Experimental Study on the Variation of Surface Widths of Lignite Desiccation Cracks during Low-Temperature Drying

Ziwen Dong,* Wenhui Yu, Tinggui Jia, Shengli Guo, Weile Geng, and Bin Peng

ABSTRACT: Significant volume shrinkage and drying cracking of high-water-content lignite will occur during low-temperature drying. To determine the variation behaviors of the drying shrinkage rate and desiccation crack surface width in the process of low-temperature drying, low-temperature and low-humidity drying experiments were conducted, and the variations of the surface widths of the desiccation crack with time and water content of old lignite were examined. The results showed that the slow drying of lignite at low temperatures caused significant volume shrinkage and desiccation crack formation, and the occurrence and development of desiccation cracks were highly nonuniform. Three stages of the variation of surface widths of the desiccation cracks were observed with the water content decrease: an initial rapid increase stage, a second slow decrease stage, and a final stable stage, and the average width of the desiccation cracks increased in a Gaussian function. The higher the evaporation rate and volume drying shrinkage rate, the lower the surface width of the desiccation cracks under low-temperature drying conditions. To achieve safe and green mining, storage, transportation, processing, and utilization of lignite, the moisture content of old lignite should be controlled to be above 13−15%.

1. INTRODUCTION

Lignite has a large pore structure and surface area. Its functional groups are rich in molecular surfaces with large electrostatic potentials. As a result, lignite often has a higher water content and has a high reaction activity. It is prone to spontaneous combustion or water vapor re-adsorption after drying or under the influence of water, and thus, it is not suitable for long-term stacking and long-distance transportation.1,2 With the consumption of coal resources, lignite mining, processing, utilization, storage, and transportation in China will increase, and the lignite spontaneous combustion problem will also become an issue.2−5

The presence of water leads to the softening of lignite. When saturated coal dries, its volume drying shrinks significantly. As the drying continues, the lignite undergoes drying shrinkage cracking, resulting in severe crushing.2−5 Low-rank coal has high porosity and connectivity and a low tortuosity of the pore structure, which causes the lignite to have strong shrinkage characteristics.9

When lignite is dried in air, the water in the pores with diameters greater than 120 nm is easily removed by evaporation.10 The pores are emptied, resulting in a significant increase in the porosity. However, the volume shrinkage of lignite is limited at this time. In the case of further drying and evaporation, multiple layers of water are removed, and the open gel structure collapses. This leads to significant volume shrinkage, and the open porosity increases.11,12 Owing to the characteristics of lignite, significant shrinkage, cracking, three-dimensional development of cracks, and connectivity enhancement occur during the drying process. As a result, the medium
is severely broken, the porosity and fracture rate increase, and the permeability is enhanced significantly. The main channels for further gas-liquid flow increase in number and range. Furthermore, the processes of oxidation and spontaneous combustion change after contact with oxygen, and the risk of spontaneous combustion increases.

At present, the dry-shrinking and cracking phenomena of porous media have mainly been reported for media such as soil, cement pavement, buildings, timber, and cultural relics, but the research on the dry-shrinking and cracking of coal, especially lignite, is still insufficient. The research of coal drying shrinkage and cracking has generally focused on the study of the drying shrinkage behaviors in the drying process under special conditions, such as negative pressures, inert gas environments, high temperatures and pressures, and underground vaporization, modification, and utilization. The relevant studies of drying shrinkage, cracking, breakage, and spontaneous combustion caused by drying under low-temperature air have been rarely reported.

In this work, low-temperature drying experiments were conducted. The drying, volume shrinkage, and cracking behaviors of lignite at low temperatures were examined. The moisture content and volume variations of lignite as well as the surface width of lignite desiccation cracks during the process of low-temperature drying were studied. The variations of the volume shrinkage and the surface widths of lignite desiccation cracks with time and water content under low-temperature drying conditions were analyzed. The drying, volume shrinkage, and cracking characteristics of lignite under low-temperature conditions were determined, providing theoretical support for the safety management of lignite mining, storage, transportation, processing, and utilization.

