Experimental Research on Electrical Parameters Variation of Loaded Coal

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**Abstract**

Experiment on electrical parameters variation of different destruction type coals under uniaxial compression are studied. The results show that electrical parameters’ change curves of the loaded raw coal samples and briquette have a very good consistency; the consistency of dielectric constant curve and coal stress - strain curve is better than the resistivity curve. The resistivity curve of loaded coal in general is "concave" shape with the stress - strain curves, and the dielectric constant curve is "convex" shape generally. Compared to the initial electrical parameter values of the coal samples, the electrical parameter change rate of raw coal samples and briquette are generally higher than 13%, up to 165%, the electrical parameter change rate of raw coal samples is generally higher than briquette. The electrical parameter change of loaded coal and its stress have significantly coherence, electrical parameters variation of loaded coal better reflects the formation, development and transfixon of micro-fractures, and the characteristics of changes in internal structure in the failure process of coal rock. In the case of uniaxial compression, coal is dominated by electronic conductivity in the I, II phases, and ionic conductivity in III, IV phases, the dielectric constant changes of loaded coal have a close relation with its changes in the structure, cracks closure and cracked degree.

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**Keywords:** loaded coal; electrical parameters; variation; coal and gas outburst

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1. Introduction

Coal is China's main energy source, 95% of China's coal is produced by pit mining. Geological conditions of China's coal seam occurrence are complex, mining strength is big, and China is the world's most outburst mines and the highest numbers of outbursts country. With the mine's annual rate of 10-20 meters deep extension, outburst mines and outburst numbers are constantly increasing [1]. Statistics show that during the may in 2009 to 2011, 81 coal mine accidents happened, and 683 people died in China, accounting for 66% of China's coal mine accidents and deaths.

Domestic and international outburst coal mining has proved that, gas outburst zone is the overlay area of deformed soft coal developed area and gas-rich region, the real highlight decisive factor is the two conditions of coal seam gas occurrence and deformed soft coal development, and proposes the existence and reaching a certain thickness of deformed soft coal can be used as an important indicator of predicting outburst region, and has been production-proven.

Studies have shown that resistivity and dielectric constant are the main electrical parameters of underground coal rock, resistivity and dielectric constant of deformed soft coal and primary structure coal are significantly different, and in the process of the birth, formation and occurrence of coal and gas outburst, in the geological structure area and the strain energy accumulated area, coal electrical parameters will change abnormally, which can cause electromagnetic fields (natural or artificial) spatial distribution and temporal distribution change significantly, so we can simultaneously or separately use its certain strong-performance electrical properties to accurately detect deformed soft coal or gas-rich region, for the purpose of predicting the occurrence of coal and gas outburst. In a sense, this is the physical base for the wave-based non-contact detection of deformed soft coal technology.

Based on this, study on the electrical parameters variation of loaded coal in the process of deformation and failure has a great significance on the use of electromagnetic waves to detect deformed soft coal, outburst forecasts and reducing and prevention the occurrence of outburst.

2. "Test Principle of Electrical Parameters"

In mining engineering, coal is in a compressed state by the surrounding and gas. A large number of experimental results show that the coal under the condition of uniaxial compression, the rupture form is mostly shear fracture, which is the same with the rupture form of coal under a certain confining pressure. In addition, the uniaxial compressive strength of coal rock is one of the most important physical and mechanical properties of the coal rock. And uniaxial compression experiment of coal rock is the easiest rock mechanics strength experiment. Therefore, study on loaded coal electrical parameters should start from the uniaxial compression condition first of all.

2.1. Testing Principle of Coal Electrical Parameters under The Condition of Uniaxial Compression

According to the theory of rock mechanics and geoelectric, an experimental system to use LCR Table (100Hz-100kHz) under the condition of uniaxial compression to test the electrical parameters in deformation and fracture process of coal is established, shown in Figure 1, the test parameters are include resistivity and dielectric constant.

