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Study on the coal seam dynamic damage evolution during coal seam pulse water infusion

There is a strong fluid-solid coupling effect during the process of coal seam pulse water infusion. Based on the basic principle of liquid-solid coupling, the dynamic damage evolution rule during coal seam pulse water infusion is simulated through secondary development of ABAQUS software. During this process the mathematical model of the strain accumulation model due to the periodic changes of pulse water pressure is embedded in SOIL module of ABAQUS software discussed in this paper, in order to obtain the dynamic damage evolution rule of coal seam around the pulse water infusion hole. It provides a new quantitative method of determining coal seam pulse water infusion parameters and location. The law of different parameters of pulse water infusion on the dynamic damage evolution of coal around the infusion hole is gotten. Numerical simulation results show that, during the process of coal seam high pressure pulse water infusion, the stress field and flow field are mutual influence and mutual restriction. The coupling of the stress and flow field have impact on the physical and mechanical properties of coal in front of the working face, these factors promote each other and prevent coal and gas outburst effectively. The coal damage quantity increases significantly with the water infusion time prolonging under constant water infusion pressure and frequency. The coal damage quantity increases significantly with the water infusion pressure increasing under constant water infusion time and frequency. The coal damage quantity increases significantly with the water infusion frequency increasing under constant water infusion pressure and time. So the pulse water infusion time needs to ensure a better effect of preventing coal and gas outburst is gotten. Meanwhile the pulse water infusion pressure needs to improve under the existing technical conditions. The frequency of pulse water infusion needs to improve under the existing technical conditions. This research results contribute to obtain accurate dynamic distribution law of damage fields around water infusion holes. It provides theoretical basis for optimizing pulse water infusion in technological parameters design and raising water infusion effect.

Keywords: *Coal seam water infusion, pulse, liquid-solid coupling, dynamic damage evolution, flow.*

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1. Introduction

Coal seam water infusion is one of the most important measures to prevent coal and gas outbursts, which can also reduce dust and coal dust explosion [1-3]. High pressure coal seam water infusion is injecting high pressure water to coal seam in front of working face through drilling, in order to change the mechanical properties, the seepage properties and stress state of coal seam, a corresponding change in the coal and gas outburst excitation and occurrence conditions, and thus to prevent or decrease coal and gas outburst. The periodic changes of high pressure water is used during water infusion for coal seam high pressure pulse in water infusion, and water is injected in maximum limit to different fracture and pore of coal seam, so the fracture, pore and permeability coefficient around infusion hole of coal seam are improved. This technology mixing water infusion, hydraulic fracturing and hydraulic extrusion in one, more effectively reduce outburst dangerous, relatively to static pressure coal seam water infusion has the following features: permeability coefficient around infusion hole of coal seam is improved through the periodic changes of high pressure water, gas of coal containing gas is pre-excreted, wetted radius of coal seam water infusion is increased, the physical and mechanical properties of coal seam is changed also, effect of coal seam water infusion preventing coal and gas outburst is greatly improved.

In the process of coal seam pulse water infusion, coal seam around the water infusion hole is loaded by the periodic change in water pressure, which caused a damage of cumulative effect of the coal body around water infusion borehole, with increasing damage accumulation of coal, the permeability coefficient around coal drilling also changed. Flow field and stress field are mutual influence and mutual restriction in the process of high pressure pulse water infusion. In the high stress state, without regard to change of the permeability coefficient will bring greater error, especially for high pressure pulse water infusion process, stress and flow fields have strong coupling effects, and the coal damage has increase during the water infusion process, the permeability coefficient of coal changed dynamically, so the coupling effects of stress field and flow field must be considered in the process of coal seam of high pressure pulse water infusion [4-6].