2. RESULTS

2.1. Drying and Volume Shrinkage Behaviors. Figure 1a shows that during the low-temperature drying process, the water content (\(W_c\), 1) decreased significantly with time (\(t, h\); \(W_c\) is calculated by eq 1. The moisture contents of samples 2 and 3 were basically the same, but they were significantly different from that of sample 1. The moisture content of sample 1 decreased faster. The results showed that the moisture contents of samples 2 (two of the outer surfaces were

![Figure 1. Changes in the moisture content, evaporation rate, surface drying shrinkage rate, and volume drying shrinkage rate during low-temperature drying: (a) water content variation with time, (b) evaporation rate per unit area variation with time, (c) surface drying shrinkage rate variation with water content, and (d) volume drying shrinkage rate variation with water content.](https://doi.org/10.1021/acsomega.1c01031)
sealed) and 3 (four of the outer surfaces were sealed) were higher than that of sample 1, where none of the outer surfaces were sealed. Under the same environmental conditions, the evaporation surface was larger, and the moisture content decreased faster. However, with the continuation of low-temperature drying, the ultimate stable moisture contents were basically identical. The size of the outer surface determined the moisture loss rate, and the drying conditions determined the final stable moisture content.

\[ W_i = 0.25W_0 - \frac{W_i}{W_i} \]

where \( W_0 \) is the initial sample mass, g, \( W_i \) is the real-time sample mass when the low-temperature drying time is \( i \) h, g, and the 0.25 term represents the initial moisture content, 25%.

Figure 1b shows that under the conditions of the same sample volume and total surface area, the smaller the outer surface that could be used for evaporation was, the greater the evaporation rate per unit area (\( E_{rup} \), g/cm²/h) is. \( E_{rup} \) is calculated by eq 2. Since the lignite surface area is constantly changing during the drying process, the evaporation rate should be determined according to the actual value of the area at different times during the drying process so as to correctly express the evaporation rate. As a result, the area that could be used for water evaporation decreased, and the loss rate from the system with some surfaces sealed with wax was reduced. However, the amount of water lost by evaporation over long times did not decrease greatly.

\[ E_{rup} = \frac{W_0 - W_i}{S_i/t} \]

where \( E_{rup} \) is the evaporation rate per unit area, g/cm²/h, \( W_0 \) is the initial sample mass, g, \( W_i \) is the real-time sample mass when the low-temperature drying time is \( i \) h, g, \( S_i \) is the real-time sample surface area when the low-temperature drying time is \( i \) h, cm², and \( t \) is the drying time, h.

Figure 1c shows that the drying moisture loss of lignite resulted in surface shrinkage, and the shrinkage values and rates of the different samples were different. In the process of low-temperature drying, the surface drying shrinkage rates (\( S_{rd,s} \), 1) increased with the decreasing water content and went through four different stages: thermal expansion, slow drying shrinkage, fast drying shrinkage, and stable shrinkage, \( S_{rd,s} \) being calculated by eq 3. As shown in Figure 2d, the volume drying shrinkage rates (\( V_{rd,s} \), 1) had the same variation trends with the decrease in water content, \( V_{rd,s} \) being calculated by eq 4. When the moisture content was greater than 14%, the order of the drying shrinkage rates (surface drying shrinkage and volume drying shrinkage) of the samples was sample 2 > sample 1 > sample 3. When the moisture content was reduced to less than 14%, the order of the surface drying shrinkage was sample 3 > sample 2 > sample 1. Through correlation tests, the drying shrinkage rate of the total surface area and volume had significant positive correlations with the lost water mass at the 0.01 significance level and significant negative correlations with the water content and evaporation rate at the 0.01 significance level.

\[ S_{rd,s} = \frac{S_0 - S_i}{S_0} \]
where $S_{\text{rd}}$ is the surface drying shrinkage rate, $V_0$ is the initial sample surface area, cm$^2$, and $V_i$ is the real-time sample surface area, cm$^2$.

\[ V_{\text{rd}} = \frac{V_0 - V_i}{V_0} \]  

(4)

where $V_{\text{rd}}$ is the volume drying shrinkage rate, $V_0$ is the initial sample volume, cm$^3$, and $V_i$ is the real-time sample volume when the low-temperature drying time is $i$ h, cm$^3$.

