Coupling Model of Stress–Damage–Seepage and Its Application to Static Blasting Technology in Coal Mine

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ABSTRACT: Most coal mine field application processes are carried out using empirical formulas because of the insufficient understanding of the fracture development law of the static blasting technology. This lack of understanding results in poor coal seam gas extraction. In this study, a stress–damage–seepage coupling model was established to investigate the construction parameters of the static blasting technology using COMSOL simulation software. Then, a stress–damage–seepage coupling model was designed to study the evolution of the fracture field (seepage field) during the static blasting process using realistic failure process analysis simulation software. Finally, the influencing factors and fracturing effects were analyzed comprehensively. The research results show the following. (1) The simulation results with previous field tests revealed that the seepage law of the numerical simulation of the static blasting technology is consistent with the field test results, verifying the rationality of the stress–damage–seepage coupling model. (2) The development of coal seam fractures is affected by the expansion pressure, elastic modulus, and guide hole arrangement; the guide hole arrangement can play a role in guiding the development direction of fractures and enhancing the effect of fracturing. (3) The coal body mainly experienced the following five stages of fracturing: coal body compaction, microdamage formation, microfracture formation, large fracture formation, and fracture propagation. In addition, because of the rapid release of soundless cracking agents during the large fracture formation stage, the gas flow decreased in a short time. (4) The static blasting technology causes the coal seam permeability coefficient to increase. Compared with conventional extraction, the effective influence radius in the horizontal direction increases by 5.1 times, and the effective influence radius in the vertical direction increases by approximately 3 times. The static blasting technology can increase the number of coal seam fractures and significantly reduce the coal seam gas pressure, thereby enhancing coal seam permeability and realizing safe coal mining.

INTRODUCTION

In China, coal mines generally have the characteristics of low pressure, low permeability, low saturation, and strong heterogeneity, which lead to difficulties in gas extraction, resulting in gas explosions and coal and gas outburst disasters. Improving the coal seam permeability and gas predrainage effect has become a technical problem that urgently needs to be solved. The static blasting technology is also known as the “soundless blasting technology,” which is a technique for cracking the coal body using expansive pressure. The expansive pressure is generated from the chemical reaction between the soundless cracking agent (SCA) and water. The SCA is stable, nonpolluting, and does not require an open flame. In low-permeability coal seams, the static blasting technology is used to achieve the leading pre-splitting, so that an interconnected fracture network is formed in the coal to improve the permeability of the coal and the effect of gas drainage.

The static blasting technology was first proposed by Japanese scholars, who found that caustic lime forms calcium hydroxide during high-temperature calcination, and its volume expands and creates expansive pressure to break rock. Based on this study, other researchers comprehensively analyzed the influencing factors of the static blasting technology and developed new types of SCAs. With the improvement of SCAs, some have proposed applying the static blasting technology to coal seam permeability enhancement, rock cross-cut coal, tunnel excavation, and so on. Cui used scanning electron microscopy, gas chromatography, infrared spectroscopy, and the mercury intrusion method to analyze changes in the coal microstructure. The results showed that the SCA improved the microfracture of coal, increased the porosity of coal because of thermal expansion, improved the migration of methane, and increased the permeability of coal. Zheng used...
analyzed the single-hole crushing, porous crushing, and fracture hole crushing mechanisms of the static blasting technology and proposed the use of the static blasting technology to address the geological structure of underground coal mines. Xie13 analyzed the principle of the static blasting technology, the mechanical process of crack holes, and field construction parameters. They concluded that the static blasting technology has the advantages of safety, no fire, and no vibration. Ma8 used the static blasting technology to weaken coal seam roofs by setting different guiding holes. Hao9 studied the crack evolution law of the static blasting technology under uniaxial stress load using acoustic emission equipment and established the relationship between the expansion force of the SCA and crack propagation radius. Through the analysis of fracture time, fracture surface density, and fracture number, Zhai10 concluded that the fracture of a coal seam is 0.01 m/d, the original gas content is 21.71 m³/t, and the floor is mudstone. The firmness coefficient of the no. 3 coal seam is 0.45—1.09, the permeability coefficient of the coal seam is 0.01 m/d, the original gas content is 21.71 m³/t, and the original gas pressure is 2 MPa. Overall, the no. 3 coal seam has the characteristics of hard coal, high gas content, high gas pressure, and low permeability. The specific parameters of the laboratory test and query data are listed in Table 1.