There are mutual influences and mutual restrictions between the flow field and stress field in the process of high pressure pulse water infusion. The fluid-solid coupling law of water and coal is analyzed using the ABAQUS software during the coal seam pulse water infusion. The research result of coupling effect of pulse water pressure field and stress field has important theoretical value and practical significance on revealing increasing permeability mechanism and enhancing the effectiveness of water infusion technological parameters as well as field application.

2. Numerical simulation

In the process of coal seam pulse water infusion, on the one hand, the coal seam around water infusion holes have different degrees of damage is caused by permeate volume strength, on the other hand, the damage is caused by pulse water pressure, which will cause a certain degree of accumulation damage effect [7].

In the process of coal seam pulse water infusion, liquid-solid coupling effect exists in coal seam between the stress field and seepage field. Based on the basic principle of liquid-solid coupling, the dynamic liquid-solid coupling of stress and seepage field during coal seam high pressure pulse water infusion is simulated through secondary development of ABAQUS software, during this process the mathematical model of the strain accumulation model due to the periodic changes of pulse water pressure is embedded in SOIL module of ABAQUS software[8,9]. The law of different parameters of high pressure pulse water infusion on the damage of coal around infusion hole is gotten.

2.1 Dimensional simulation model

The dimensional simulation model with 1m cross section around water infusion hole is used in this paper, the model length is 2 m, the width is 2 m, and the diameter of water infusion hole is 0.075m. Considering the problem as a plane strain problem, plane strain coupling unit (CPE4PH) is used as the unit type in ABAQUS. Numerical simulation model and the grid division are shown in Fig.1.

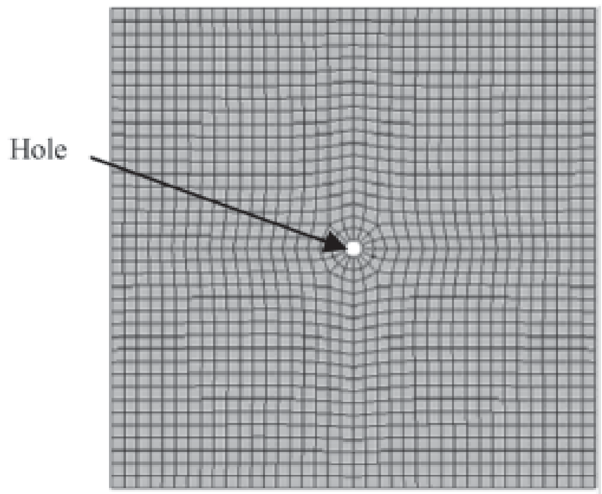


Fig.1 Dimensional simulation model

(1) Damage accumulation law of coal under cyclic loading

The plastic hysteretic loop of coal body around water infusion hole will appear in each infusion cycle during coal seam pulse water infusion. The hysteresis loop area in the early coal seam pulse water infusion displayed is larger, with the increasing of pulse time, the hysteresis loop area produced by pulse water pressure will become smaller. The plastic strain will be generated by pulse water pressure, so the plastic strain change law reflected the damage evolution of coal body.

The predecessors have done many researches about materials damage evolution under periodic load. According to the three stages damage evolution law of material, Xiao Jianqing [10] put forward axial strain accumulation inverted S model. This model can reflect the materials damage evolution law, the parameters are easily determined and engineering applications is convenient. Non-linear axial strain damage accumulation model shown in Eq.(1) is used in this simulation.

$$\begin{cases} \varepsilon = \alpha\left(\dfrac{-\beta}{n/N-\beta}-1\right)^{1/p} \cdot \varepsilon' \\ \beta = 1+\left(\dfrac{1}{\alpha}\right)^{-p} \end{cases} \quad \dots \quad (1)$$

where, p is instability speed factor, the value range is [2,8]. α is the instability of the scaling factor, the value range is [0,1]. β is instability factor,and β is non-linear function of p and α. ε is axial strain, ε' is axial strain extreme of coal under periodic load.