The drying shrinkage amounts and moisture contents of samples 1, 2, and 3 were fitted with the Boltzmann equation, defined as eq 5

\[ V_{\text{rd}} = A_0 + \frac{A_1 - A_0}{1 + e^{(W_0-x_0)/d_x}} \]  

(5)

where $V_{\text{rd}}$ is the volume drying shrinkage rate, $W_i$ is the water content, $x_0$ is the value of $W_i$ when $V_{\text{rd}} = (A_0 + A_1)/2$, and $A_0$, $A_1$, and $d_x$ are the fitted constants.

The fits are shown in Figure 1d; the fitted coefficients in eq 5 are shown in Table 1.

### Table 1. Fitted Boltzmann Function Coefficients of Three Different Samples

| s. no. | $A_1$ value | $A_1$ error | $A_0$ value | $A_0$ error | $x_0$ value | $x_0$ error | $d_x$ value | $d_x$ error | $R^2$ value |
|--------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| 1      | 0.1054      | 0.0040      | 0.0183      | 0.0039      | 0.0996      | 0.0008      | 0.0030      | 0.0008      | 0.9692      |
| 2      | 0.1779      | 0.0057      | 0.0032      | 0.0037      | 0.1230      | 0.0015      | 0.0016      | 0.0016      | 0.9954      |
| 3      | 0.1839      | 0.0031      | -0.006      | 0.0080      | 0.1349      | 0.0016      | 0.0105      | 0.0013      | 0.9891      |

2.2. Variation of Surface Widths of Lignite Desiccation Cracks.

#### 2.2.1. Development of Surface Widths of Lignite Desiccation Cracks.

Figure 2 shows the surface width of the lignite desiccation crack at observation point 5 on surface 2 of sample 3. When the moisture content was 21.5%, the variation of surface widths of desiccation cracks with time and water content of surfaces 1 and 2 in sample 1: (a) variation of the crack width with time of surface 1 in sample 1, (b) variation of the crack width with water content of surface 1 in sample 1, (c) variation of the crack width with time of surface 2 in sample 1, and (d) variation of the crack width with water content of surface 2 in sample 1.
the width of the drying shrinkage crack was 0.051 mm, Figure 2a. When the moisture content decreased to 17.5, 14.6%, the width of the drying shrinkage crack increased to 0.471, 0.653 mm, Figure 2b,c. The width of the drying shrinkage crack then decreased with the decrease in the water content. When the water content decreased to 8.8, 8.5, and 8.4%, the surface widths of the lignite desiccation cracks were 0.341, 0.331, and 0.341 mm, respectively, as shown in Figure 2j–l.

2.2.2. Variation of Surface Widths of Lignite Desiccation Cracks. During low-temperature drying and shrinkage, cracks gradually appeared, and their width development is shown in Figure 2. The cracks widened but narrowed at a decreasing rate and finally became stable. The details are shown in Figure 3. Figure 3 shows the variation of the crack width with time and water content for surfaces 1 and 2 of sample 1.

Figure 3a,c shows that with the continuation of low-temperature drying, the widths of the lignite cracks increased linearly after the appearance of drying shrinkage cracks. After reaching the maximum values, the widths decreased slowly. After a long drying time at low temperatures, the width basically remained constant. This indicated that drying shrinkage cracks developed rapidly and the width increased rapidly. After reaching a certain width, the cracks no longer widened. Instead, the phenomenon of narrowing occurred, that is, after reaching their maximum widths, the cracks narrowed, initially rapidly and then more slowly, and finally, the crack width stabilized.

Figure 3b,d shows that with the decrease in the water content, the width of the drying shrinkage crack first increased to a maximum value and then decreased slowly. Finally, the width tended to be stable with the slow decrease in water content. Therefore, once the low-temperature evaporation is no longer sustained, the moisture inside and outside the coal tends to balance out, the water content is no longer significantly reduced, and the desiccation crack width no longer changes significantly.