Resistivity Test

Coal resistivity means the ability that coal conducts current. Resistivity (resistivity) uses symbol to express, and is the physical quantity mainly used to represent the resistance characteristics of various
substances. Resistivity $\rho$ is numerically equal to the unit area ($S=1$), unit length ($L=1$) media resistance. It is in ohm $\cdot$ m, denoted by $\Omega \cdot m$.

$$|Z| \cos \theta = R$$

$$\rho = |Z| \cos \theta \frac{S}{L} = R \frac{S}{L}$$

(1)

(2)

Where: $|Z|$ - impedance absolute; $\rho$ - resistivity ($\Omega \cdot M$); $R$ - resistance ($\Omega$); $S$ - sample cross-sectional area ($m^2$); $L$ - sample length ($m$).

Fig. 1. Experimental facility of electrical parameters of uniaxial compression tests on the coal samples

1 A shielded chamber; 2 PTFE insulated panels; 3 conductive electrode plates; 4 coal; 5 pressure sensors; 6 press head; 7 presses dynamic strain device; 8 LCR Table; 9 ground flapper

Test of dielectric constant

The classic definition of dielectric constant is the ratio of capacitance when the metal-plate capacitor is filled with the medium and the metal plate capacitor is in vacuum. The dielectric constant in low-frequency electromagnetic fields is generally referred to static dielectric constant. The method of dielectric constant measurement is different based on different measuring frequencies. In this study, the test frequency is 100Hz-100 kHz, a low frequency, it is generally used parallel-plate capacitor method to measure. The upper and lower surfaces of the sample are required parallel and smooth, in order to facilitate contact electrode plate. Test is calculated as follows:

$$\varepsilon_r = \frac{tC}{\pi(d/2)^2 \varepsilon_0}$$

$$\varepsilon^\prime = \varepsilon_r \varepsilon_0$$

$$\varepsilon^\prime\prime = \varepsilon^\prime D = \varepsilon^\prime \tan \delta$$

(3)

(4)

(5)

Where, $\varepsilon^\prime, \varepsilon^\prime\prime$ - the complex permittivity real and imaginary parts of the samples respectively; $C$-equivalent parallel plate capacitor; $t$-sample thickness; $d$-electrode plate diameter; $\varepsilon_0 = 8.854 \times 10^{-12} F/m$; $D = \tan \delta$ - Loss tangent, measured by the LCR meter.

3. "Preparation of Coal Samples and Basic Parameters Preparation of Coal Sample"
Sampling locations are mainly in Zhaogu 2ed mine and Jiulishan mine in Jiaozuo minings, Hebi sixth mine in Hebi minings and Dingji mine in Huainan minings. Among them, the mines to take deformed soft coal are outburst mines, the coal types are anthracite and bituminous coal. In order to ensure the objective truth of the results, to accurately reflect the real situation of the seam electrical parameters in experimental coal mines, 100 coal samples are taken in the three coal mines (the number of samples of each structure type in each coal mining area 10 blocks or above, coal samples 20 above). Zhaogu 2ed mine and Jiulishan mine in Jiaozuo minings are anthracite, Hebi sixth mine in Henan is meager lean coal, and Dingji mine in Anhui is gasfat coal.

Preparation of primary structure coal samples (referred to "raw coal sample") takes the use of underground coal sampling, through the 50 × 100mm Core tube drill pillar, and then cut the appropriate length by cutting machine, and finally polish to make the upper and lower surfaces of the of coal samples parallel and smooth, to facilitate uniformly forced and in good contact with the conductive electrode. Deformed soft coal is the product of primary structure coal which has significant physical and chemical changes under the action of tectonic stress, the coal is soft, beddings are in disorder, low hand-tested intensity, mostly granular, earthy. Preparation of deformed soft coal samples (referred to as "briquette") achieves mainly through laboratory dies and stripping tools.

**Basic Parameters of Coal Samples**

In order to facilitate analysis of coal samples results, water (Mad), Ash (Ad), volatile (Vdaf), apparent density (ARD), porosity (F), absorption constant (a, b) and f value and other basic parameters are determined, measurement results are shown in Table 1.

