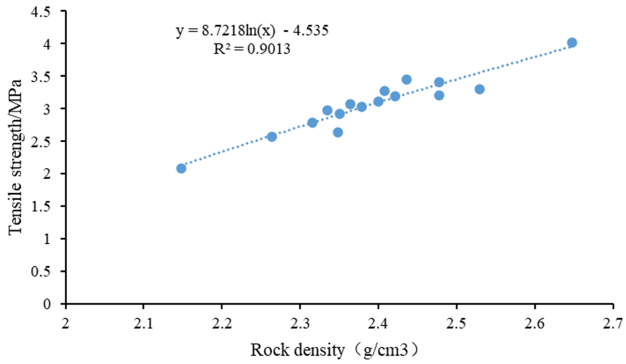

Figure 2. Fitting Relationship between Tensile Strength and Rock Density

The increase in rock density is typically accompanied by an increase in rock tensile strength. This is because an increase in rock density signifies a more compact internal structure, allowing it to effectively resist external tension and damage. High-density rocks generally exhibit stronger atomic bonding and particle interactions, which contribute to enhanced strength and durability. For tight sandstones, an increase in density leads to a reduction in porosity, thereby increasing the rock's tensile strength. During hydraulic fracturing, denser tight sandstones possess greater resistance to crack propagation, making it more challenging for fractures to expand and propagate, resulting in a relatively smaller range of reservoir stimulation.

Based on the aforementioned analysis, we can consider tensile strength as the objective function and use the density of tight sandstones and conventional well log data as independent variables for regression analysis to obtain a regression fitting function. This regression fitting function can be utilized to predict the tensile strength of rocks and provide crucial references for rock engineering and geological research. In the regression analysis, statistical methods and mathematical models can be employed to optimize the fitting performance, ensuring the resulting regression function possesses high accuracy and reliability.

$$\begin{cases} \sigma_t = 8.7218\ln(\rho) - 4.535 \\ R^2 = 0.9013 \end{cases} \tag{2}$$

It is evident that the tensile strength is directly proportional to the rock density, and under a logarithmic fitting relationship, the tensile strength and rock density exhibit the highest correlation, with a correlation coefficient of 0.9013.

4. Conclusions and Outlook

The tensile strength of 16 sets of tight sandstones from the Yanchang Formation in the Ordos Basin was determined using the Brazilian splitting test, ranging from 2.73 to 8.35 MPa, with an average value of 5.13 MPa.

A predictive model for the tensile strength of tight sandstones based on geophysical well logging data (density logging) was established, with a correlation coefficient exceeding 0.90. According to the predictive model, the tensile strength is directly proportional to the rock density.

Through further research and experimentation, we can collect more rock sample data, including parameters such as density and tensile strength, and use this data to validate and improve the regression model. Additionally, we can explore other possible influencing factors, such as pore structure and rock composition, to gain a deeper understanding of the relationship between rock tensile strength and density. This will provide important support and guidance for decision-making in rock mechanics research and geological engineering.

References

[1] Zhang, S., Wang, F., Zhang, X., et al. (2023). Optimization of Configurations and Dimensions of Double Circular Ring Specimens for Tensile Strength Testing of Rocks. Journal of China University of Mining and Technology, 52(1), 10.

[2] You, M., & Su, C. (2004). Experimental Study on Brazilian Disc Splitting and Tensile Strength of Rocks. Chinese Journal of Rock Mechanics and Engineering, 23(18), 3106-3106. DOI: 10.3321/j.issn:1000-6915.2004.18.014.

[3] Zheng, W., Cheng, J., & Li, B. (2022). Analysis of Improved Disk Test Method and Correction of Tensile Strength Formula. Chinese Journal of Underground Space and Engineering, 18(4), 7.

[4] Ni, Y., & Zhai, C. (2016). Prediction Study on Variation of Rock Characteristic Parameters with Pore Pressure. Liaoning Chemical Industry, (6), 4. DOI: 10.14029/j.cnki.issn1004-0935.2016.06.033.

[5] Zhou, K. (1977). Point Load Test Method for Rock Tensile Strength. Hydraulic Technology and Information, (02), 49. DOI: CNKI:SUN:JJSL.0.1977-02-005.