According to previous studies of the lengths, widths, and depths of desiccation cracks and the size of fractured blocks by O’Callaghan and Loveday,19 Scott et al.,20 Velde,21 Preston et al.,22 Hallaire,23 Vegel et al.,24 Samouélian et al.,25 and Laloui et al.,26 with the decrease in the water content, not only the widths of the desiccation cracks but also the lengths and depths of the desiccation cracks changed significantly. The desiccation cracks grew from the surface to the interior with a “V-shaped”
development trend. When the desiccation cracks reached a certain depth, they became interconnected to form fracture communication. Water evaporation mainly occurred on the surface and shallow layers of lignite initially. The desiccation cracks arose mainly at the surface, and with the continuous decrease in the water content, the surface widths of the desiccation cracks increased significantly. When the surface or shallow water content decreased, evaporation occurred from the deep layers, and the deep-layer water content began to decrease rapidly. As a result, the desiccation cracks slowly grew down into the deeper layers. Thus, the surface widths of desiccation cracks did not grow significantly after a certain time, but the depth increased rapidly.

When the tensile stress was greater than the tensile strength, the desiccation cracks developed and expanded. The tensile stress was strongly related to the water content and pore size and distribution. When the evaporation of shallow water was close to zero, the tensile stress did not change but actually decreased, and the shallow cracks did not continue to expand; however, the deep-water evaporation occurred rapidly so that deep tensile stresses increased significantly. The tensile stress in the deep layer increased and became higher than the tensile strength, which caused the desiccation cracks to expand in the depth direction.

In the process of the development of the desiccation cracks into the deep layers, the deep-layer tensile stress caused the deep coal body on both sides of the crack to stretch outward. The result of the deep-layer tensile stress stretching was that the desiccation crack depth increased and the surface crack width decreased. This shows that the surface widths of the desiccation cracks decreased in a small range. When the coal water was close to equilibrium, the tensile stress on both sides of the formed crack disappeared or was lower than the tensile strength, and the width and depth of the crack did not change. Thus, the desiccation crack width of lignite tended to become stable after the evaporation rate became small and nearly constant.

Variations of desiccation crack surface widths of surfaces 1 and 2 in sample 1 with drying time and sample water content are shown in Figure 3a–d. Variations of desiccation crack surface widths of surfaces 3, 4, 5, and 6 in sample 1 with sample water content are shown in Figure 4a–d.
 Variations of average desiccation crack widths in each surface with water content of samples 1, 2, and 3 are shown in Figure 5a–c. The average crack widths on different surfaces (\( \bar{w}_{dh} \), mm, calculated by eq 6) of the three samples in Figure 5 show that the average surface widths of the desiccation cracks on different surfaces of the same sample were different. This proves that the desiccation crack development in the low-temperature drying process of lignite had significant non-uniformity. Before the desiccation crack width became stable, the change in the average width with the water content followed a Gaussian function relationship, defined as eq 7

\[
\bar{w}_{dh} = y_0 + \frac{A}{\omega \sqrt{\pi/2}} e^{-2(w_c - x_c)^2/\omega^2}
\]

(6)

where \( \bar{w}_{dh} \) is the average desiccation crack width on each surface, mm, \( w_i \) is the surface width of each desiccation crack at the observation point in the same surface, mm, and \( N \) is the number of effective observation desiccation cracks in the same surface.

The variations of the average surface width of the desiccation crack on each surface with the water content were fitted with eq 7, and the fitted constants are shown in Table 4. According to eq 7 and Table 2, when \( w_c = x_c, \bar{w}_{dh} \) reaches the maximum number; in the low-temperature drying process, the average value of \( x_c \) of the six surfaces in sample 1 is 0.106, the average value of \( x_c \) of the four surfaces in sample 2 is 0.121, and the average value of \( x_c \) of the two surfaces in sample 1 is 0.125. The results are in good agreement with Figure 1, the higher the \( R_{wav} \) \( \bar{S}_{ds} \) and \( \bar{V}_{ds} \) values are, the higher the moisture content \( (w_c = x_c) \) is when \( \bar{w}_{dh} \) reaches the maximum number.