### OPTIMIZATION OF CONSTRUCTION PARAMETERS OF THE STATIC BLASTING TECHNOLOGY

**Overview of the Mine.** A coal mine no. 3 coal seam (buried depth 450 m, thickness 5.12—6.20 m, and average 5.25 m) was studied. The roof of the coal seam is mudstone, sandy mudstone, and siltstone, the local is fine sandstone, and the floor is mudstone. The firmness coefficient of the no. 3 coal seam is 0.45—1.09, the permeability coefficient of the coal seam is 0.01 m/d, the original gas content is 21.71 m³/t, and the original gas pressure is 2 MPa. Overall, the no. 3 coal seam has the characteristics of hard coal, high gas content, high gas pressure, and low permeability. The specific parameters of the laboratory test and query data are listed in Table 1.

**Numerical Simulation of Damage Distribution Modeled by COMSOL.** (1) Model Establishment. COMSOL software was used to simulate the distribution of the coal damage zone during stress loading. A three-dimensional numerical model was established: 5 m long, 5 m wide, and 5 m high. In the model X-axis direction, a confining pressure of 4 MPa was applied. In the Y-axis direction, roller support was applied. At the coal seam top plate, the ground stress was 12 MPa, and a fixed constraint was applied to the bottom plate. In the field application of the static blasting technology, the larger the diameter of the borehole, the more prone it is to spray holes, so the borehole diameter of 65 mm was selected. Field tests showed that the ratio of borehole spacing to borehole diameter was 14 to 15, so the borehole spacing of 0.9 m was selected. The borehole depth was 3.5 m. The stress boundary conditions applied to the blasting hole were 5, 10, 15, 20, and 30 MPa, and the free boundary conditions of the guide hole were obtained. The model coupled five solid mechanics physics components to study the evolution of the static blasting technology under five-step pressure load. The stresses of 5, 10, 15, 20, and 30 MPa were applied sequentially to these five steps. The component considers the stress—damage coupling model. Elastic modulus changes with the development of the damage zone before each step of stress loading (Figure 8 shows the elastic modulus evolution of the static blasting technology). After the coal body produced the damage zone, the elastic modulus decreased with the development of the damage zone. When the blasting hole was subjected to

![Table 1. Parameters of the Numerical Model](https://doi.org/10.1021/acsomega.1c05574)
stress loading again, the elastic modulus of the damaged area was the residual elastic modulus and that of the undamaged area was the original elastic modulus. The physical model is shown in Figure 1, and the specific mechanical parameters are shown in Table 1.

(2) Numerical Simulation of Damage Distribution Evolution Using COMSOL. The damage distribution evolution of the static blasting technology is shown in Figure 2. When a stress of 10 MPa stress is applied to the blasting hole, the coal around the blasting hole is slightly damaged. With the energy release of the SCA, the expansion pressure in the blasting hole reaches 15 MPa, and the damage zone around the blasting hole continues to develop. At the same time, under the action of ground stress and expansion pressure, microdamage occurs around the guide hole. When the expansion pressure in the blasting hole reaches 20 MPa, the development direction of the damage zone tends to guide the hole. When the expansion pressure in the blasting hole reaches 30 MPa, the guiding and blasting holes are connected, the development of the horizontal damage zone with the guiding hole is more obvious, the fracturing effect is better, and the energy release of the SCA is completed.

