Improvement of Quantitative Evaluation of Rock Brittleness Based on Stress-Strain Curve

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Abstract

Accurate assessment of brittle of rock is the key to the transformation of oil and gas reservoirs. In view of this, Therefore, through literature research, summarized more than 30 kinds of brittleness index, and analysis the limitations of the brittleness evaluation index. A new brittle evaluation index, based on the stress characteristics of the stress-strain curve, and considering the two kinds of rock breaking behavior, is proposed. And carry out uniaxial compression test to verify the evaluation index of brittleness. The test results show that the new brittle index can evaluate the two kinds of rock brittleness, which is more general and reliable than other indexes. The results have important significance to enrich and improve the existing evaluation methods of rock brittleness.

Key words: Rock mechanics; Brittleness index; Stress-strain curve

INTRODUCTION

The brittleness of the rock is closely related to the rock mass stability and reservoir stimulation in the reservoir engineering. Brittleness index is an important indicator of rock burst prediction. It is directly related to the brittle fracture of rock mass and structure stability of surrounding rock in the underground caverns. At the same time, brittleness index is also an important indicator of reservoir mechanical properties evaluation, wellbore stability evaluation and hydraulic fracturing effects evaluation. There is no standard, uniform definitions and test methods of brittle rock at present. Brittleness is defined as the lack of material plastic by A. Morley[1] and M. Hetenyi[2]. J. G. Ramsey[3] believed, material brittle failure occurred when the loss of cohesion within the rock. L. Obert and W. I. Duvall[4] defined brittleness as the property of material such as cast iron and most rock material at or slightly exceed the yield strength of the destruction. Currently, the geology and related subjects scholars believe that brittleness refers to the characteristics of material fracture or damage before it showed minimal or no plastic deformation characteristics[5]. However, brittle material with properties have reached the following consensus: (a) Damage occurred in the low strain; (b) Brittle failure modes dominated by the internal control microcracks; (c) Rock is mostly composed of fine particulate matter; (d) High compressive strength, tensile strength ratio (Rabbi pressure); (e) High resilience energy; (f) Internal friction angle is large; (g) Cracks development completely when Hardness tests.

The properties of brittle rock are closely related to their mechanical properties. Many scholars have done a lot of research work in this respect, and they have formed dozens of brittle evaluation methods (Table 1).

