Application of a Simulation Method for the Shock Wave Propagation Law of Gas Explosion

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ABSTRACT: Gas explosion is one of the main causes of casualties in coal mines. Studying the propagation law of shock wave of mine gas explosion can reduce the economic loss and personnel injury caused by mine gas explosion. To solve the difficulty in the research of shock wave propagation of gas explosion in the mine scale, the segmented relay simulation method of shock wave propagation of gas explosion in a coal mine was put forward, the related key problems were studied, and the results were successfully applied in Yangchangwan No. 2 Mine. The results show the following: (1) When the length of the forked roadway exceeds 50 m, the length of the forked roadway has little effect on the shock wave overpressure in the main roadway. When the length of the forked roadway is short, the closure of the forked roadway has a great influence on the change curve of the shock wave overpressure in the main roadway. When the length of the forked roadway is short, the closure of the forked roadway has a great influence on the change curve of the shock wave overpressure in the main roadway. Therefore, the length of the bifurcation roadway should not be less than 50 m in numerical simulation. (2) The angle of the bifurcated roadway has a great influence on the shock wave propagation of explosion in the main roadway. With the increase in the angle of the bifurcated roadway, the overpressure in the main roadway tends to increase at first and then decrease, and the peak overpressure is the highest when the angle of the bifurcated roadway is 90°. (3) The influence range of the roadway pressure-outlet boundary is about 5 m, and the dynamic parameter monitoring point should be set at about 10 m away from the pressure outlet; dynamic boundary monitoring parameters should include static pressure, dynamic pressure, and temperature. (4) When the gas explosion occurs in the heading face, the shock wave will cause great damage to the adjacent heading face. When the shock wave reaches the head-on and upper corner of the heading face, it will be reflected violently, which will cause the local overpressure to rise obviously. The peak overpressure and gas accumulation length conform to the logarithmic function.

1. INTRODUCTION

Coal mine gas explosion accident is one of the most serious disaster accidents, especially the major and large gas explosion accident, resulting in a large number of casualties and serious equipment damage. Accurate shock wave propagation law of gas explosion in the mines is of great guiding significance to reduce the loss of manpower and material resources caused by gas explosion shock wave. Numerous scholars have carried out plenty of research on the shock wave propagation law of gas explosion. Zhao et al.,5 Jiang et al.,5,6 and Zhu et al.7 have experimentally studied the propagation law and influencing factors of the flame and shock wave of gas explosion in square straight pipes with a centimeter diameter. Yu et al.8 studied the influence of a pressure relief port on gas explosion shock wave and flame propagation in a 10 cm × 10 cm × 1 m square pipe. Sapko et al.5 simulated the gas explosion accident in the Upper Big Branch (UBB) coal mine in the United States, and Zipf et al. and Davis et al.10,11 simulated the shock wave propagation characteristics of gas explosion in parallel roadways and shock wave propagation law to the adjacent coal working face during the gas explosion in the heading face. Lin et al.12−15 studied the influence of pipeline bifurcation and bend on the propagation characteristics of gas explosion. Qiu et al.16 used the k-ε turbulence model and laminar flow rate/vortex dissipation combustion model to simulate the propagation law of shock wave in a bent pipeline, bifurcated roadway, and roadway with an abrupt cross section. Meng et al.17 used the RNG k-ε turbulence model and EDM combustion model to simulate and analyze the influence of obstacles in a large-scale ventilation pipe network on the shock wave propagation characteristic of gas explosion.
The actual mine roadway layout is complicated, and accurately predicting the propagation law of shock wave in coal mine scale gas explosion can reduce the economic loss and casualties caused by coal mine gas explosion. However, most of the current research results, whether experimental research or numerical simulation, focus on the research of characteristics and the shock wave propagation law of gas explosion in small-sized pipelines/local roadways in the laboratory and fail to objectively and quantitatively reflect the shock wave propagation law of gas explosion in the real mine scale; the existing experimental research on gas explosion in the mine scale is limited by risk and cost. The methane-air premixed volume is small, and the roadway configuration and sensor arrangement are simple, which is not enough to fully reflect the shock wave propagation law of gas explosion in the mine scale. In this paper, the numerical simulation method of shock wave propagation of gas explosion in the roadway of the site size and scale was studied, and the research results were applied to Yangchangwan No. 2 Mine. The law of the influence of shock wave on the overpressure close to the working face in gas explosion of different volumes was studied. The research results play a guiding role in the design of mine roadways and the accurate study of shock wave propagation law.