Fig.2 is curve of ultimate strain-relative cycle at different α of Baodian mine coal sample cycle load experimental data by Yang Yongjie[11] when the p =8, ε' =1.1%. It can be seen from Fig.2, the acceleration section proportion of curve ultimate strain-relative cycle is mainly influences by the parameter α. When α = 0.3, the acceleration section proportion of curve ultimate strain-relative cycle is smaller than α = 0.8.m. so the greater the value of α, the acceleration section proportion is larger. According to the Baodian mine coal mine sample experimental data fitting, the suitable value of f¿ is 0.5, it is the reference value in the process of this numerical simulation.

Fig.3 is curve of ultimate strain-relative cycle at different

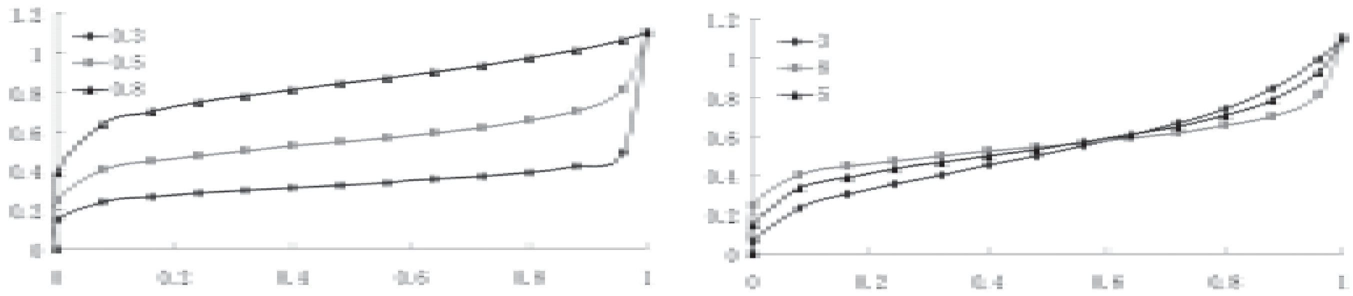
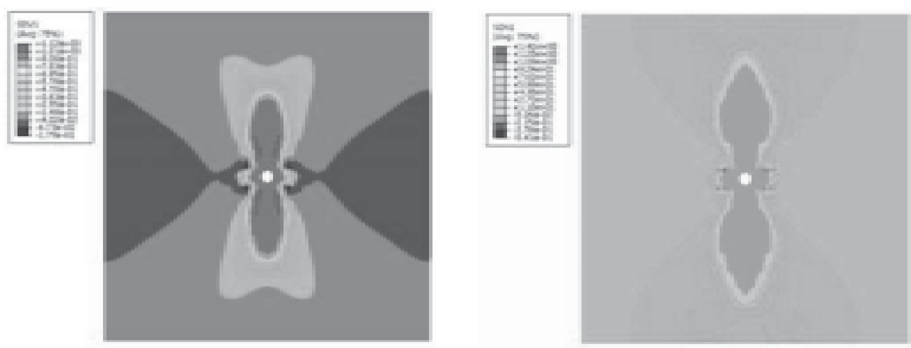


Fig.2 Curve of ultimate strain-relative cycle at different α (p = 8)

(1)1min (2)3min

Fig.3 Curve of ultimate strain-relative cycle at different p (α = 0.5)



(3)5min (4)10min

Fig.4 Damage distribution at different time

p of Baodian mine coal sample cycle load experimental data by Yang Yongjie[11] when the α = 0.5, ε' = 1.1%. It can be seen from Fig.3, the convergence rate of curve of ultimate strain-relative cycle is mainly influenced by the parameter p. According to the Baodian mine coal sample experimental data fitting, the suitable value of p is 8, it is the reference value in the process of this numerical simulation.