Table 1
Domestic and Foreign Rock Brittleness Index and Test Method Summary

Test Method	Formula	Formula description	Literature source
Hardness test method	$B_1 = (H_m - H)/K$	H is macro hardness, H_m is micro hardness	H. Hond and Y. Sanada[5]
Proctor impact test	$B_2 = q\sigma_c$	Q is less than 0.6 mm debris percent content, σ_c is uniaxial compressive strength of rock	M. M. Protodyakonov[6]
Stress-strain curve	$B_3 = (\tau_p - \tau_t)/\tau_p$	τ_p is peak intensity, τ_t is residual strength	A. W. Bishop[7]
Stress-strain curve	$B_4 = \varepsilon_r/\varepsilon$	Ratio of recoverable strain ε_r to total strain ε	V. Hucka and B. Das[8]
Pressure rabbi	$B_5 = \sigma_c/\sigma_t$	Ratio of uniaxial compressive strength σ_c to tensile strength σ_t	V. Hucka and B. Das[8]
Pressure rabbi	$B_6 = (\sigma_c - \sigma_t)/(\sigma_c + \sigma_t)$	Function of uniaxial compressive strength σ_c and tensile strength σ_l	V. Hucka and B. Das[8]
Moore circle	$B_7 = \sin\psi$	Sine value of internal friction angle	V. Hucka and B. Das[8]
Stress-strain curve	$B_9 = W_t/W$	The ratio of the recoverable strain energy to the total energy	V. Hucka and B. Das[8]
Hardness test, Fracture test	$B_{10} = H/K_{IC}$	H is coefficient of hardness, K_{IC} is fracture toughness	B. R. Lawn and D. B. Marshall[9]
Fracture test	$B_{13} = K_{IC}/(\sigma_y h^{1/2})$	K_{IC} is Plane strain fracture toughness, σ_y is yield stress, h is the characteristics of the sample size	Z. P. Bazant and M. T. Kazcmi[10]
Hardness test, fracture test	$B_{16} = HE/K_{IC}^2$	H is Hardness coefficient, E is Young's modulus, K_{IC} is fracture toughness	J. B. Quinn and G. D. Quinn[11]
Impact test	$B_{17} = S_{20}$	The percentage of diameter less than 11.2 mm of fine elastic	Q. T. Blindheim and A. Bruland[11]
Penetration test	$B_{20} = \sigma_c\sigma_t/2$	The ratio of the maximum impact load and penetration depth	R. Altindag[12]
Pressure rabbi	$B_{21} = (\sigma_c\sigma_t/2)^{1/2}$	The mean of product of uniaxial compressive strength and tensile strength	R. Altindag[12]
Pressure rabbi	$B_{22} = (\varepsilon_t^p - \varepsilon_c^p)/\varepsilon_c^p$	The function of uniaxial compressive strength and tensile strength ratio	V. Hajiabdolmajid[13]
Penetration test	$B_{24} = (\varepsilon_p - \varepsilon_\tau)/\varepsilon_c^p$	The incremental load and the ratio of attenuation of load	V. Ajiabdolmajid and P. Kaiscr[14]
Stress-strain curve	$B_{25} = \overline{E} + \overline{v}$	On the function of peak strain ε_p and residual strain ε_t	R. Rickman[15]
Stress-strain curve	$B_{26} = (\varepsilon_p - \varepsilon_t)/\varepsilon_c^p$	The mean value of the elastic modulus and Poisson's ratio after normalization	R. Rickman et al.[16]
Mineral composition analysis	$B_{27} = \mathrm{d}W_t/\mathrm{d}W_c$ $= (E - M)/M$	Ratio of brittle mineral content to total mineral content	A. N. Stavrogin and G. Tarasov[17]
Stress-strain curve	$B_{20} = \dfrac{\varepsilon_{\mathrm{BRIT}} - \varepsilon_n}{\varepsilon_m - \varepsilon_n} + \alpha CS_{\mathrm{BRIT}}$ $+ \beta CS_{\mathrm{BRIT}} + \eta$	Ratio of post fracture damage energy of rock to peak before elastic strain energy	Li Qinghui[18]
Stress-strain curve	$B_{29} = \dfrac{\tau_p - \tau_r}{\tau_p} \dfrac{lg \parallel k_{ac(AC)} \parallel}{10}$	The sum of the peak strain index and the post curve shape index	Zhou Hui[19]

1. BRITTLENESS INDEX OF ROCK BASED ON STRESS STRAIN CURVE

According to the analysis of existing brittleness evaluation methods, the rock is the comprehensive property of rock. It is the common result of the interaction between the internal structure and the external loading conditions of the material. According to the definition, it shows that:

(a) Brittleness is the comprehensive property of the material, is the common function of the internal structure of the material and the external loading conditions. We need to establish a specific brittleness index in order to taking brittleness.

(b) The brittleness of the material will change. Brittleness is a kind of variable static state, which is the ability of the material to produce a local fracture in the current state and form many dimensions fractures.

Brittleness test is important basis of rock reservoir evaluation, select perforation and reform interval and design of fracturing scales. According to the above brittle defines, laboratory evaluation of rock brittleness need comprehensive evaluation, but complete stress-strain feature can showing the macroscopic and microscopic characteristic of brittle fracture, however, when the whole stress-strain curve is obtained, the compression of rock will damage the internal structure, and the evaluation of the brittleness needs to be considered. So based on the stress strain mechanical characteristics in this paper, combined with the rock mineral composition ,we established a brittle evaluation method.

In uniaxial compression tests, there are two types of rocks (I, II) in the brittleness of the apparent monotonic and continuity as shown in Figure 1.
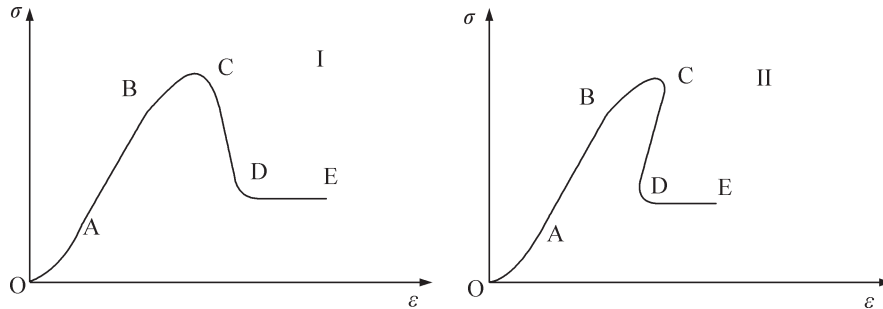