2. MATERIALS AND METHODS

2.1. Experiments. The gas explosion experiment in the turning pipeline was carried out by Dr. Jia Zhiwei. The pipe size and monitoring point location in the explosion test are shown in Figure 1. The pipe sections were all 0.08 m × 0.08 m, the straight pipe length was 19.2 m, and the vertical pipe length was 5 m. Two measuring points were set up in the experiment. Measuring point 1, being 19 m away from the leftmost end, was located on the central line of the horizontal pipeline; measuring point 2, 1 m away from the vertical pipeline, was located on the central line of the vertical pipeline.

When the gas accumulation lengths are 4.0, 5.5, and 7.0 m (the pipeline angle is 90°), the peak values of shock wave overpressure at monitoring points 1 and 2 are shown in Table 1.

### Table 1. Experimental Test Results

| Gas accumulation length/m | Peak overpressure of point 1/kPa | Peak overpressure of point 2/kPa |
|---------------------------|---------------------------------|---------------------------------|
| 4.0                       | 348.53                          | 264.70                          |
| 5.5                       | 461.53                          | 295.70                          |
| 7.0                       | 635.07                          | 363.97                          |

2.2. Mathematical Equation and Verification. By comparing the simulation results of different models with the experimental results in refs 19 and 20, the use of the LES turbulence model and eddy-dissipation EDM model as the mathematical models of shock wave propagation of gas explosion was determined, as shown in formulas 1–4. A simple algorithm was used for iterative solution, with the iteration step of 0.001 s.

\[
R_{ji} = -\min\left( |R_{ij}|, |R_{ji}| \right) \tag{1}
\]

\[
R_{ij} = v_{ij}M_{ai}A\rho_{sgs}\tau_{sgs}^{-1} \min \left( \frac{Y_{ij}}{v_{ij}M_{ai}} \right) \tag{2}
\]

\[
R_{ij} = v_{ij}M_{ai}A\rho_{sgs}^{-1} \sum_{i} \frac{Y_{ij}}{v_{ij}M_{ai}} \tag{3}
\]

\[
\tau_{sgs}^{-1} = \sqrt{2S_{ij}S_{ji}} \tag{4}
\]

where \( Y_{ij} \) is the mass fraction of any production species, \( Y_{ij} \) is the mass fraction of a particular reactant, \( A \) and \( B \) are empirical constants equal to 4.0 and 0.5, respectively, \( \tau_{sgs}^{-1} \) is the subgrid-scale mixing rate, and \( S_{ij} \) is the strain rate tensor.

To verify the correctness of the selected mathematical models, four commonly used models, namely, LES turbulence model + eddy-dissipation model (EDM), \( k-\varepsilon \) turbulence model + laminar flow/eddy-dissipation model, RNG \( k-\varepsilon \) + eddy-dissipation model (EDM), and \( k-\varepsilon \) turbulence model + eddy-dissipation conceptual (EDC) model, were used for numerical simulation. In the simulation of the four models, the grid spacing of the geometric model was set to 5 mm, the time step length was set to 0.001 s, and the maximum number of iterations was 30 steps. When the lengths of the gas filling area were 4.0, 5.5, and 7.0 m, the overpressure results measured at measuring points 1 and 2 by numerical simulation of four mathematical models were obtained, which were then compared with the test results of Jia Zhiwei’s gas explosion experiment, as shown in Figure 2.

It can be seen from Figure 2 that the numerical simulation results of the LES turbulence model and eddy-dissipation model (EDM) were closer to the experimental results, and the relative errors were less than 10%. Therefore, the established mathematical model of gas explosion can be used to simulate the propagation law of gas explosion shock wave.