The damage zone distribution of the static blasting technology, as shown in Figure 2, reveals that under the construction parameters of a maximum SCA, expansion pressure of 30 MPa, borehole diameter of 65 mm, and borehole spacing of 0.9 m, the connection of the guide hole and blasting hole can be realized, and a better coal seam drainage effect is achieved.

Figure 1. Physical model diagram.

NUMERICAL SIMULATION OF THE FRACTURE FIELD AND SEEPAGE FIELD EVOLUTION BY RFPA

Construction of the Stress–Damage–Seepage Coupling Model. Gas Seepage Field Equation. The gas flow in a coal seam conforms to Darcy’s law

\[ q_i = -\lambda_i \text{grad} P \]  

where \( q_i \) is the gas seepage velocity (m/d), \( \lambda_i \) is the gas permeability coefficient (m²/(MPa²·d)), and \( P \) is the square of the gas pressure (MPa²).

The gas is simplified as an ideal gas, and the gas flow seepage equation in the coal seam can be obtained from the gas state equation and mass conservation equation

\[ \alpha_p (\lambda \nabla^2 P) = \frac{\partial P}{\partial t} \]  

where \( \alpha_p = 4A^{-1}P^{3/4} \).

Coal Deformation Field Equation. The deformation field equation for coal can be derived from the stress equilibrium equation, deformation coordination equation, constitutive equation, and effective stress principle.

\[ (k + G)u_{ij,\beta} + G\sigma_{ij,\beta} + f_i + (\alpha_p) = 0 \]
where $k$ and $G$ are the Lame constant and shear modulus, respectively; $u$ is the deformation displacement (m); $i, j = 1, 2,$ and $3; f_i$ is body force (Pa); and $\alpha$ is the gas pressure coefficient, $0 < \alpha < 1$.

**Evolution Equation of the Gas Permeability Coefficient and Coal Body Stress.** The static blasting technology causes fractures in coal seams, thereby improving the permeability of coal seams. In the numerical simulation of static blasting, the influence range and the increased range of the permeability coefficient caused by the seepage–stress coupling model are considered. Based on this, the simplified seepage–stress coupling equation can be expressed as

$$
\frac{\lambda}{\lambda_0} = e^{-\beta\sigma'}
$$

where $\lambda/\lambda_0$ is the ratio of the permeability coefficient to the initial permeability coefficient, $\beta$ is the coupling coefficient, and $\sigma'$ is the effective stress.

**Evolution Equation of the Gas Permeability Coefficient and Coal Body Damage.** The static blasting technology causes coal body damage and deformation. When the stress state meets a given damage threshold, the permeability of the coal changes. The evolution equation of the elastic modulus under the damage element can be expressed as

$$
E = (1 - D)E_0
$$

where $D$ is the damage variable and $E$ and $E_0$ are the elastic modulus after damage and the original elastic modulus, respectively (MPa).

When the unit stress reaches the Mohr–Coulomb criterion, the permeability coefficient of coal increases accordingly.\textsuperscript{20} Eq 7 shows the change in the permeability coefficient under compressive shear stress, and eq 8 shows the change in the permeability coefficient under tensile stress; hence, the permeability coefficient damage evolution equation can be expressed as

$$
\delta = \begin{cases}
\lambda_0 e^{-\beta(\sigma - \alpha)} & (D = 0) \\
\frac{\delta\lambda_0 e^{-\beta(\sigma - \alpha)}}{\lambda_0} & (D > 0)
\end{cases}
$$

where $\lambda_0$ is the initial permeability coefficient ($m^2/(MPa^2 \cdot d)$) and $\delta, \alpha,$ and $\beta$ are the permeability increase multiple, gas pressure coefficient, and stress coupling coefficient, respectively.
\[
\begin{align*}
\lambda &= \begin{cases} 
\delta \delta e^{-\beta(\sigma - ap)} & (D = 0) \\
\delta \delta e^{-\beta(\sigma - ap)} & (0 < D < 1) \\
\delta \delta e^{-\beta(\sigma - ap)} & (D = 1)
\end{cases}
\end{align*}
\]

where \(\delta\) is the increase coefficient of the permeability coefficient when the unit is destroyed.