The results show that, the water, ash, volatile, true density, apparent density, porosity difference between the raw coal sample and briquette are not obvious, a difference of pore volume is 4 to 10 times, f values are quite different.

<table>
<thead>
<tr>
<th>Number</th>
<th>Sampling sites</th>
<th>Water Mad</th>
<th>Ash Ad</th>
<th>Volatile Vdaf</th>
<th>True Density TRD</th>
<th>Apparent Density ARD</th>
<th>Porosity F</th>
<th>f Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>J1</td>
<td>Raw coal of Zhaogu 2ed mine in Jiaozuo</td>
<td>3.9</td>
<td>10.87</td>
<td>7.24</td>
<td>1.53</td>
<td>1.61</td>
<td>4.97</td>
<td>1.04</td>
</tr>
<tr>
<td>J2</td>
<td>Briquette of Jiulishan mine in Jiaozuo</td>
<td>1.92</td>
<td>9.82</td>
<td>9.49</td>
<td>1.54</td>
<td>1.47</td>
<td>4.76</td>
<td>0.28</td>
</tr>
<tr>
<td>H1</td>
<td>Raw coal of Hebi sixth mine</td>
<td>1.25</td>
<td>7.39</td>
<td>15.94</td>
<td>1.38</td>
<td>1.34</td>
<td>3.8</td>
<td>0.51</td>
</tr>
<tr>
<td>H2</td>
<td>Briquette of Hebi sixth mine</td>
<td>4.36</td>
<td>8.88</td>
<td>11.38</td>
<td>1.41</td>
<td>1.35</td>
<td>4.26</td>
<td>0.11</td>
</tr>
<tr>
<td>D1</td>
<td>Raw coal of Dingji mine in Huainan</td>
<td>2.0</td>
<td>10.83</td>
<td>33.37</td>
<td>1.43</td>
<td>1.32</td>
<td>7.69</td>
<td>0.79</td>
</tr>
<tr>
<td>D2</td>
<td>Briquette of Dingji mine in Huainan</td>
<td>2.59</td>
<td>21.22</td>
<td>30.66</td>
<td>1.74</td>
<td>1.56</td>
<td>10.34</td>
<td>0.28</td>
</tr>
</tbody>
</table>

**Coal Sample SEM Analysis**

SEM experiment is to observe the coal micro-hole cracks, understand the structure, size, distribution, morphology, fracture density and other characteristics of coal samples, and thus determines the characteristics affect on coal electrical parameters. The experiments used JSM-6390LV tungsten filament
scanning electron microscope. By using scanning electron microscopy magnification microscope, fracture length of different magnifications, width and density are statistics, and fracture density uses the surface density to characterize, as is shown in Table 2.

<table>
<thead>
<tr>
<th>Sampling Number</th>
<th>Rate</th>
<th>Fracture Length /μm</th>
<th>Fracture Width/μm</th>
<th>Fracture Density /cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>J1</td>
<td>100</td>
<td>159.8</td>
<td>1.6</td>
<td>155.0388</td>
</tr>
<tr>
<td>J2</td>
<td>100</td>
<td>386.1</td>
<td>3.2</td>
<td>116.279</td>
</tr>
<tr>
<td>H1</td>
<td>100</td>
<td>289.8</td>
<td>2.1</td>
<td>62.0116</td>
</tr>
<tr>
<td>H2</td>
<td>120</td>
<td>558.1</td>
<td>4.3</td>
<td>46.636</td>
</tr>
<tr>
<td>D1</td>
<td>300</td>
<td>246.3</td>
<td>7.9</td>
<td>707.7141</td>
</tr>
<tr>
<td>D2</td>
<td>100</td>
<td>556</td>
<td>4.3</td>
<td>587.54</td>
</tr>
</tbody>
</table>

Table 2 shows that the fracture length range of the primary structure coal and deformed coal is respectively 155 ~ 290μm and 385 ~ 560μm, the length of fracture in the deformed coal is greater than the primary structure coal. The reasons are shearing and folding make the endogenous fractures of primary structure coal develop, expand, and transfix. Fracture length increases, reticular, irregular-shaped. A large number of endogenous fractures extend and will form transitional cracks and exogenous cracks. Fracture width will generally increase, or even to 10μm or more.

