An experimental study on the correlation between the elastic wave velocity and microfractures in coal rock from the Qingshui basin

To cite this article: Zhou Feng et al 2012 J. Geophys. Eng. 9 691

View the article online for updates and enhancements.

Related content
- Analytical modeling of mercury injection in high-rank coalbed methane reservoirs based on pores and microfractures: a case study of the upper carboniferous Taiyuan Formation in the Heshun block of the Qinshui Basin, central China
  Yang Gu, Wenlong Ding, Shuai Yin et al.

- Log evaluation of a coalbed methane (CBM) reservoir: a case study in the southern Qinshui basin, China
  Hou Jie, Zou Changchun, Huang Zhaohui et al.

- Investigation on log responses of bulk density and thermal neutrons in coalbed with different ranks
  Peiqiang Zhao, Zhiqiang Mao, Ding Jin et al.

Recent citations
- Higher-order source-wavefield reconstruction for reverse time migration from stored values in a boundary strip just one point wide
  Wim A. Mulder

- Log evaluation of a coalbed methane (CBM) reservoir: a case study in the southern Qinshui basin, China
  Hou Jie et al.

- Comment on 'Reverse time migration with source wavefield reconstruction strategy'
  Hongwei Liu and Hong Liu
An experimental study on the correlation between the elastic wave velocity and microfractures in coal rock from the Qingshui basin

Zhou Feng1,2,3, Xu Mingjie1, Ma Zhonggao2, Cai Liang2, Zhu Zhu2 and Li Juan1

1 School of Earth Science and Engineering, Nanjing University, Nanjing 210093, People’s Republic of China
2 Sinopec Geophysical Research Institute, Nanjing 210014, People’s Republic of China
3 Sinopec Key Laboratory of Geophysics, Nanjing 210014, People’s Republic of China

E-mail: zhoufeng.swty@sinopec.com

Received 25 November 2011
Accepted for publication 18 September 2012
Published 30 October 2012
Online at stacks.iop.org/JGE/9/691

Abstract
In order to study the impact of microfractures on the elastic wave velocity, multi-azimuth elastic wave velocity experiments were performed with coal rock samples under a confining pressure similar to the one in the buried coal strata of the Qinshui basin. The results indicate that (1) the microfractures in coal rock reduce the elastic wave velocity. In the experiments, the velocity was increased with a confining pressure. However, when the confining pressure was increased to 10 MPa, the velocity became stable because most of the microfractures in the coal rock samples were closed. (2) The elastic wave velocity is sensitive to the microfracture orientation in coal rock. The elastic wave propagates rapidly along the microfracture direction, while it propagates slowly perpendicular to the microfracture direction. This research provides the basic data to predict microfractures in coal rock.

Keywords: coal rock sample, fracture, velocity, pressure

(Some figures may appear in colour only in the online journal)

1. Introduction
The elastic wave velocity in rock is a critical index for rock mass quality evaluation. There are two types of dynamic research experiment on the mechanical properties of rock: the resonance frequency method and the ultrasonic time method. The latter mainly makes use of an elastic pulse that means the propagation of an elastic wave in the solid media. Since the elastic wave not only has the capacity to penetrate and distinguish rock, it also interacts with the media during propagation; the received wave contains different kinds of information on the mechanical properties of rock physics, which could be widely used. Scientists have conducted numerous experimental and theoretical studies, and have achieved remarkable results and significant progress (Kottas 1963, 1964, Dullmamm 1976, Krautkämper 1975, Wang 1997, Cheng et al 2000, Gebrande et al 1982, Ciccotti et al 2004, Ma et al 1996, Xie et al 1998). It is reported that, in the rock, there is a good correlation between the mechanical properties and elastic wave velocities (Meng and Peng 2000, Meng et al 2006). The elastic wave velocity in rock contributes to a real-time understanding of the changes in rock properties with a large range. Therefore, the dynamic ultrasonic-time testing method is used for systematic studies on the characteristics of the velocities of elastic waves in this paper. Besides, the main factors affecting the velocities of elastic waves in coal strata are explored, by providing experimental evidence for
Table 1. Data for macerals and reflectivity.

