Research on the anisotropy of the coal rock under different bedding direction

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Abstract

The Fu Rong mining area was selected to analyse the micro view characteristics of the coal, the ultrasonic acoustic characteristics and the uniaxial compression feature from different directions (the parallel direction and the vertical direction). The results show that: (1) Coal rock has large discreteness with strong anisotropic properties. (2) The impulse wave velocities have obvious anisotropic characteristics. The parallel and vertical wave velocities are different. The parallel bedding velocity is greater than the vertical of coal rock no matter the longitudinal wave or transverse wave of coal rock. (3) The uniaxial compressive strength of parallel bedding coal rock is less than the vertical bedding of coal rock. The uniaxial compressive strength is normally distributed vertical wave velocity, obeying exponential functions or power functions. (4) Failure pattern of the coal rock in the parallel bedding direction is splitting, while the vertical bedding direction of coal rock is shearing. The uniaxial compression strength and deformation parameters in two directions are obviously different. In other words, the anisotropic is apparent.

Keywords: coal rock, bedding, anisotropy, ultrasonic velocity, uniaxial compression test

1 Introduction

Coal rock is a kind of micro heterogeneity, which has original injury. The different direction of bedding within the coal rock will heterogeneity and these properties will have a certain effect on the mechanical properties. Sui Wang-hua found that there is an obvious anisotropic with mechanical properties of the rock through variance analysis for the engineering geological property index of the rock [1]. Wang Yun found that there is a linear correlation between the velocity and density by ultrasonic measuring six coal samples collected from different regions [2]. Zhao Qun found that the coal has an obvious anisotropy when testing the ultrasonic speed and decay using the pulsed transmission technology [3]. Wu Ji-wen tested the velocity and the tensile in the coal using wave velocity determination of tensile strength of coal seam and found there is anisotropy within the coal rock. So the ultrasonic acoustic can be selected for measuring the anisotropic characteristics of the coal rock. The coal rock ultrasonic wave velocity anisotropy was used to reflect the anisotropic feature of the coal structure and for further exploration of coal structure [4]. Yin Guang-zhi made a dynamic CT test on the micro damage evolution law in the process of coal rock failure and drew a conclusion that the coal rock has a constitutive relationship [5]. Liu Bao-xian calculated a coal rock damage evolution curve equation after uniaxial compression of coal rock's acoustic emission characteristics analysis has conducted [6]. Lai Xing-ping analysed the relationship with acoustic emission energy on the stage of coal fracture [7]. So far, there are many researches about the energy and strength change of uniaxial compression destruction of the coal. However, the mechanical properties in different direction of coal are still less considered. Therefore, it is very important to make a further research in different directions of the coal rock. The two different directions (Parallel and perpendicular) were selected to make the ultrasonic acoustic test, the uniaxial compressive strength test and the deformation analysis. These researches will clarify the mechanical properties under different directions of the coal rock and will provide a theoretical basis and the parameters for coal mine disaster prevention and safe and efficient exploitation.

2 Microscopic parameter of coal

The anthracite from Furong Baijiao coal mine was selected as the experimental sample in this research; three coal samples were randomly selected for analysis. The X- ray diffraction, electron microscope scanning and the X-ray fluorescence test were selected to determine the microscopic parameter of coal. The results show that Furong Baijiao coal mineral contents are quartz (11.74%), Kaolinite (5.58%), Calcite (5.04%) and other amorphous mineral (77.64%).