To sum up, during lignite drying under low-temperature conditions, the moisture evaporated and dissipated, and volume shrinkage occurred, leading to the desiccation crack emergence and development. There were three stages—rapid increase, slow decrease, and stabilization—as the water content decreased and the drying time increased.

The variation of the average surface width of the desiccation cracks of all the effective observation points in each coal sample with the water content is shown in Figure 6. \( S_{wav}^1, \) \( S_{wav}^2, \) and \( S_{wav}^3, \) are the average surface widths of desiccation cracks in sample 1, sample 2, and sample 3, respectively. With the decrease in the water content, the average width of the desiccation cracks increased in a Gaussian function, defined by eq 8, and the fitted constants are shown in Table 3.

### Table 2. Gaussian Function Fitting Results of the Variation of the Average Crack Width with the Water Content of Each Surface

| surface | \( y_0 \) | \( x_c \) | \( w \) | \( A \) | \( R^2 \) |
|---------|---------|---------|-------|-------|-------|
| 1–1     | 0.01914 | 0.10474 | 0.08107 | 0.1241 | 0.97876 |
| 1–2     | -0.00774 | 0.10578 | 0.08751 | 0.0452 | 0.99763 |
| 1–3     | -0.01349 | 0.10942 | 0.09275 | 0.07862 | 0.99027 |
| 1–4     | -0.03284 | 0.10937 | 0.09817 | 0.0718 | 0.99081 |
| 1–5     | 0.00549 | 0.10221 | 0.07931 | 0.04037 | 0.98331 |
| 1–6     | -0.02331 | 0.10749 | 0.09568 | 0.07449 | 0.97868 |
| 2–1     | -1.16906 | 0.12451 | 0.32478 | 0.5979 | 0.97087 |
| 2–2     | -1.35979 | 0.11342 | 0.27118 | 0.7079 | 0.99311 |
| 2–3     | -3.29106 | 0.12754 | 0.51227 | 2.30664 | 0.96156 |
| 2–4     | -8.09472 | 0.11844 | 0.71328 | 7.65766 | 0.97806 |
| 3–1     | -0.44934 | 0.12611 | 0.20427 | 0.1974 | 0.94638 |
| 3–2     | -0.33692 | 0.12335 | 0.17094 | 0.16379 | 0.96218 |

### Table 3. Gaussian Function Fitting Results of the Variation of the Average Crack Width with the Water Content of Sample 1, Sample 2, and Sample 3

| sample   | \( y_0 \) | \( x_c \) | \( w \) | \( A \) | \( R^2 \) |
|----------|---------|---------|-------|-------|-------|
| sample 1 | -0.00665 | 0.10629 | 0.08884 | 0.07231 | 0.98979 |
| sample 2 | -4.73365 | 0.11948 | 0.55018 | 3.5719 | 0.99038 |
| sample 3 | -0.37305 | 0.12454 | 0.18317 | 0.17163 | 0.95822 |

The results in Figures 6 and 1b show that the larger the evaporation rate per unit area was, the smaller the maximum width and stable surface width of the desiccation crack were. The results in Figure 6 show that at the stage of slow volume drying shrinkage, the surface desiccation cracks of lignite were produced, and the width increased rapidly with the decrease in the water content. However, the larger the volume of the drying shrinkage was, the smaller the maximum and stable.
surface widths of the desiccation crack were. The volume drying shrinkage generally began to increase significantly when the moisture content decreased to less than 15%, and the volume of drying shrinkage reached the maximum value when the moisture content decreased to about 10%. However, the surface width of the desiccation crack reached its maximum value when the moisture content decreased to 10–13%.