2.3. Proposal of the Segmented Simulation Method of the Shock Wave Propagation Law of Gas Explosion. As...
shown in Figure 3, the whole process of gas-air premixed gas explosion from occurrence and development to propagation can be divided into four stages: ignition stage, combustion wave acceleration stage, shock wave formation stage, and shock wave attenuation stage.

Gas-air premixed gas will form spherical flame with the ignition source as the center after encountering the ignition source in the roadway, and the flame at this time is mainly laminar flame. When the spherical flame spreads to the wall, due to the obstruction of the wall, the burning state of the flame turns to turbulent flame and continuously radiates energy to the adjacent premixed gas; with the continuous development of turbulence, when the combustion flame develops to a distance of 5–10 times the roadway width, the flame speed increases rapidly. The combustion changes to explosion, and the shock wave is formed until the shock wave intensity and overpressure reach the maximum value when the premixed gas reactants react completely; the shock wave with the maximum intensity propagates forward in the roadway, and its intensity will be continuously attenuated due to the loss of the energy supply of the explosion until it disappears and the pressure returns to normal.

The first three stages, including the ignition stage, combustion wave acceleration stage, and shock wave formation stage, belong to the chemical reaction stage in the gas accumulation area, and the last stage belongs to the process of shock wave (high-pressure gas) propagation and attenuation in the roadway, which does not involve chemical reaction and is mainly controlled by aerodynamic equations. To realize the large-scale numerical simulation study of shock wave propagation of gas explosion, this paper proposed a segmented simulation method of shock wave propagation of gas explosion, as shown in Figure 4. It divides the whole ventilation network into several sections according to the four stages of gas explosion. That is, the first
three stages of gas explosion are divided into one section (shock wave formation stage), and the last stage of explosion is divided into several sections (shock wave attenuation stage) according to its length. The simulation process is as follows:

(1) Simulation of the shock wave formation section: As shown in Figure 4, select the area prone to gas accumulation to establish a geometric model according to the actual size and connection mode of the roadway, and complete the simulation of processes in the first section, including ignition of gas explosion, flame development, shock wave intensity formation, and reaching the maximum value. According to the actual roadway situation, select the appropriate physical model boundary as the dynamic boundary outlet and monitor its temperature, overpressure, total pressure, and other parameters. Use them as the dynamic boundary parameters of the pressure inlet in the second section.

(2) Simulation of the shock wave propagation section: As shown in Figure 4, divide the shock wave propagation section into several sections according to the research object on the basis of the actual size and connection mode of the roadway, and establish a simplified geometric model for numerical simulation. Set the inlet at the junction of the second section and the first section. Write the data monitored at the outlet of the first section as a specified file and import it into the inlet of the second section for numerical simulation.

The problems that need to be solved by the segmented simulation method of shock wave propagation of gas explosion are as follows: (1) Determination of dimensions of the geometric model: the authors pointed out in ref 20 that the gas explosion shock wave simulated by simplifying the whole mine ventilation roadway into a two-dimensional model has a high overpressure error; using the segmented simulation method, the gas explosion and shock wave formation area are simulated by a three-dimensional model, and the shock wave propagation area is simplified as two-dimensional model simulation, which can accurately reflect the overpressure change law in the process of shock wave propagation. (2) Reasonable simplification of the geometric model of a complex mine ventilation system: the actual mine ventilation system is complex, with many bifurcated roadways. To facilitate the study, it is necessary to reasonably simplify the ventilation system roadways and determine the reasonable length of the bifurcated roadway. (3) Determination of the dynamic boundary position and dynamic parameters of the roadway: how to determine the dynamic boundary position of each section and the dynamic boundary parameters of subsequent sections. These key issues need to be studied and determined.