(2) Boundary conditions

The main parameters need to be set in numerical simulation process, the bulk density of coal γ=14000 N/m^3, elastic modulus E=1 GPa, Poisson's ratio ν =0.36, cohesive strength c=2 Mpa, friction angle ϕ=25º. The upper and lower boundary of Fig.1 is constrained, the entire boundary are set as constant pressure permeable boundary. The Mohr-Coulomb criterion is used as the coal yield condition. The seam pulse water infusion is simulated by SFLOW command and the pulse water pressure amplitude and frequency is defined by FLOW subroutine.

2.2 Results and analysis

(1)The impact of infusion time on coal damage quantity

The pulse water infusion frequency is 2t/min, maximum water pressure is 9Mpa, and the amplitude value is 3 Mpa in this numerical simulation.

Fig.4 is dynamic damage evolution distribution at different time around water infusion hole are respectively 1min, 3min, 5min and 10min. It can be seen from it, with the increasing of water infusion time, the damage quantity around water infusion hole exhibited dynamically increased change law, and continued to radiation spread around the infusion hole.

Fig.5 is curve of water infusion time - dynamic damage evolution at two positions with 0.2 m and 0.5 m at the bottom of water hole, it can be seen with the infusion increased time, damage quantity displayed in non-linear increasing trend, the reason is coal seam crack caused by pulse water pressure which continued to expand. The greater change in coal damage quantity, the larger water infusion impact radius can be gotten.

(2) The impact of water pressure on coal damage quantity

The amplitude value is 3 Mpa, pulse water infusion frequency is 2 t/min, and the water infusion pressures are respectively 8 Mpa, 10 Mpa and 12 Mpa in this numerical simulation.

Fig.6 is the curve of time-damage quantity at different pressure when the water infusion pressures are respectively 8 Mpa, 10 Mpa and12 Mpa at the bottom of water hole 0.5 m