Combining eqs 3, 4, 7, and 8, the stress–damage–seepage coupling mathematical model in the static blasting process is constructed. RFPA software was used to simulate the gas drainage in the process of static blasting loading to study the evolution of coal seam fractures, the seepage law, and gas drainage.

**Model Establishment and Parameter Selection.** Because COMSOL simulation software cannot simulate the evolution law of the fracture field in the static blasting technology, RFPA-Thermo software was used to simulate the evolution law of the fracture field and seepage field in the static blasting process. According to the different expansion coefficients of the SCA and coal matrix, the hydration expansion reaction of the SCA was simulated when the temperature of the circular unit material increased. When the temperature increases, the SCA expands, and the coal matrix does not expand. The SCA squeezes the coal matrix, and the pressure generated is applied to the coal matrix. The model used a 5 m length and 5 m height to establish a 250 \times 250 mesh numerical model, 1 m is 50 meshes, and 62,500 meshes are divided. The two ends of the model were blasting holes, and the middle was the guide hole (extraction hole). The diameter of the borehole was 65 mm, the spacing of the borehole was 0.9 m, and the surrounding was a fixed boundary. The negative pressure of the extraction was 30 kPa. The seepage boundary and gas pressure around the model were 2 MPa. The loading step of the static blasting technology was set to 40 steps (including step in step). The mechanical parameters and seepage parameters are listed in Table 1.

**RESULTS AND DISCUSSION**

**Dynamic Evolution Results of the Fracture Field during Static Blasting.** Figure 3 shows the dynamic evolution of coal seam fractures during static blasting. In the figure, the gray level represents stress. The brighter the gray level, the greater the stress. The figure shows that during the static blasting process, with the increase in stress, the crack length continues to increase until the release of the SCA ended and the crack propagation ended. The static blasting process can be divided into five stages: coal body compaction, microdamage formation, microfracture formation, large fracture formation, and fracture propagation.

1) Coal body compaction stage. The hydration expansion reaction of the SCA starts to expand, and the expansion pressure reaches 2.33 MPa. The primary pores of the coal body begin to close, owing to the extrusion. Because the tensile stress of the coal body is not reached, no cracks appear around the coal body, as shown in Figure 3 (step 1).

2) Microdamage formation stage. When the expansion force of the hydration expansion reaction of the SCA reaches 8.14 MPa, the weak unit around the blasting hole is damaged, as shown in Figure 3 (step 2).

3) Microfracture formation stage. As the expansion pressure continues to increase (14.7 MPa), the damage elements are connected to form microfractures. Because the blasting and extraction holes are not connected, the constraint degree of coal on the SCA remains high, as shown in Figure 3 (step 5).

4) Large fracture formation stage. The hydration expansion reaction of the SCAs enters the stage of rapid energy release. Under the action of the expansion force (18.2 MPa), three to four large fractures appear around the borehole, as shown in Figure 3 (step 7).

5) Fracture propagation stage. The hydration expansion reaction of the SCA continues to expand, the expansion force reaches 26 MPa, and the fractures expand and penetrate along the direction of the large fractures, as shown in Figure 3 (step 10). When the blasting and extraction holes are connected, the expansion pressure increases slowly, and fractures continue to expand around the coal. When the hydration expansion reaction of the SCA ends, the fracture propagation ends, as shown in Figure 3 (step 25).

The numerical simulation results of the dynamic fracture evolution of the static fracturing technology show that the tensile shear stress produced by the static fracturing technology can...
enhance the permeability and relieve pressure in the coal seam. The fractures mostly have a transverse, longitudinal, and multiangle distribution, and the guide hole can play a guiding role in fracture distribution. The static blasting technology can effectively crack coal bodies and generate many fractures.