### 3. RESULTS AND DISCUSSION

#### 3.1. Study on Related Problems of the Segmented Simulation Method of Shock Wave Propagation of Gas Explosion

3.1.1. Reasonable Simplification of the Bifurcated Roadway. To study the influence of the bifurcated roadway on explosion shock wave propagation of the main roadway and determine the reasonable length of the bifurcated roadway, a geometric model is established as shown in Figure 5. The main roadway (horizontal roadway) is 500 m long and 3 m wide. The lengths $L$ of the bifurcated roadway (inclined roadway) are 20, 50, 100, 200, 300, and 500 m, and its width is 3 m. Its included angles $\theta$ with the main roadway are $45^\circ$, $67.5^\circ$, $90^\circ$, and $112.5^\circ$. 

![Figure 5. Schematic diagram of the geometric model of the bifurcated roadway.](https://example.com/figure5)

![Figure 6. Variation curves of shock waves at the monitoring point under different bifurcated roadway lengths.](https://example.com/figure6)
The left side of the roadway is the premixed gas accumulation area, which is 50 m long. Intersection O is 100 m from the left wall of the main roadway, and the distance between intersection O and monitoring point P is 200 m. There is also a roadway on the right side (point B) of the main roadway, which is set as a pressure outlet. Considering that the actual roadway has a damper and seal, point A of the bifurcated roadway is set to open and close, respectively.

3.1.1.1. Determination of the Reasonable Length of the Bifurcated Roadway.

When the bifurcated roadway is closed and opened (the included angle of the roadway is 67.5°) respectively, the curve of overpressure at point P with different bifurcated roadway lengths is shown in Figure 6a,b.

Figure 6 shows the following: (1) When the bifurcated roadway is closed, the length of the bifurcated roadway has a certain influence on the explosion shock wave propagation of the main roadway. With the increase in the length of the bifurcated roadway, the peak overpressure of the shock wave at monitoring point P decreases sharply at first and then fluctuates in a small range. When the length of the bifurcated roadway is longer than 50 m, the peak overpressure at point P basically remains unchanged. When the length of the bifurcated roadway is 20 m, the second peak value of the overpressure curve at point P will exceed the first peak value under the influence of the shock wave reflection of the closed wall, and the peak value is higher than that at point P when the length of the bifurcated roadway is longer than 50 m. (2) The length of the bifurcated roadway has little influence on the explosion shock wave propagation in the main roadway when the bifurcated roadway is opened. When the bifurcated roadway keeps different lengths, the fluctuation amplitude of the peak overpressure at point P is very small (within 3%). This is mainly because when the shock wave passes through intersection O of the bifurcated roadway and the main roadway, the energy of the shock wave is divided into the bifurcated roadway according to a fixed proportion, and a stable shock wave is formed in the bifurcated roadway to propagate forward. When the shock wave reaches the top of the bifurcated roadway, the energy disappears directly from the pressure outlet, and no reflection will occur. Therefore, bifurcated roadways of different lengths have little influence on the peak overpressure of the shock wave. (3) When installing the damper or seal in the actual bifurcation roadway, the distance between the damper or seal and the bifurcation point of the roadway must be greater than 50 m. In the numerical simulation of shock wave propagation of gas explosion, the bifurcated roadway can be appropriately simplified, and the length of the bifurcated roadway is not less than 50 m to meet the simulation needs.

3.1.1.2. The Influence of the Angle of the Bifurcated Roadway on the Shock Wave Propagation of Explosion in Main Roadway.

When the bifurcated roadway is closed and
The following can be seen from Figure 7: (1) The included angle of the bifurcated roadway when it is closed or opened has a great influence on the explosion shock wave propagation of the main roadway. With the increase in the angle of the bifurcated roadway, the peak overpressure at monitoring point P increases at first and then decreases. The peak overpressure at point P under the bifurcated roadway included angles of 45° and 90° is the minimum and maximum, respectively. (2) In the design of the mine roadway, the angle of the bifurcated roadway should not be set to 90°. In the numerical simulation of shock wave propagation of gas explosion, the included angle of the bifurcated roadway in the geometric model should be set according to the actual roadway included angle.