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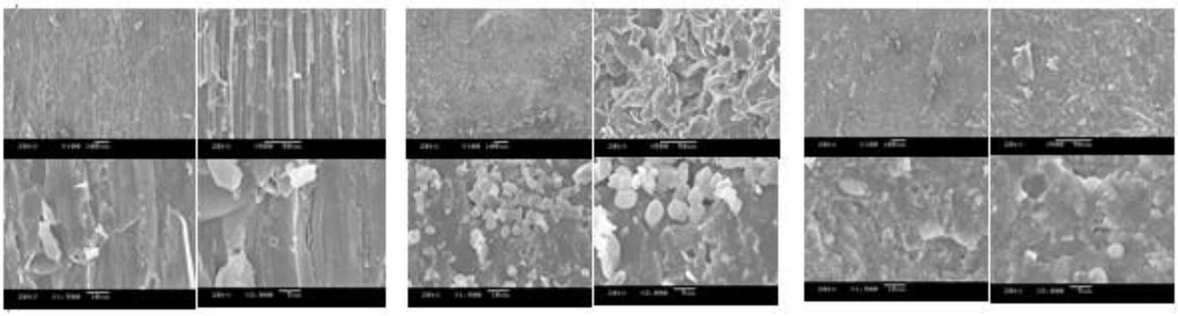


1#Coal 2#Coal 3#Coal

FIGURE 1 Coal mineral scanning electron microscope

The coal rocks were magnified with 100, 500, 1500 and 3000 times by using scanning electron microscopy (shown in Figure 1). We find the coal rocks are porous materials and the pores are rich which mainly include the original hole, the exogenous hole, the metamorphic hole and the mineral hole [8]. There are plurality groups of micro cracks in the coal rock which are almost developed in parallel and perpendicular to the surface [9].

3 Ultrasonic testing

3.1 THE BASIC PHYSICAL PROPERTIES OF COAL

According to "Method for determination the physical and mechanical properties of coal rock (GB/T 23561.7-2009), the Fu Rong mining area which was made into a cylindrical according to vertical and parallel bedding direction, the diameter is 50mm and the height is 100 mm. The non-parallelism of the two end surface is less than 0.05 mm and perpendicular to the sample axis. The maximum deviation should be less than 0.25^0, the samples are numbered according to the different directions after the samples are processed (Figure 2).

The basic coal parameters are measured (Table 1), the data show that the density of rock is different (ρmax=1541.94 kg/m3). We find that the value (Ratio between the coal rock specimen density and the largest coal rock specimen density) is between 0.93 and 1; we conclude this distribution feature may be with respect to the origin, component and the internal micro cracks of coal. This conclusion may help us to definite the discrete initial grouping on the basis of different density.

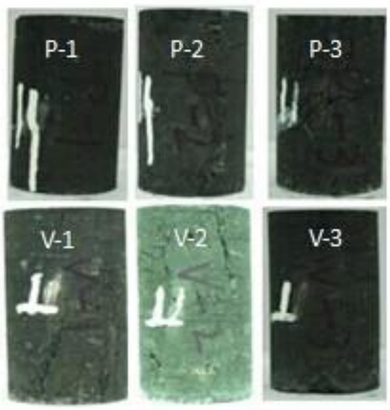


FIGURE 2 Pictures of coal rock

TABLE 1 The basic parameters of coal rock

Coal No.	Diameter/*mm*	Height/*mm*	Volume/ cm^3	Weight/*g*	Density kg/m^3	ρ/ρ_{max}
P-1	50.33	81.86	162.78	233.50	1434.47	0.93
P-2	50.07	100.18	197.15	304.00	1541.94	1.00
P-3	50.43	90.19	180.06	258.54	1435.89	0.93
Mean value	50.28	90.74	180.00	265.35	1470.77	0.95
V-1	50.06	101.93	200.52	293.11	1461.76	0.95
V-2	49.86	100.32	195.78	291.46	1488.73	0.97
V-3	49.72	100.09	194.23	293.77	1512.46	0.98
Mean value	49.88	100.78	196.84	292.78	1487.65	0.96