**Dynamic Evolution Results of the Seepage Field during Static Blasting.** Figure 4 shows the dynamic evolution of gas flow during static blasting. The gray level in the figure represents the size of the gas pressure. The darker the gray level, the smaller is the gas pressure. As shown in Figure 4, the gas pressure of the coal seam decreases continuously with the hydration expansion reaction of the static blasting agent, and the influence range of the drainage borehole expands continuously. Taking the 0.5 m gas pressure from the extraction hole as an example, the specific evolution process is as follows.

1) Coal body compaction stage. The coal body near the blasting hole is compacted, the permeability of the coal seam decreases, and the local gas pressure increases from 1.03 to 1.29 MPa, as shown in Figure 4 (step 1).

2) Microdamage formation stage. The gas pressure in the fractured area near the blasting hole decreases from 1.29 to 1.13 MPa, but the gas pressure in the nonfractured area between the blasting holes increases, as shown in Figure 4 (steps 7 and 8).

3) Microfracture formation and large fracture formation stages. When the blasting hole and extraction hole are connected, the influence range of the extraction hole increases significantly. The gas pressure decreases sharply from 1.13 to 0.4 MPa, and the gas pressure between blasting holes decreases more obviously, as shown in Figure 4 (steps 9 and 10).

5) Stable extraction stage. With the increase in extraction time, the gas pressure of the coal seam is reduced significantly. The effective influence radius of the extraction hole increases from 0.3 to 1.54 m compared with the coal seam without static blasting technology, as shown in Figure 4 (step 25).

The numerical simulation results of the dynamic evolution of gas seepage show that the static blasting technology can relieve pressure and enhance the permeability of coal seams. After the application of the static blasting technology, the permeability of the coal seam greatly increases, and the gas flow in the coal seam accelerates, resulting in a sharp decline in gas pressure in the fracturing area near the extraction hole—that is, pressure relief and permeability enhancement.

**Discussion of Dynamic Evolution Law of the Fracture Field.** The evolution of the fracture field in the process of static blasting must be analyzed in terms of the stress state of the coal body, elastic modulus, and layout of the guiding hole. The stress–damage–seepage model established by RFPA software can be used to obtain the quantitative evolution of the load and acoustic emission. At the same time, the stress–damage model is established using COMSOL software to study the stress state and elastic modulus evolution of coal during static blasting.

The evolution law of the load and acoustic emission quantity in the RFPA simulation static blasting process is shown in Figure 5, and the evolution law of stress in the COMSOL simulation static blasting process is shown in Figures 6 and 7. Figure 5 shows that the Y load increases slowly from −194 to 30 N, then rapidly increases from 30 to 1368 N. It finally stabilizes at 1450 N. In the application of the static blasting technology, the load acting on the coal body is consistent with the measured curve of the expansion pressure, which
experiences slow, rapid, and stable energy release stages. The number of acoustic emissions in step 8 increases significantly, and the number of acoustic emission (AE) events reaches 157. This stage (step 8) is in the stage of fracture propagation; therefore, rapid energy release is conducive to fracture propagation. Figures 6 and 7 show the stress state of the coal body under expansion pressures of 10, 15, 20, and 30 MPa. At 0.7 m from the blasting hole ($x = 1$ m), the coal body stresses are 7.91, 8.36, 8.95, and 13.1 MPa, respectively. Thus, as the expansion pressure increases, the coal body stress gradually increases, and the increase in speed becomes greater. When the coal stress state exceeds the tensile shear stress, microdamage occurs in the coal body, resulting in a decrease in the elastic modulus, which leads to the numerical simulation results of the dynamic fracture evolution of the static blasting technology, showing that the tensile shear stress produced by the static fracturing technology can enhance the permeability and relieve pressure in the coal seam. The fractures mostly have a transverse, longitudinal, and multilateral distribution, and the guide hole can play a guiding role in fracture distribution. The static blasting technology can effectively crack coal bodies and generate many fractures in the coal.