3. DISCUSSION

3.1. Moisture Content Control of Pingzhuang Mining Area Lignite Based on Desiccation Crack Development. The moisture content of aged lignite in the Pingzhuang mining area, Inner Mongolia, China, should be controlled to be above 13–15% based on the variation of the desiccation crack width and volume with the moisture content under low-temperature drying conditions of high-water-content lignite. With this moisture content, the shrinkage of high-water-content lignite did not occur significantly, and the desiccation cracks were relatively narrow. This could effectively control the increase in the porosity and the enhancement of the pore connectivity caused by the volume drying shrinkage and desiccation crack development of high-water-content lignite due to the slow drying at low temperatures. Thus, the change in the pore structure and the enhanced oxidation capacity caused by slow drying at low temperatures can be avoided. This can lower the spontaneous combustion risk and inhibit the carbon and oxygen emissions caused by drying shrinkage and drying cracking to a certain extent.

3.2. Limitations and Work That Need To Be Improved. At present, this paper only points out the law of the possible influence of crack development on spontaneous combustion characteristics. There are many factors affecting the complicated process of coal spontaneous combustion, and the change in the physical structure is only an important factor affecting spontaneous combustion, not the whole reason. Based on macroscopic experiments, we carried out a study on the variation in the crack surface width, aiming to provide a more direct visual judgment for lignite mining, processing, storage, transportation, and other technological processes. In order to determine the complete influence mechanism of the physical structure change on coal spontaneous combustion, a pore structure change test must be carried out. In subsequent studies, we will use low-field NMR to conduct a comprehensive study on the pore structure, connectivity, and permeability of the pore system in the process of low-temperature drying of lignite and strive for a more complete explanation of physical structural changes, and at the same time, experimental study on coal spontaneous combustion under the same conditions will be carried out to reveal the influence law of the pore structural change on coal spontaneous combustion characteristics.

4. CONCLUSIONS

(1) Significant shrinkage and drying cracking of high-water-content lignite occur during slow drying at low temperatures. With the decrease in the water content, the surface widths of the desiccation cracks increased rapidly and reached maximum values. When the low-temperature drying evaporation was stable, the water content no longer decreased, and the surface widths of the desiccation cracks no longer changed. Before the desiccation crack width developed to a stable value, the change in the average width with the water content followed a Gaussian function relationship.

(2) Under low-temperature drying conditions, the volume shrinkage of lignite lagged behind the water evaporation. When the moisture content dropped below 15%, the volume shrinkage phenomenon was significant. The occurrence and development of desiccation cracks occurred simultaneously with the occurrence of drying shrinkage. However, when the water content decreased to about 10–13%, the surface widths of the desiccation cracks reached maximum values. The surface widths of the desiccation cracks increased faster than the bulk shrinkage. Finally, the higher the evaporation rate per unit area of lignite was, the higher the volume drying shrinkage rate and the lower the surface widths of the desiccation cracks became during low-temperature drying.

(3) To avoid significant volume shrinkage and desiccation crack height development for the safe and green mining, storage, transportation, processing, and utilization of lignite, the moisture content of old lignite in the Pingzhuang mining area of Inner Mongolia should be controlled to be above 13–15%.

5. MATERIALS AND METHODS

5.1. Experimental Materials. The samples of lignite in this experiment were obtained from the Fengshuigou coal mine of the Pingzhuang Coal Company in Inner Mongolia, China. The proximate analysis indices are shown in Table 4, and the proximate analysis of coal samples was completed by the author in the testing laboratory of the Anhui University of Science and Technology, where $M(\text{ad})$ is the moisture content of the coal sample, $A(\text{ad})$ is the ash content of the coal sample, $V(\text{ad})$ is the volatile content of the coal sample, and $F(\text{ad})$ is the fixed carbon content of the coal sample. The uniaxial compressive strength of the coal was 4.87–5.66 MPa, and the tensile strength was 0.93 MPa.

5.2. Experimental Method. 5.2.1. Sample Cutting and Polishing. In order to not destroy the coal sample structure during the cutting process, a 25 MPa high-pressure water cutter was used to cut large samples. A multi-functional jade carving and polishing machine was used to polish the edges and corners, making all the sides flush and achieving horizontal edges.

5.2.2. Surface Wax Seal and Immersion. The surface label of the sample is shown in Figure 7, the Oxy plane is the stratification plane, the upper and lower surfaces parallel to the stratification plane are marked as 1 and 2, and the other four surfaces perpendicular to stratification plane are marked as 3, 4, 5, and 6. The water evaporation rate is the key factor controlling water loss, volume shrinkage, and crack develop-
In order to create different evaporation rates in the same dry environment, the surface area of water evaporation is controlled by sealing different surfaces with wax.