3.2 DYNAMIC MECHANICAL ULTRASONIC TESTING MODEL

The coal physical mechanics index is essential basis for the mining and coal sample design. The elastic parameter method and the acoustic method are selected to test the anisotropy of mechanical properties of the rock [10]. Considering the acoustic velocity can reflect the strength and structure of the coal [11], the coal acoustic characteristics was used to reflect the feature of the coal and to seek what caused the external differences [12]. The ultrasonic testing system consists of three system (The fluorescence oscilloscope (TDS3014), the ultrasonic pulse receiver (5077PR) and the data acquisition instrument (3499B). The centre frequency of emission and receiving transducer is 50 kHz. The system can complete testing and data recording combined with the MTS rock mechanics test system. Equation of dynamic mechanical ultrasonic parameters can be expressed as follows:

$$\begin{aligned} E_d &= v_{mp}^2 \rho \frac{(1+\mu_d)(1-2\mu_d)}{1-\mu_d} = 2v_{ms}^2 \rho (1+\mu_d) \\ \mu_d &= \frac{v_{mp}^2 - 2v_{ms}^2}{2(v_{mp}^2 - v_{ms}^2)} \\ G_d &= \frac{E_d}{2(1+\mu_d)} v_{ms}^2 \rho \end{aligned} . \quad (1)$$

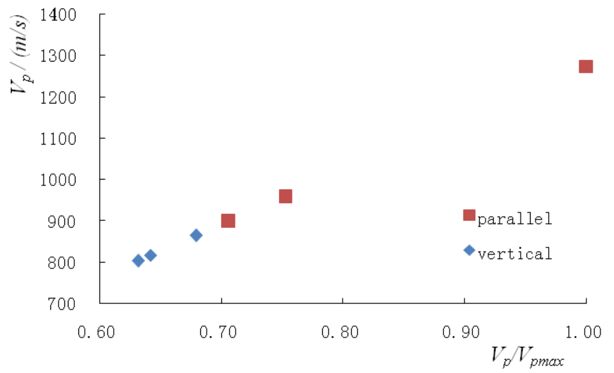
The calculation results are shown in Table 2.

TABLE 2 Physical and mechanical parameters of coal rock

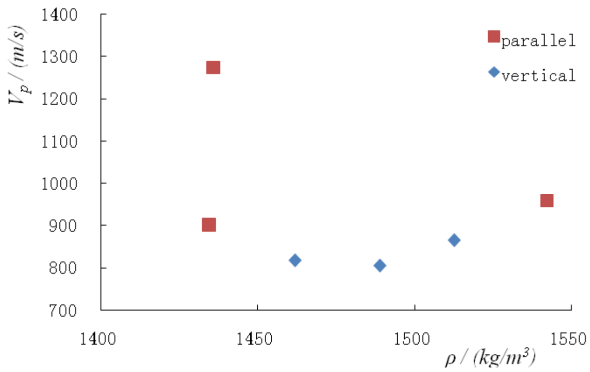
Coal sample No.	Density kg/m^3	P-wave velocity *m/s*	Shear velocity *m/s*	Wave velocity ratio	Poisson's ratio υ	Dynamic elastic modulus *E/MPa*	Shear modulus G/*MPa*	Bulk modulus K/*MPa*
P-1	1434.471	899.450	458.210	1.963	0.325	797.973	590.881	758.933
P-2	1541.941	958.720	527.570	1.817	0.283	1101.101	767.672	845.041
P-3	1435.892	1274.100	844.930	1.508	0.107	2270.571	1272.022	964.137
Mean value	1470.768	1044.090	610.237	1.763	0.238	1389.882	876.858	856.037
V-1	1461.764	817.280	485.120	1.685	0.228	844.894	547.208	517.695
V-2	1488.734	804.370	393.320	2.045	0.343	618.554	470.657	656.150
V-3	1512.463	864.860	503.280	1.718	0.244	953.129	630.369	620.506
Mean value	1487.654	828.837	460.573	1.816	0.272	805.526	549.411	598.117
Total	1478.005	951.839	546.095	1.786	0.253	1139.443	736.524	745.500