To explore the evolution law of the elastic modulus in the process of static blasting, the elastic moduli of the microdamage, microfracture, large fracture, and fracture propagation stages were selected. Figure 8 shows the evolution of the elastic modulus during static blasting. As shown in Figure 8a, when an expansion pressure of 10 MPa is applied to the blasting hole, a small elastic modulus range decreases around the blasting hole.

![Stress evolution of the static blasting technology](Figure 6)

(a) The stress distribution of blasting hole 10 MPa
(b) The stress distribution of blasting hole 15 MPa
(c) The stress distribution of blasting hole 20 MPa
(d) The stress distribution of blasting hole 30 MPa

![Stress distribution of the static blasting technology](Figure 7)
Owing to the ground stress, a small elastic modulus range decreases around the guiding hole. As shown in Figure 8b, when an expansion pressure of 15 MPa is applied to the blasting hole, the decrease range of the elastic modulus around

Figure 8. Elastic modulus evolution of the static blasting technology.

Figure 9. Gas drainage parameters of the static blasting technology.

(a) Evolution curve of gas flow(seepage velocity)
(b) Evolution curve of gas flow (Ren Jianwei 2015)
Figure 10. Gas pressure variation curves with distance.

(a) Gas pressure evolution curve during static blasting

(b) Gas pressure comparison curve after 40 days drainage

The blasting hole and guiding hole expands. As shown in Figure 8c, when a 20 MPa expansion pressure is applied in the blasting hole, owing to the existence of the guiding hole, the decrease in the direction of the elastic modulus tends toward the direction of the guiding hole. As shown in Figure 8d, when 30 MPa is applied to the blasting hole, the elastic modulus decrease range increases again, making a fracture connection between the blasting and guide holes. Finally, the SCA reaches the maximum energy release, and the application of the static blasting technology ends.

The fracture evolution in the process of static blasting is affected by the expansion pressure, elastic modulus, and guide hole arrangement. First, the increase in expansion pressure causes microdamage to the coal body and reduces the elastic modulus. Under the combined action of expansion pressure and elastic modulus, fractures develop, expand, and penetrate. Secondly, the guiding hole can play a guiding role, guide the fracture development direction, and enhance the fracturing effect.

Discussion of Dynamic Evolution Law of the Seepage Field. The increase in the expansion pressure during static blasting causes the redistribution of stress. When the stress reaches the tensile shear strength of the coal body, the coal experiences fractures, which have a significant impact on the gas seepage velocity (gas flow). The variation curve of the gas seepage velocity (gas flow) in the coal seam during numerical simulation is shown in Figure 9a. The variation curve of gas flow (gas concentration) with time during the static fracturing process in previous studies is shown in Figure 9b.21

Figure 9a shows that in the compaction stage of the static blasting technology (step 1), the seepage velocity of the coal seam decreases from 0.01 to 0.0097 m/d, which is lower than the original seepage velocity. As the loading step increases, the gas seepage velocity gradually increases from 0.0097 to 0.011 m/d. In the fracture propagation stage (step 8), owing to the large stress and low elastic modulus of coal, the permeability coefficient increases rapidly, leading to a rapid increase in the gas seepage velocity from 0.011 to 0.013 m/d. In steps 9 and 10, the blasting and drainage holes are connected, and the pressure difference between the coal seam fracture and drainage hole increases suddenly; hence, the gas seepage velocity increases rapidly from 0.013 to 0.0145 m/d. After step 10, the release of the SCA is basically complete, and the pressure difference between the coal seam fractures and drainage hole does not change again. Thus, the gas seepage velocity is stable at 0.0145 m/d. Comparing Figure 9a,b reveals that the gas flow decreases in the rapid release stage of the SCA. This is because, in this stage, large fractures do not form; the whole coal body is in the compaction stage, and the permeability coefficient of the coal seam is reduced, which eventually leads to a reduction in the gas flow. In general, compared with the coal seam without static blasting technology, the gas seepage velocity increases by 1.45 times, and the gas flow increases by 12 times. Therefore, the static blasting technology can increase the permeability coefficient of the coal seam and reduce the gas content (gas pressure) of the coal seam. A comparison of Figure 9a,b shows that the gas flow in the process of gas extraction experience a stable extraction stage (original coal seam), rapid increase stage, and stable extraction stage (fractured coal seam). The variation laws of gas flow obtained by the field test and numerical simulation are the same, verifying the rationality of the stress—damage—seepage coupling model.