3.1.3. Determination of Boundary Dynamic Parameters. The propagation of shock wave after the complete reaction of combustible gas can be regarded as the propagation of high-pressure gas along the roadway at an extremely high speed. The density of high-pressure gas changes with the change of temperature and pressure; gas pressure is composed of static pressure, dynamic pressure, and total pressure. Total pressure is equal to the sum of static pressure and dynamic pressure, and static pressure is overpressure. All of them jointly control the speed and pressure of gas flow. Therefore, the flow state of high-pressure gas can be determined by overpressure, total pressure, and temperature. The pressure inlet in Fluent can be set with three variable parameters, namely, total pressure, gauge pressure, and total temperature. To determine the boundary dynamic parameters, numerical simulations are carried out when different boundary dynamic parameters are taken, as shown in Table 2.

The geometric models with a section of 3 m × 3 m and a length of 250 m and the model with a width of 3 m and a length of 200 m are established, as shown in Figure 10. A is the monitoring point of dynamic boundary parameters. B is the pressure inlet of segmented simulation, and C is the pressure outlet. Parameters obtained by explosion simulation at upper point A are respectively introduced into the pressure inlet at point B according to different groups of pressure-inlet conditions, and monitoring points are set at different positions along the way to obtain the overpressure comparison diagram as shown in Figure 11.

It can be seen from Figure 11 that the simulation results obtained by assigning the three boundary dynamic parameters, including static pressure, total pressure, and temperature, at the same time are the closest to those obtained by direct simulation. The error of simulation results is extremely low, which also proves the feasibility of the segmented simulation method.

3.2. Field Application. 3.2.1. Shock Wave Propagation Law of Gas Explosion in the Heading Face of the II04909 Ventilation Roadway. Yangchangwan No. 2 Mine was formerly known as Ciyaobao No. 2 Mine. Yangchangwan No. 2 Mine is located in Ningdong town, Lingwu City, Ningxia Hui Autonomous Region, in the middle of Yangchangwan well field in the gravel well exploration area of Lingwu coal field, adjacent to Lingxin Coal Mine in the north, Yangchangwan No. 1 Mine in the south, and Meihuajing coal mine in the east. The average length of the well field is 7.5 km, the average inclined width is 2.6 km, and the well area is 19.5 km². The approved production capacity of Yangchangwan Coal Mine is 12 million
tons/year, of which the approved production capacity of the No. 2 well is 3 million tons/year.\textsuperscript{21,22} The No. 2 well is provided with the II04907 coal working face, the II04098 standby working face, and two heading faces including the II04909 ventilation roadway heading face and II04909 transporting roadway heading face, as shown in Figure 12.

To study the impact of shock wave on the heading face of the II04909 transporting roadway when the gas explosion occurs in the heading face of the II04909 ventilation roadway by segmented simulation, the main roadway of the mine ventilation system is simplified based on the conclusions of previous research, and the simplified roadway is shown in Figure 13. The whole geometric model is divided into two sections. The first section is near the heading face of the II04909 ventilation roadway (3D model), and other roadways are the second section (2D model). In the first section, the part from A to D is the gas explosion and shock wave-forming area. B and C are the transport gateway bypass of the II04909 working face, the transport gateway bypass of the II04907 working face, and the ventilation roadway bypass. Since their dampers are less than 50 m away from the intersection, they are modeled according to the actual length; D is the pressure outlet. Its distance from the intersection is 40 m, which is larger than the influence range of the outlet boundary. In the second section, the E-I roadway section is the main shock wave propagation roadway, and the horizontal roadway section F-H is the return air downhill of the second mining area. The distance between points F, H, and G

Figure 10. Determination of the physical model of the roadway with the dynamic boundary.

Figure 11. Comparison of simulated overpressures at different pressure inlets.

Figure 12. Ventilation system diagram of Yangchangwan Mine.
and the roadway intersection is reserved to be 20 m, and the points are all set as pressure outlets. The formation process of shock wave of gas explosion with 30 m gas accumulation in the head of the heading face of the II04909 ventilation roadway is shown in Figure 14. As can be seen from Figure 14, in the initial stage of gas explosion (t = 0.006 s), a high-pressure area is formed within a certain distance near the ignition source. With the continuous chemical reaction of gas explosion (t = 0.046 s), a stable planar high-pressure shock wave is gradually formed, and the pressure in the shock wave propagation area gradually rises; with the continuous forward movement of the shock wave, when t = 0.094 s, the shock wave surface propagates to the right pressure outlet to relieve pressure.