3.3 EXPERIMENTAL RESULTS AND ANALYSIS

Figure 3 is the longitudinal wave velocity distribution diagram. The value $V_P/V_{P\ max}$ is the ratio between the coal wave velocity and the sample coal maximum P-wave velocity. From the Figure 3a we can see that the coal wave P-wav velocity has two obvious segmented regions according to the different layering surface. The wave velocity with parallel layer coal distributes in the range from 890m/s to 1300m/s and the wave velocity from the parallel direction is greater than the wave velocity from the perpendicular direction. From Figure 3b, we can find that there is a certain distribution relationship between the density and the wave velocity of the coal. We find that the wave velocity from the longitudinal wave has a discrete phenomenon and the coal density from the longitudinal appears a less discrete phenomenon. The coal density from parallel layer has a large dispersion and the wave velocity from the longitudinal direction also has a large difference at the similar density. We can draw a conclusion that this phenomenon may due to the presence and the hole exists in the coal. The results also show that the large differences with the wave velocity from the longitudinal direction may attribute to the different directivity.



a) V_P-V_P/V_{Pmax}

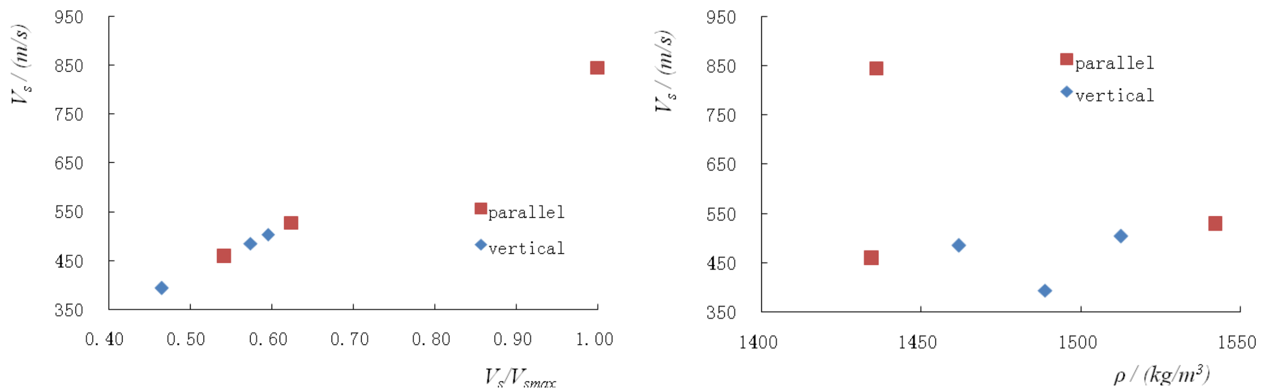


b) ρ-V_P

FIGURE 3 The distribution diagram of longitudinal wave velocity for coal rock

Figure 4 is the distribution relationship of transverse wave velocity. The value $V_s/V_{s\,max}$ is the ratio between the transverse wave velocity and the sample coal maximum transverse wave velocity. From Figure 4a we find that the shear wave has a larger discreteness when it crosses the bedding surface.

The transverse wave velocity of the parallel bedding coal distributes from 450m/s to 850m/s, the transverse wave velocity of the vertical bedding coal distributes from 390 to 510m/s. From the above we can see that the transverse wave velocity of the coal from the vertical direction remains larger than the transverse wave velocity from the parallel direction. The Figure 4b is the distribution relationship between the density and the transverse wave velocity of the coal and we find that the Figure 3b has a similarly changing regulation with Figure 3a and Figure 3b. The results above sufficiently prove that there is a certain relationship between the ultrasonic wave velocity, density and the micro crack distribution of the coal rock.



a) V_S-V_S/V_{Smax} b) ρ-V_S

FIGURE 4 The distribution diagram of shear wave velocity for coal rock

4 The uniaxial compression experiment of coal rock

4.1 EXPERIMENTAL METHOD

The rock mechanics test system (MTS815 Flex Text GT) is selected in this research which is from rock mechanics laboratory, Si Chuan University. During the experiment, when the data reaches 10kN/min, the system has loaded and turns to circumferential control with 0.08mm/min when the data reaches 7kN.