<table>
<thead>
<tr>
<th>Sample code</th>
<th>Vitrinite</th>
<th>Inertinite</th>
<th>Clay</th>
<th>Sulfide</th>
<th>Carbonate</th>
<th>Average maximum reflectivity (%)</th>
<th>Density (g cm$^{-3}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>QS1</td>
<td>80.79</td>
<td>18.22</td>
<td>0.24</td>
<td>0.48</td>
<td>0.27</td>
<td>1.891</td>
<td>1.79</td>
</tr>
<tr>
<td>QS2</td>
<td>86.17</td>
<td>13.01</td>
<td>0.25</td>
<td>0.28</td>
<td>0.29</td>
<td>1.784</td>
<td>1.65</td>
</tr>
<tr>
<td>QS3</td>
<td>87.28</td>
<td>11.78</td>
<td>0.45</td>
<td>0.23</td>
<td>0.26</td>
<td>1.864</td>
<td>1.71</td>
</tr>
<tr>
<td>QS4</td>
<td>88.05</td>
<td>11.09</td>
<td>0.22</td>
<td>0.20</td>
<td>0.44</td>
<td>1.847</td>
<td>1.74</td>
</tr>
<tr>
<td>QS5</td>
<td>85.81</td>
<td>13.61</td>
<td>0.19</td>
<td>0.21</td>
<td>0.18</td>
<td>1.815</td>
<td>1.56</td>
</tr>
<tr>
<td>QS6</td>
<td>87.93</td>
<td>11.05</td>
<td>0.27</td>
<td>0.26</td>
<td>0.49</td>
<td>1.836</td>
<td>1.84</td>
</tr>
<tr>
<td>QS7</td>
<td>84.21</td>
<td>14.88</td>
<td>0.22</td>
<td>0.23</td>
<td>0.46</td>
<td>1.828</td>
<td>1.83</td>
</tr>
<tr>
<td>QS8</td>
<td>86.86</td>
<td>12.01</td>
<td>0.28</td>
<td>0.29</td>
<td>0.56</td>
<td>1.796</td>
<td>1.67</td>
</tr>
<tr>
<td>QS9</td>
<td>83.63</td>
<td>15.34</td>
<td>0.27</td>
<td>0.25</td>
<td>0.51</td>
<td>1.845</td>
<td>1.69</td>
</tr>
<tr>
<td>QS10</td>
<td>84.91</td>
<td>13.64</td>
<td>0.26</td>
<td>0.52</td>
<td>0.67</td>
<td>1.858</td>
<td>1.67</td>
</tr>
</tbody>
</table>
in the highly metamorphic coal in the Qingshui basin did not get worse. Most of the microfractures are of network and isolated network type; the isolated type are secondary. The microfractures are fully open and seldom filled up. Some mines encountered multistage tectonic movement and developed multistage microfractures.

The slice identification results suggest that the microfractures developed well in the inner layer of the coal rock. Two groups of endogenic microfractures were common (figure 1). The distribution of microfractures was uneven. Several groups of microfractures developed only in some areas. Some microfractures were fully filled up, some were partly filled up and some were totally unfilled; the widths range from several micrometres to dozens of micrometres. Micro stomata developed in some areas, which were filled locally by kaolinite and in which magnesium iron calcite was precipitated. The diameter of the micro stomata is about a few micrometers.

The existence of microfractures affected the propagation velocities and energy attenuation of the elastic wave. Normally it reduced the velocities of the seismic wave and increased the attenuation of the seismic wave. At the same time, microfractures will lead to changes in the properties of the media. Different microfracture development models have different performance characteristics.

### 3.2. Analysis of the pressure effect on elastic wave velocities

Generally, the elastic wave velocity in sedimentary rock is controlled by the sediment environment, sedimentary character and rock density. Recent research demonstrated that the elastic wave velocity in sedimentary rock is closely related to the effective confining pressure. Typically, the inner factors of a rock’s elastic wave velocity are the compounds and structure of the rocks. The effect of the confining pressure on the elastic wave velocity is a result of changes in the inner structure of the earth.

The experimental results show that the elastic wave velocities of the coal beds increased with higher confining pressures (figure 2). This illustrates that there were originally some microfractures in the samples. Pore microfractures were compacted as a result of the confining pressure. Thus the density of rock increased; so did the elastic wave velocity. When the confining pressure reached 10 MPa, the impact on the coal rock velocity rapidly declined, because most of the microfractures were closed. Eventually the velocity stabilized.

### 3.3. The effect of microfractures on velocity

The microfractures in coal beds exist for complex reasons that are not yet clear. There are always a few sets of microfractures in coal rock; most of them are perpendicular to the coal bed or intersect the coal bed at high angles. Their intersection is of network or irregular type and cuts the coal rock into different sizes of substrate block. The direction of regional tectonic tensions controlled the basic distribution of the microfractures; the direction of the microfractures reflected the direction of the main tension.