Various surfaces of the samples were sealed with 64° paraffin wax. The wax was melted in a low-power electric rice cooker, and the desired surfaces were wax-sealed. During wax-sealing, a brush was dipped in liquid paraffin wax for uniform smearing, and for each sample type, zero, two, or four outer surfaces were sealed. The sample group 1 is not wax-sealed, the sample group 2 is sealed with two outer surfaces (5 and 6), and the sample group 3 is sealed with four outer surfaces (3, 4, 5, and 6). In this study, the melting point of 64° paraffin used for wax-sealing is 64 °C, and under the condition of 35 °C in the drying oven, it is soft but not hard; therefore, the paraffin wax will not fall off before the sample is completely broken. In the process of the experiment, there was no evidence that flaking-off of paraffin during experiments compromised the sealing effect.

After the wax seals were complete, the quality and wax seal thickness were measured again. The samples were immersed in water, and the immersion was stopped when the tested moisture content reached 25%. The sample size and quality after being immersed in water are shown in Table 5.

5.2.3. Drying Experiments. Before drying, the surfaces of the samples were numbered, and the various points were examined by electron microscopy and a high-speed camera. A TGP-1260 plant growth chamber, which was a constant-temperature and -humidity box, was used for drying. The initial conditions and experimental treatment conditions of each sample are shown in Table 5. Lignite in the Pingzhuang mining area show drying and cracking noticeably in the summer. The surface widths of the lignite desiccation cracks were determined using an electron microscope (Dino-Capture2.0) with a 30X magnification and a 1250 × 1024 pixel resolution. During the determination of desiccation cracks, only the cracks on the fixed point were measured.

5.2.4. Determination of Drying and Volume Shrinkage. The weights of the samples were measured at predetermined times, and each drying surface of the sample was scanned using an Eloam S1010 model 12 megapixel auto-focus high-definition portable scanner. After scanning and obtaining photographs, computer-aided design (CAD) software was used to process the images, measure the area of the drying surface, and obtain other data.

The quality and area changes of the drying surface before and after drying were compared. The drying and shrinkage behaviors and variations of the surface widths of lignite desiccation cracks were analyzed. In CAD, the latest shape of each surface is redrawn according to the picture contour; the surface area can be calculated automatically with the proportion coefficient calculated by the reference ruler. Due to the small size of the sample, no significant bending deformation is likely to occur. Therefore, when calculating the sample volume, the three-dimensional length, width, and height data of the sample are determined according to the average length and width data of each surface, and then, the volume is calculated by multiplying the length, width, and height.

5.2.5. Determination of Surface Widths of Lignite Desiccation Cracks. The sample surfaces were numbered before drying. Fixed points were established and labeled on an “S” shape for sampling, as shown in Figure 7. Points 1–7 from the top to the bottom were marked on the surface of the coal sample. Cracks may not appear at selected points during the drying process; thus, in the actual experiment, a point near the originally selected point was substituted for it when necessary. The surface widths of the lignite desiccation cracks were determined using an electron microscope (Dino-Capture2.0) with a 30X magnification and a 1250 × 1024 pixel resolution. During the determination of desiccation cracks, only the cracks on the fixed point were measured.

| sample number | pre-drying mass (g) | initial moisture content | length (cm) | width (cm) | height (cm) | initial volume (cm³) | number of surface wax sealed | wax-sealed surface |
|---------------|---------------------|-------------------------|-------------|------------|------------|---------------------|---------------------------|-------------------|
| 1             | 45.58               | 25%                     | 4.91        | 2.93       | 2.89       | 41.58               | 0                         |                   |
| 2             | 53.92               |                         | 5.45        | 2.86       | 2.83       | 44.11               | 2                         | 5,6               |
| 3             | 54.06               |                         | 5.68        | 2.84       | 2.73       | 44.04               | 4                         | 3,4,5,6           |
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