The samples are divided into two groups, namely the parallel directions and the vertical directions. There are three samples in each group and each sample records the destroyed morphology themselves. The aspect ratio (L/D) of the coal has a great influence on the experimental results. Equation (2) is revised due to the coal P-1 and P-3 is nonstandard sample:

$$\sigma_c = \frac{\sigma_c'}{0.788 + 0.22\frac{D}{L}}, \quad (2)$$

where σ_c is actual rock uniaxial compressive strength, σ_c' is measured rock uniaxial compressive strength.

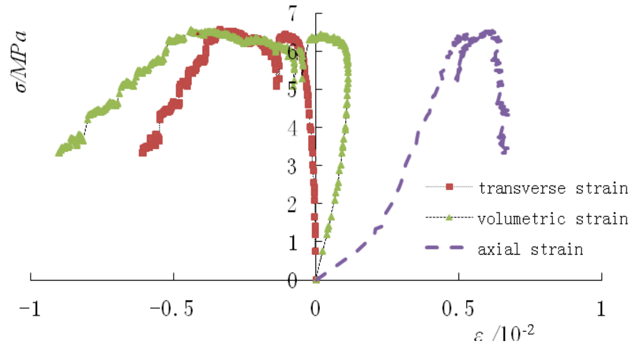
4.2 RESULTS

Coal rock under uniaxial compression results and the statistical parameters are shown in Table 3.

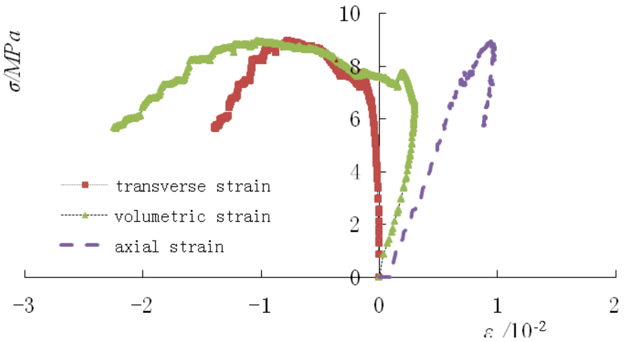
The Uniaxial compression strength test and the deformation of coal are shown in the Figure 5 and Figure 6 respectively. The axial strain of coal, the volumetric strain，the transverse strain and the failure modes graph are shown in Figures 5 and 6 (a–d) respectively.

TABLE 3 Test results of coal samples under uniaxial compression

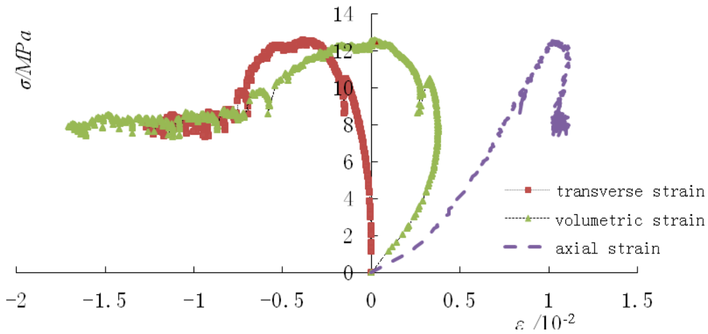
Coal No.	Peak load /kN	Compressive strength /MPa	Modulus of elasticity /MPa	Deformation modulus /MPa	Poisson's ratio (50%)	Poisson's ratio (100%)
P-1	11.95	6.571	1914	1011.940	0.04	0.54
P-2	17.68	8.986	1201	1006.311	0.05	0.82
P-3	23.12	12.596	1710	975.574	0.05	0.37
Mean value	17.58	9.384	1608.33	997.94	0.05	0.58
V-1	28.76	14.618	1761	1062.915	0.14	0.39
V-2	18.70	9.582	1413	1012.894	0.13	0.33
V-3	30.32	15.624	1921	1349.610	0.09	0.17
Mean value	25.93	13.275	1698.33	1141.81	0.12	0.30