The peak overpressure at each point along the road during gas explosion at the heading face of the II04909 ventilation roadway under different gas accumulation lengths is shown in Figure 15. It can be seen from Figure 15 that the peak overpressure decreases the fastest from monitoring point 4 to monitoring point 5. This is because there are detours and bifurcations between the two points. When the shock wave passes through this area, it passes through the bifurcated roadway and is divided into three energy streams to spread to different roadways. Therefore, the peak overpressure decreases the fastest in this section.

The curves of overpressure, total pressure, and temperature change at point E obtained by dynamic monitoring are shown in Figure 16. It can be seen from Figure 16 that the peak temperature at point E is slightly behind the peak values of static pressure and total pressure, and there are two obvious peaks, indicating that the propagation speed of the flame surface is less than that of shock wave. The dynamic monitoring data are converted into a Fluent readable file and used as the inlet boundary dynamic parameters of the subsequent section.

3.2.2. Analysis of the Influence of Gas Explosion on the Heading Face of the II04909 Transporting Roadway. The law of shock wave propagation when explosion shock wave propagates to the heading face of the II04909 transporting roadway is shown in Figure 17. As can be seen from Figure 17, when t = 0.268 s, the shock wave passes through the intersection of the east side of the return air downhill of the second mining area and the heading face of the II04909 transporting roadway. When t = 0.427 s, the shock wave reaches the heading face of the transporting roadway. When t = 0.430 s, the shock wave reaches the heading face, and the reflection in the head is the strongest, with the maximum shock wave overpressure of 92 kPa. When t = 0.448 s, the reflected shock wave in the head of the heading face propagates back, forming a high-pressure area nearby. The peak overpressures at all points along the way of the II04909 transporting roadway under different gas accumulation lengths are shown in Figure 18.
It can be seen from Figure 18 that the peak overpressure decreases the most from monitoring point 7 to monitoring point 8, mainly because monitoring point 7 is located at the intersection of return air downhill of the second mining area and the shock wave is divided into three strands at the intersection, which propagate to the east and west sides of return air downhill of the second mining area and the I04098 standby working face, respectively. Among them, the shock wave propagating to the west side of return air downhill of the second mining area and the I04098 standby working face carries a lot of energy; the peak overpressure between monitoring point 8 and point 11 shows a slow downward trend, mainly because these monitoring points are located in the return air downhill of the second mining area and there is no bifurcation along the roadway. All the energy of shock wave propagates along the same roadway, so the peak overpressure decreases at a low rate; the overpressure peak at monitoring point 14 is greater than that at monitoring point 13. As monitoring point 14 is located at the head of the heading face of the transporting roadway in the II04909 working face, the shock wave will be reflected violently after reaching the wall here, and the overpressure peak will increase.

The relationship between the peak overpressure at point I of the heading face and the gas accumulation length in the heading face of the II04909 ventilation roadway is shown in Figure 19. As can be seen from Figure 19, the peak overpressure at point I in
the heading face of the transporting roadway increases with the increase in gas accumulation length in the heading face of the II04909 ventilation roadway, and the relationship between them obeys the logarithmic function, namely, \( y = -30.8 + 27.6 \ln(x + 3.6) \), \( R^2 = 0.978 \).

3.2.3. Analysis of the Influence of Gas Explosion on Shock Wave Propagation in the Standby Working Face. To study the influence of gas explosion shock wave in the heading face of the II04909 ventilation roadway on the II04098 standby working face by segmented simulation, some main roadways are simplified, and the simplified roadways are shown in Figure 20.

As shown in Figure 20, the study on the law of shock wave propagation in the II04098 standby working face is divided into two sections. The first section is near the heading face of the II04909 ventilation roadway; the follow-up main roadway E-J-K-L is the second section, in which J-K is the II04098 spare working face. E is the pressure inlet; F-G is the roadway of return air downhill of the II04098 standby working face on the upper and lower sides of the return air way of the II04098 standby working face. The length of the roadway is 20 m, and it is set as the pressure outlet. J and K are the upper corner and lower corner of the II04098 spare working face, respectively; the part in L 20 m from K is set as the pressure outlet.