In the scanning electron microscope, the fracture density of primary structure coal is about 1.3 times of the deformed coal. As metamorphic grade increases, the coal pores and small holes increase, large holes and medium holes reduce, and fracture density shows a high - low - high trend, which is generally the same with coal fracture growth degree controlled by the metamorphism of coal or coal-level [2].

The results shows that the macerals of deformed coal are mainly desmocollinite, the distribution is in disorder, the bedding is unclear, the original sedimentary disturbance mark is clear, the particles shapes are mostly brecciform, granular powder, flake structure and mylonites, showing more fracture types and fault structures and fracture ridges are intensive, porosity characteristics are significant [3].

4. "Experimental Results Analysis"

Electrical Parameters Variation of Loaded Coal

The experimental coal is dried coal. In uniaxial compression condition, the raw coal and briquette electrical parameters typical curves are shown in Fig. 2 to Fig. 5.

(a) Deformed coal sample of Jilulishan coal mine  (b) Undeformed coal sample of Zhaogu No.2 mine  

![Fig. 2. The resistivity curve of Jiaozuo coal samples of uniaxial compression tests of loading coal](image-url)
The loaded coal comes into the nonlinear compaction phase (Ⅰ) and linear elastic phase (Ⅱ) at first. In both phases, endogenous and exogenous (microcracks, micropores, etc.) existing in the coal are gradually pressure consolidated and closed, leads to closer contact between particles, the pore volume is reduced, the gas within the coal is discharged, and the resistivity decreases. When reaching to the peak stress, the resistance rate achieves the minimum; the dielectric constant achieves the maximum. In the stable propagation of micro-fracture phase (Ⅲ) tip or internal of secondary fractures along the body of the coal are defective, sandwiched between impurities leads to the local stress concentration and cracks shear movement and then intergranular fracture occurs, which makes new micro-cracks gradually increase, and new gaps form. This leads to increasing resistivity and decreasing dielectric constant. When loaded coal comes into the unstable phase of fracture development (Ⅳ), the fractures of internal oblique or parallel to the loading direction rapidly expand, transgranular fractures are formed by poles and coal and rock particles whose axis direction is changed by high stress, resulting in higher density of micro-burst, beginning to connect with each other, cluster grouping nucleation, extending,
and transfixion and some macro-cracks form. Coal in this phase has been in the damaged critical state, as long as there is external stress disturbance, coal will soon accelerate expansion until rupture instability, at this point resistivity increases, and the dielectric constant decreases.

Experimental results show that, though the basic parameters of raw coal samples and briquette are different, the two are in very good consistency on the experiment of testing electrical parameters variation of loaded coal and it can be used as the study object of electrical parameters variation of deformed coal. The consistency of dielectric constant curve between coal stress-strain curve is better than the resistivity curve. The resistivity curve of loaded coal in general is "concave" shape with stress-strain curves, and the dielectric constant curve is "convex" shape generally.

Experimental data shows that, compared to the initial electrical parameter values of the coal, resistivity change rates of Jiaozuo raw coal samples and briquette are 60.0% and 16.4%, resistivity change rates of Huainan raw coal samples and briquette are 38.2% and 19.4%; the dielectric constant change rates of Hebi raw coal samples and briquette are 28.8% and 13.7%, the dielectric constant change rates of Jiaozuo raw coal samples and briquette are 165% and 18.6%. The electrical parameter change rate of raw coal samples is generally higher than briquette. The reasons are in the process of coal loaded, briquette is based on plastic deformation, raw coal samples are based on brittle deformation.