Figure 1
Stress and Strain Curves of Two Kinds of Rock Under Uniaxial Compression

From the line of stress and strain, it can be seen the first is a kind of brittle rock, and the twice is a kind of plasticity and brittle rock. According to the stress-strain curve at the peak of the mechanical characteristics of the definition of the new brittle evaluation index.

The new brittleness evaluation index firstly defines the post peak stress reduction degree:

$$P_k = \frac{\sigma_p - \sigma_r}{\sigma_p} . \tag{1}$$

Among them: for the peak stress, for the residual stress, the value range of 0~1.

Post peak stress reduction rate K:

$$K = \frac{\arctan(-\frac{\varepsilon_p - \varepsilon_r}{\sigma_p - \sigma_r})}{90} . \tag{2}$$

$\arctan(-\frac{\varepsilon_p - \varepsilon_r}{\sigma_p - \sigma_r})$ is the angle between the peak after peak stress to reduce the residual stress and the slope and peak vertical. K is the normalized angle. The value range of K is -1~1; the physical meaning of the representative: The greater the angle, reduce the stress of the same should be changed, the less brittle. The angle is smaller, the more brittle. When the angle is less than <=0, the rocks belong to pure brittle, angle is negative, they belong to the super brittle rock.

Define brittleness evaluation index is:
$$B = Pk \cdot K , \tag{3}$$

$$B = \frac{\sigma_p - \sigma_r}{\sigma_p} \Box \frac{\arctan(-\frac{\varepsilon_p - \varepsilon_r}{\sigma_p - \sigma_r})}{90} . \tag{4}$$

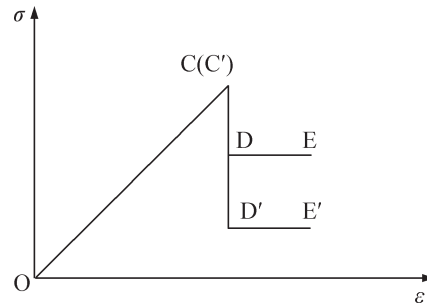When K is zero, however, the case is shown in Figure 2:

Figure 2
Residual Stress of Pure Brittle ($K = 0$)

Rock brittleness can't be distinguished. However, when the rock is pure brittle, the main influence factors which cause the difference of the residual stress or the peak stress are changed into the mineral composition of the rock.

Therefore, the definition of brittle mineral coefficient of rock G:

$$G = \frac{W_k}{W} . \tag{5}$$

W_k for the rock mineral content; W for the total weight of the rock.

Based on the above factors, the evaluation index of brittleness is established on the basis of the two kinds of rock breaking behavior:

$$B = e^{-PK} \cdot G , \tag{6}$$

$$B = e^{-\frac{\sigma_p - \sigma_r}{\sigma_p} \cdot \frac{\arctan(-\frac{\sigma_p - \sigma_r}{\varepsilon_p - \varepsilon_r})}{90}} \cdot \frac{W_k}{W} + a . \tag{7}$$

Rock brittleness evaluation index is used to characterize brittleness, the weaker the rock is, the more close to zero, the stronger the brittleness , the greater the brittleness index .