The law of shock wave propagation near the upper corner of the II04098 spare working face (screenshot of the second section) obtained by segmented simulation is shown in Figure 21.

It can be seen from Figure 21 that when \( t = 0.383 \) s, the shock wave propagates to the upper corner intersection. Because of the existence of L-shaped roadway intersection, the pressure will be released first. When \( t = 0.386 \) s, the maximum overpressure of the shock wave is 100 kPa. The front of the shock wave will turn into an arc. With the propagation of the shock wave, a local overpressure area is formed at the outer corner of the L-shaped intersection. At this time, the maximum overpressure of the shock wave is 210 kPa. That is, due to reflection, the maximum overpressure rises to 2.1 times that when \( t = 0.386 \) s. When \( t = 0.392 \) s, the reflection of the shock wave forms a U-shaped high-pressure zone, followed by the shock wave overpressure oscillation. The shock wave fluctuates significantly. When \( t = 0.437 \) s, the shock wave forms a stable plane wave and propagates to the working face.

II04098 peak overpressures at various points along the way in the standby working face under different gas accumulation lengths are shown in Figure 22.

It can be seen from Figure 22 that when the shock wave propagates to the II04098 standby working face, the overpressure attenuates rapidly, and the attenuation speed gradually slows down. The decline rate is the highest between point 6 and point 7, because there is an intersection of return air downhill of the second mining area between the two points, the shock wave is divided into three strands at the intersection, and a large amount of energy of the shock wave propagates separately; when the gas accumulation length is more than 10 m, the shock wave is...
reflected violently at the upper corner (at point 10) of the II04098 standby working face. The overpressure peak rises obviously, even exceeding the overpressure at point 9.

The relationship between the peak overpressure of the shock wave at the upper corner (point 10) of the II04098 standby working face and the gas accumulation length at the heading face of the II04909 ventilation roadway is shown in Figure 23. It can be seen from Figure 23 that the peak overpressure of the upper corner shock wave increases with the increase in gas accumulation length in the heading face of the II04909 ventilation roadway, and the relationship between them follows the logarithmic function, namely, \( y = a - b \ln(x + c) \), \( R^2 = 0.979 \).

4. CONCLUSIONS

(1) A segmented simulation method of shock wave propagation of gas explosion in the mine scale is proposed. The propagation process of mine gas explosion shock wave is divided into several sections, such as the gas explosion shock wave-forming section and shock wave propagation section. The pressure and other parameters near the outlet boundary of the previous section are monitored and are taken as the dynamic parameters of the inlet boundary of the subsequent adjacent section, and the gas explosion and shock wave propagation processes of each section are simulated successively by relay.

(2) The key problems related to the segmented simulation method of gas explosion are determined. The influence of different included angles and bifurcated roadway lengths on the shock wave of main roadways is analyzed to determine the reasonable reserved length of the bifurcated roadway (not less than 50 m), and the reasonable simplification of the geometric model of the complex ventilation system is realized. The monitoring position of dynamic parameters (about 10 m from the outlet boundary) and the dynamic parameters to be monitored (total pressure, static pressure, and temperature) are determined, and the feasibility of the segmented simulation method is proved.

(3) Numerical analysis of the influence of shock wave on the adjacent working face when gas explosion occurs in the ventilation roadway heading face of No. 2 well II04909 in Yangchangwan is performed. When the gas explosion occurs in the heading face of the II04909 ventilation roadway, the shock wave will cause great damage to the adjacent roadway, and the shock wave will propagate to the head of the heading face of the transporting roadway and the upper corner of the standby working face, causing the local overpressure to rise obviously. The peak overpressure and gas accumulation length conform to the logarithmic function relationship. The research results have a guiding significance for the mine roadway design and reduction of asset losses and casualties caused by gas explosion.

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## Notes

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