Summing up the appeal, the electrical parameter change of loaded coal and its stress have significantly coherence; electrical parameters variation of loaded coal better reflects the formation, development and transfixion of micro-fracture, and the characteristics of changes in internal structure in the failure process of coal rock.

5. "Study on Loaded Coal Resistivity Variation Mechanism"

Dry coal is a dielectric or semiconductor, because of its different structural compositions, impurities defects existing in internal, positive and negative charge in the atoms or molecules are tightly bound, and can not be separated from each other under normal conditions, so the free movement charges (e) coal within the coal are fewer, so it has a weak conductivity. Under normal circumstances, we take the low metamorphic grade coal as the dielectric to study, the high metamorphic grade coal as semiconductors to study.

The coal conductive nature is a physical quantity reflected its internal structure and composition, is mainly formed by the electronic conductivity (electron conduction) and ionic conductivity (ionic conduction). Electronic conductivity relies on the free electrons of basic physical coal components for conductivity; and ionic conductivity relies on ions in aqueous solution of coal pores for conductivity. In the I, II load phase, coal is always in a state of stress compaction; in growing stress makes electron clouds between the molecules overlap, mobility of electrons in the molecular is increasing, the electronic conductivity increases. At the same time, the space between molecules reduces, the free space of ions in the transition between molecules decreases, which will make ions transition difficult, ions mobility decrease and ion conductivity decrease. As the stress continues to increase, loaded coal transits to the III, IV phase, intergranular fracture and transgranular fracture occur, the internal bond is damaged, large amounts of particle radiation produces. In addition, the heat produced during coal rupture will increase the activity of particles, ionic conductivity will form. Therefore, in the case of uniaxial compression, electronic conductivity is the main in I, II two phases ionic conductivity is supplemented; ionic conductivity is the main in III, IV two phases, electronic conductivity is supplemented.

6. "Study on Loaded Coal Dielectric Constant Variation Mechanism"
Coal dielectric constant is one of the main macro-physical quantities reflected internal bounding charges and polarization behavior affected by the electromagnetic field. Microscopic mechanisms of dielectric polarization are four: (1) electronic displacement polarization; (2) ion displacement polarization; (3) the orientation of polarization; (4) space charge (or surface) polarization. The changes of coal dielectric constant have some links with coal cracks.

In the \( I \), \( II \) loading phase, the coal endogenous cracks are compacted, the structure of coal is more dense, in the effect of external electric field, polar molecules or some charged particles in the coal have a rotating by the role of rotating torque, electronic displacement polarization and orientation polarization occur, dielectric constant increases. When loading into \( III \), \( IV \) two phases, micro-cracks in the coal stably develop, and transit to unstable instability state, a large number of the cracks and macro cracks produce, structure is not close, the heat generated by the crack formation process destroy the polar molecules or the polarization of charged particles, dielectric constant decreases. Therefore, the dielectric constant changes of loaded coal have a close relation with its changes in the structure, cracks closure and cracked degree.

7. Conclusion

- The fracture length range of the primary structure coal and deformed coal is respectively 155 ~ 290μm and 385 ~ 560μm, fracture width of deformed coal is large, or even to 10μm or more. The fracture density of primary structure coal is about 1.3 times of the deformed coal.
- Electrical parameters’ change curves of the loaded raw coal samples and briquette have a very good consistency, and it can be used as the study object of electrical parameters variation of deformed coal. The consistency of dielectric constant curve and coal stress-strain curve is better than the resistivity curve. The resistivity curve of loaded coal in general is "concave" shape with stress-strain curves, and the dielectric constant curve is "convex" shape generally.
- Compared to the initial electrical parameter values of the coal samples, the electrical parameter change rate of raw coal samples and briquette is generally higher than 13%, up to 165%; the electrical parameter change rate of raw coal samples is generally higher than briquette.
- The electrical parameter change of loaded coal and its stress have significantly coherence, electrical parameters variation of loaded coal better reflects the formation, development and transfixion of micro-fracture, and the characteristics of changes in internal structure in the failure process of coal rock.

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