a) P-1



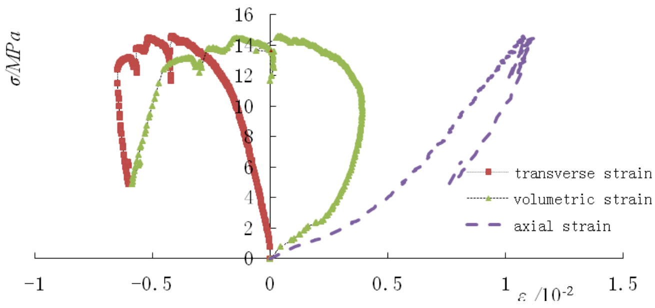
b) P-2



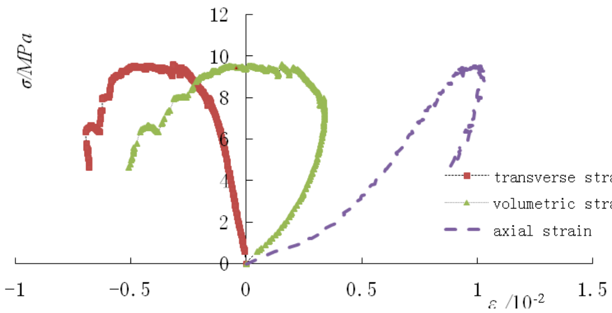
c) P-3

d) failure mode

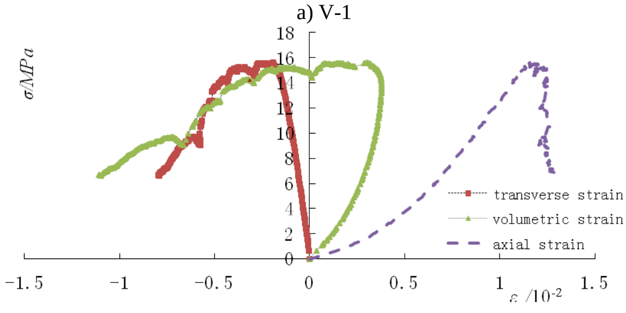
FIGURE 5 Test results of coal rock with parallel bedding under uniaxial compression



a) V-1



b) V-2



c) V-3

d) failure mode

FIGURE 6 Test results of coal rock with vertical bedding under uniaxial compression

4.3 EXPERIMENTAL RESULTS AND ANALYSIS

The corresponding situations between the acoustics and the uniaxial compression properties are analysed from two different directions of coal (the vertical and parallel bedding direction).

1) The uniaxial compressive strength of the coal from parallel bedding is 6.5～12.6MPa and the mean value is 9.38MPa. The uniaxial compressive strength of the coal from vertical direction is 9.5～15.7MPa and the average value is 13.27MPa. We find that the compressive strength from the parallel bedding is less than that from the direction of vertical bedding.

2) From Figure 5d and Figure 6d we can see that the uniaxial compression failure mode from the parallel

direction is splitting and forms a sheet damage phenomenon.

3) Figure 7 represents the uniaxial compressive axial stress and the strain curve at the different directions. We can find that the compression test of the coal has experienced four stages: compacting, elastic, yield and destruction [13]. There is a great difference between stress and strain curves of coal rock at different directions:

The pre-peak deformation with parallel bedding coal has a great difference; the P-1 presents the yield deformation in the earlier time. However, the yielding time of the other two samples presents a time lag; the stress drop phenomenon will appear after reaching the peak value and have a different extent. The pre-peak deformation with vertical bedding coal is similar and presents stable mechanical properties.

4) We make a comparison between Table 3 and Figure 7 and get some conclusions: The modulus of elasticity in the parallel bedding coal is 1200～1914MPa and the average value is 1608.33MPa; The deformation modulus is 975～1012MPa and the average value is 997.94MPa. The Poisson's ratio is 0.17～0.39 and the mean value is 0.30. The research above demonstrates that the in-depth analysis can be made for anisotropic properties of coal by using modulus of elasticity, deformation modulus and Poisson's ratio.