In this study, we use ordinary and scanning electron microscopy to observe the microporous system in the samples.
The results of scanning electron microscopy showed the endogenic microfractures that had developed in the samples (figure 3). There were two sets of microfractures perpendicular to the bedding. The origin of the microfractures was the internal tension caused by the uniform gel substance shrinking at an appropriate temperature and pressure.

Microfractures greatly impact on the propagation velocity and energy attenuation of the elastic wave; they reduce the elastic wave velocity and increase attenuation. The characteristics of the media change with microfractures. Different fracture development models have different features. In order to understand the impact of microfractures in a coal bed on the elastic propagation velocity, we selected two coal samples to ascertain the development direction of the main fracture by CT scanning. The scanning results showed that the distribution of microfractures in QS1 was not uniform in the horizontal direction. In the lower half of the sample, there were two sets of microfractures with a width of 1 mm. The angles between the microfractures were 45° and 90°. There was one set of clear fractures in the QS2 sample. The distribution of the microfractures at the top of the sample is not uniform (figure 4).

Based on the distribution of the main microfractures in the samples, we then performed multipoint measurements. We selected the starting position. Since the angles increased by 45° along the same circumference counterclockwise, we have
seven points in total, marked 0, 45, 90, 135, 180, 225 and 270, respectively (figure 5). We conducted a set of confining pressure ultrasonic velocity tests at each point, with the line parallel to the axis of the samples. The axis compression stayed at 5 KN. The confining pressure started at 0 and increased by 5 MPa increments to 20 MPa.

The results showed that the velocity values at different directions were different (figure 6). The maximum difference in P-wave velocities was as high as 10% in QS1 samples, and the maximum difference in S-wave velocities was as high as 8%, while the maximum differences in QS2 were 8% and 7%. There would always have been high values in some locations of the two samples. By a comparison of the location and direction of the main microfractures, we found the line of the highest value of the velocity was along the main fracture direction or came across the location of the main fracture. We think that the difference in velocities at different locations is due to the locations of the inner microfractures.

4. Conclusions

(1) An increased confining pressure promotes the elastic wave velocities in coal rock. When the confining pressure reaches a particular degree (10 MPa), its impact on the coal rock velocity will rapidly decline, because most microfractures are closed. The coal rock velocity is determined by the characteristics of the mineral compounds. Eventually the velocity will stabilize.

(2) The orientation of the microfractures has an effect on the acoustic propagation velocity to some extent. The changes in velocity matched well the distribution of microfractures. The acoustic velocity reached a peak.
along the direction of the microfractures, but declined along the direction perpendicular to the microfractures.

The results show that microfractures have an obvious impact on the propagation velocity of ultrasonic waves in coal rock. If we could launch further research on the development of microfractures in coal rock and get more experimental data for a statistical analysis, the changes in the ultrasonic velocity could be explained more clearly.

Acknowledgements

The authors acknowledge the financial support of the National Research Program of China (no 2011ZX05035-001).

Reference

Dullmann H 1976 Die Ermittlung der elastischen kennwerte von gesteinen mittels uhraschall-laufzeit-messungen und einaxialer druckversuche unter beson-derer berücksichtigung einer durch das korn gefügebedingten mechanischen anisotropie RWTH Aachen 5–18
Gebrände H, Kern and Runnel F 1982 Elasticity and inelasticity in Landolt-Bornstein numerical data and functional relationships in science and technology Physical Properties of Rocks ed K H Hellwege (Berlin: Springer)
Kottas 1964 Das resonanzverfahren zur messung mechanischer schwingung und materjaleigenschaften Z. Instrum. 72 199–204
Krautkrämer 1975 Werkstoffprüfung Mit Ultraschall[M] (Berlin: Springer)
Ma R, Lu M and Yang X 1996 Experiment study about elastic wave velocities in rocks under different pressure and temperature Seismol. Geol. 18 259–65
Meng Z and Peng S 2000 Characters of the deformation and strength under different confining pressures on sedimentary rock J. China Coal Soc. 25 15–8
Meng Z, Zhang J and Joachim T 2006 Relationship between physical and mechanical parameters and elastic waves velocity of coal measures rocks Chin. J. Geophys. Edn 49 1505–10
Xie H et al 1998 Measurement of elastic wave velocities in rocks at high temperature and high pressure Earth Sc. Front. 5 329–37