Figure 10a shows the variation curve of the gas pressure with distance during static blasting. Figure 10a shows that the gas pressures of steps 1, 7, and 8 at 0.3 m from the drainage hole are 0.72, 0.73, and 0.75 MPa, respectively. With an increase in the loading step, the gas pressure increases. This is because the rapid energy release of the SCA results in the coal body being in the compaction stage, and the gas permeability is reduced, causing a small increase in the local gas pressure. Once the blasting and extraction holes are connected (step 9), the gas pressure decreases from 0.75 to 0.46 MPa, and the gas pressure between the blasting holes decreases significantly. There are two reasons for this phenomenon: (1) the static blasting technology increases the permeability coefficient of the coal seam and (2) after the connection of the coal seam fracture and extraction hole, the influence range of the extraction hole is increased, significantly reducing the gas pressure. Therefore, the construction parameters of the static blasting technology should be reasonably arranged in the field application process; otherwise, the drainage and blasting holes are not connected, leading to a poor gas drainage effect.

Figure 10b shows the variation curve of the coal seam gas pressure distribution with distance after 40 days of extraction. After 40 days of extraction, the effective radius of conventional extraction is 0.3 m. However, through the application of the static blasting technology, the effective influence radius in the...
horizontal direction (line 1) is 1.54 m, and the effective influence radius in the vertical direction (line 2) is 0.86 m. Compared with the conventional extraction, the effective influence radius in the horizontal direction increases by 5.1 times, and the effective influence radius in the vertical direction increases by approximately three times. The calculation shows that for the coal seam, the static blasting technology improves the permeability coefficient, accelerates the gas flow, causes the gas pressure to decrease significantly, and realizes safe and efficient mining.

**CONCLUSIONS AND PROSPECTS**

The laws of coal seam fracture development and gas seepage in the process of static blasting were studied based on the coupling model of stress, damage, and seepage. The main conclusions are as follows.

(1) Combined with an engineering geological background, a numerical model considering the coupling effect of stress, damage, and seepage can better reflect the actual situation in the process of gas extraction. By comparing the simulation results with previous field tests, the seepage law of the numerical simulation of the static blasting technology was found to be consistent with the field test results, verifying the rationality of the numerical model.

(2) In the static blasting process, the development of coal seam fractures is affected by three factors: expansion pressure, elastic modulus, and guide hole arrangement, and the guide hole arrangement can play a role in guiding the development direction of fractures and enhancing the effect of fracturing.

(3) The coal body mainly experienced the following five stages: coal body compaction, microdamage formation, microfracture formation, large fracture formation, and fracture propagation. In addition, because of the rapid release of SCAs during the large fracture formation stage, the gas flow decreased in a short time.

(4) There are two main reasons why the static blasting technology reduces coal seam gas pressure. On the one hand, the static blasting technology enables coal seam fracture development to increase the gas permeability of the coal seam. On the other hand, the development of coal seam fractures increases the range of the negative pressure effect, which increases the amount of coal seam gas extracted. Compared with the conventional extraction, the effective influence radius in the horizontal direction increases by 5.1 times, and the effective influence radius in the vertical direction increases by approximately three times.

(5) To further guide the site construction, the following work will use the stress–damage coupling model to quantitatively analyze the relationship between damage radius and ground stress, damage radius, and coal strength, and damage radius and gas pressure.

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**Notes**

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