5) The correlation analysis is made for both compressional wave velocity and uniaxial compressive strength of coal [14]. The Figure 8 is the relationship curve between the ultrasonic P-wave velocity and uniaxial compressive strength within the coal rock and we find that the uniaxial compressive strength σ_c will enlarge along with the increasing p-wave velocity V_P [15].

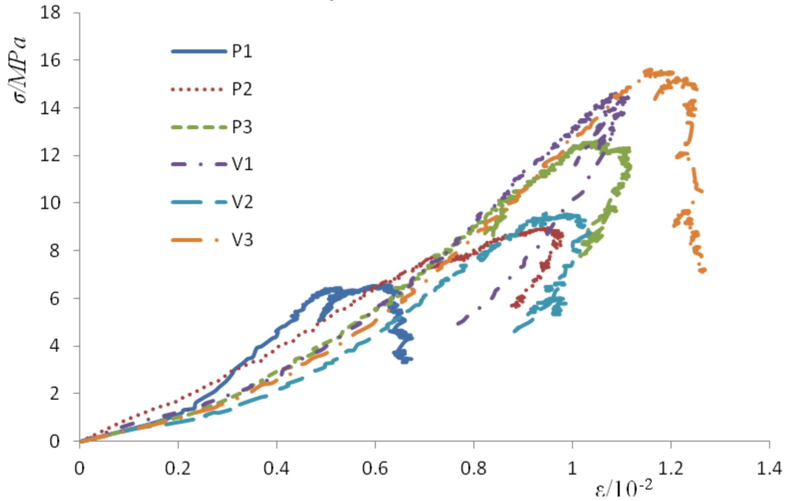


FIGURE 7 Axial stress-strain curves of coal rock in different directions to the bedding plane under uniaxial compression

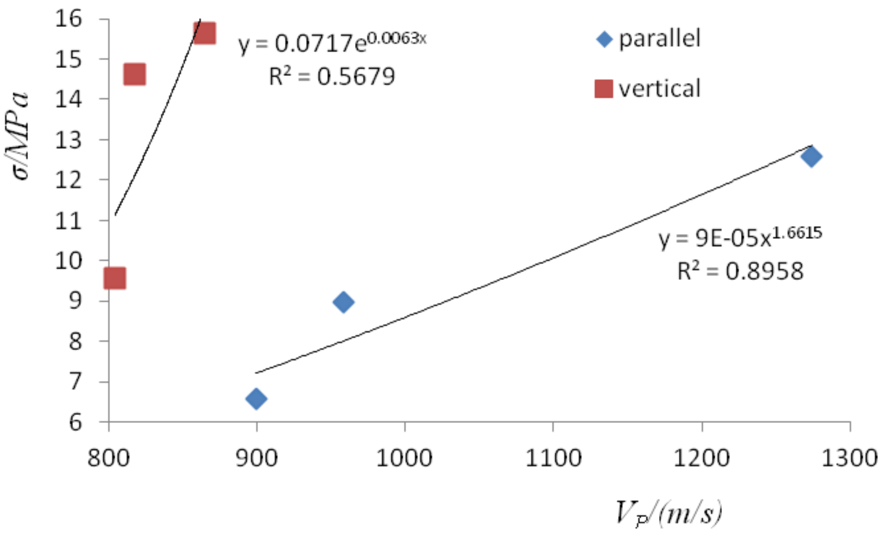


FIGURE 8 The relationship curve between ultrasonic velocity and compression strength

5 Conclusions

1) The coal rock is a porous materials, dispersion phenomenon in the coal may be caused by the micro cracks and the laminar distribution.
2) The longitudinal and transverse wave velocity are different, the transverse wave velocity from the parallel bedding direction is greater than that from the vertical direction.
3) The uniaxial compressive strength from the parallel bedding direction is less than that from the vertical direction and the compressive strength of the coal has a normal distribution with the compressional wave velocity.
4) Failure pattern of the coal rock in the parallel bedding direction is splitting, while the vertical bedding direction of coal rock is shearing. There are obvious differences with the uniaxial compression and the deformation parameters.

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