2. APPLICABILITY TEST OF B

2.1 Different Rock Uniaxial Stress State Under Uniaxial Stress State

In order to verify the brittleness index in describing the more different kinds of rock brittle characteristics of adaptability, the selection of marble, granite, cement mortar, shale and sandstone 5 rock materials were uniaxial compression test, 5 in compression test stress-strain curve as shown in Figure 3, and the brittleness evaluation method for the evaluation of the five kinds of rock brittle.
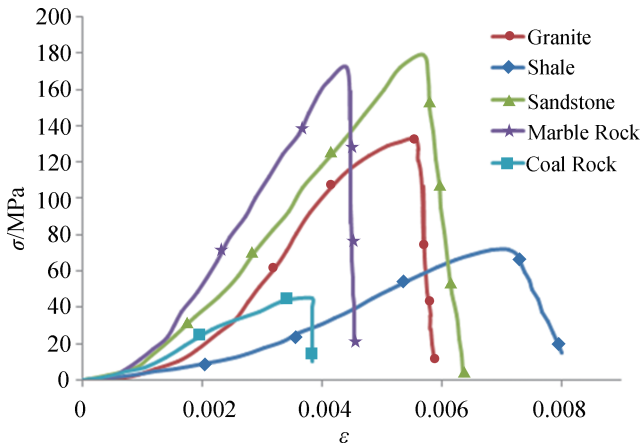
Figure 3
Stress and Strain Curves of 5 Kinds of Rock Under Uniaxial Compression Under Uniaxial Compression

Table 2
Brittleness Evaluation Index of 2 Kinds of Different Rocks Under the Same Confining Pressure

Rock Type	Granite	Shale	Sandstone	Marble Rock	Coal Rock
The brittleness index	0.591	0.604	0.586	0.596	0.73

From Table 2 can be seen, marble, granite, sandstone and the degree of brittleness decreases gradually. Therefore, the brittleness evaluation method can better evaluation of brittle rock degree.

2.2 Different Species of Rock Should be Verified Under Stress

To describe the rock under different confining pressure, brittle variation, with a depth of shale and processed into a diameter is 25 mm cylinder specimen and loading design confining pressure is 0 MPa, 15 MPa and 35 MPa three confining pressure, due to the characteristics of the brittle fracture of part of the samples, the experiment of axial stress and deformation control of load, the loading rate is 0.005 M/S. By loading the stress strain curve as shown in Figure 4.
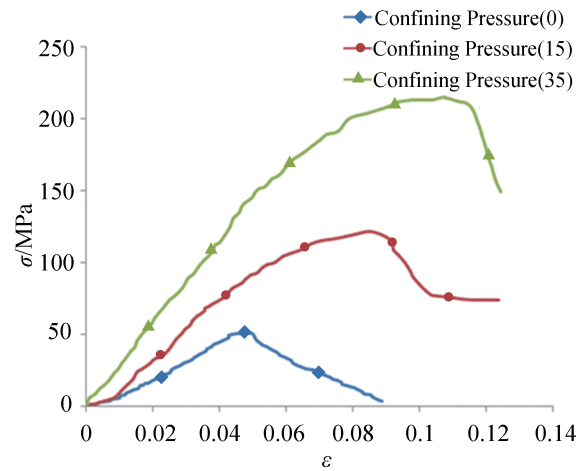
Figure 4
Stress and Strain Curves Under Different Confining Pressures

Table 3 Rock Brittleness Index Under Different Confining Pressures

Confining Pressure (MPa)	0	15	35
The brittleness index	0.817	0.790	0.671

As can be seen from Table 3, in the laboratory test, shale with the confining pressure increases, the shale brittleness decreases, but because of the confining pressure, the rock breaking delay, the greater the damage, the strain becomes smaller.

CONCLUSION

(a) The method of evaluating rock brittleness at home and abroad is summarized, and the advantages and disadvantages of the method are analyzed. From two kinds of behavior of brittle fracture of rock, it is a comprehensive characterization of internal and external factors. The brittle index of science should not only be able to characterize the damage of the rock, but also can be characterized by the degree of rock brittleness when the damage is similar.

(b) A new method for evaluating rock brittleness is proposed. The brittleness evaluation index is composed of the post peak damage degree and the ratio of the rock minerals, which can comprehensively evaluate the strength and difficulty of the brittle failure of the rock. The method can accurately evaluate the rock brittleness, and predict the degree of the same rock brittleness.

(c) By comparing with other evaluation indices, the results are similar to those of other indexes, but more accurate. At the same time, in this paper, 3 kinds

of experiments are carried out under the condition of experiment, and the brittleness of rock is increased with the increase of mineral content. The experimental results meet the brittle fracture characteristics of rock.

Needs to be pointed out is that the evaluation index of brittleness is in Hui Zhou brittleness evaluation method based on improved. Considering the super brittle fracture characteristics of rock and solve the pure brittle rock evaluation index in the constant 0, re analyzes and deduces the calculation formula.

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