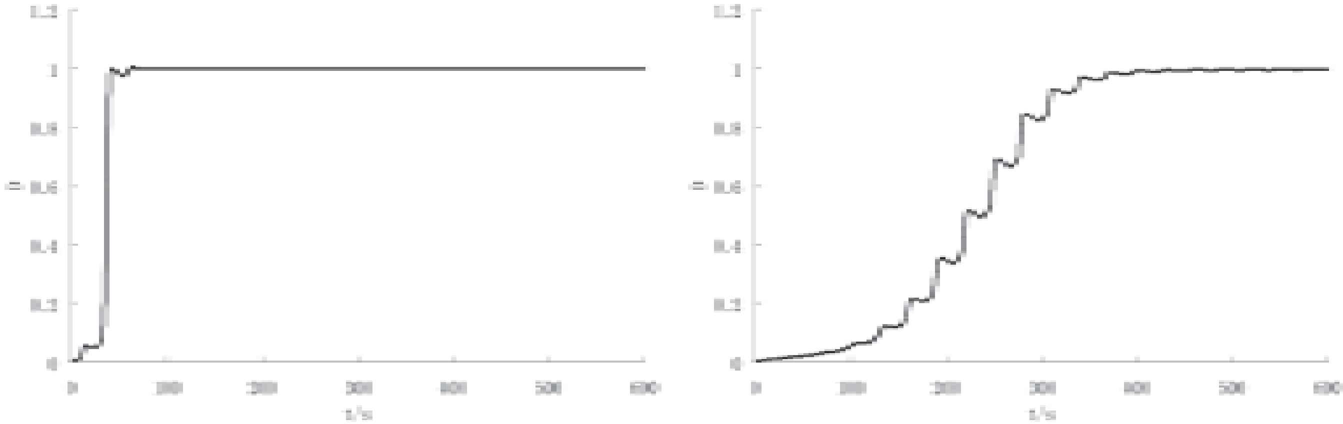


Fig.5 Curve of time-dynamic damage evolution

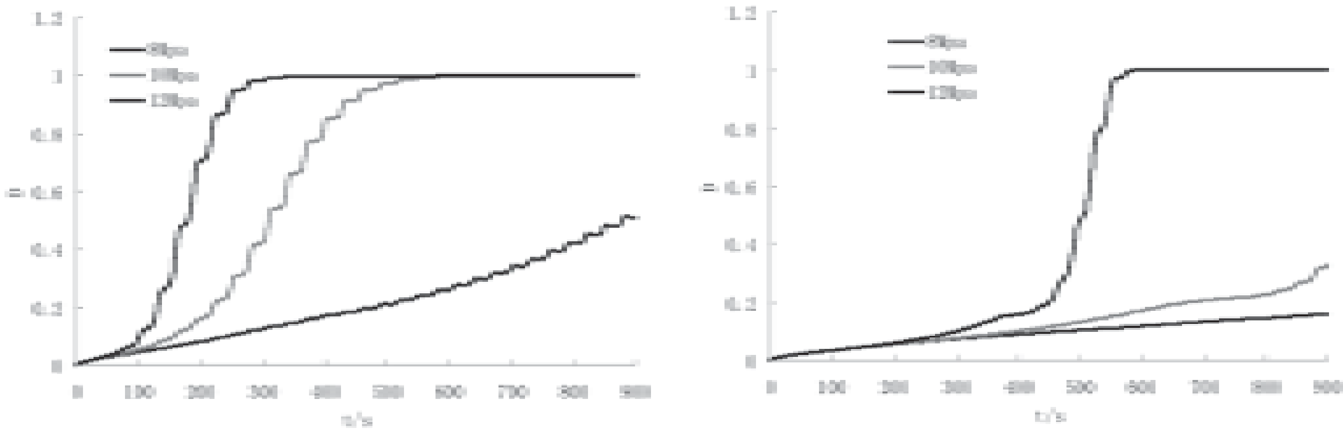


Fig.6 Curve of time-damage at different pressure

and 0.95 m. It can be seen that when other conditions are constant, under different pulse water pressure, the coal damage quantity with time have uniform change rule. The damage quantity increases with the infusion time, the coal damage quantity in initial stage changes greatly. After a certain time of water infusion, damage quantity change rate becomes slowly. Lastly the coal damage quantity increases to a certain degree, the damage quantity increases rapidly, and it tends to stable. Overall, the evolution of coal damage quantity under high pressure pulse water infusion shows typical non-linear three sections development law. The initial damage quantity changes stage, the damage quantity is in constant change stage and accelerated damage stage, because of the change of coal damage quantity is mainly due to the damage of coal, so coal damage quantity change law are consistent with variation of three stage coal damage. The proportion of three stages is related to the coal seam water infusion parameters, physical and mechanical properties of the coal itself, as well as the stress state of coal. When coal seam infusion is in specific mine, physical and mechanical properties of coal body itself and the stress state is certain, then by changing the parameters of coal seam high pressure pulse water infusion can effectively improve the effect of coal seam water infusion efficiency [12,13].

Fig.7 is curve of location distance of water infusion hole dynamic damage evolution at two water infusion time with 5min and 15min at the bottom of water infusion hole. It can be seen from Fig.7 that, other conditions remain constant, on the same water infusion time, the higher water pressure, the greater coal damage quantity can be gotten. It shows water infusion pressure has significant effects on the coal seam damage quantity.

The results show that, the damage quantity of coal increase significantly with the water infusion pressure improving under constant water infusion time and frequency. So the pulse water infusion pressure needs to improve under the existing technical conditions and not cause big coal fissure in order to get a better effect of preventing coal and gas outburst.

(3) The impact of pulse frequency on coal damage quantity

The pulse water infusion pressure amplitude value is 3 Mpa, pulse water infusion pressure is 10 Mpa, frequency are respectively 1 t/min, 2 t/min and 6 t/min in this numerical simulation. The influence of pulse frequency on coal seam damage quantity is analyzed.

Fig.8 is the curve of time-damage quantity at different frequency when the infusion frequencies are respectively 1 t/

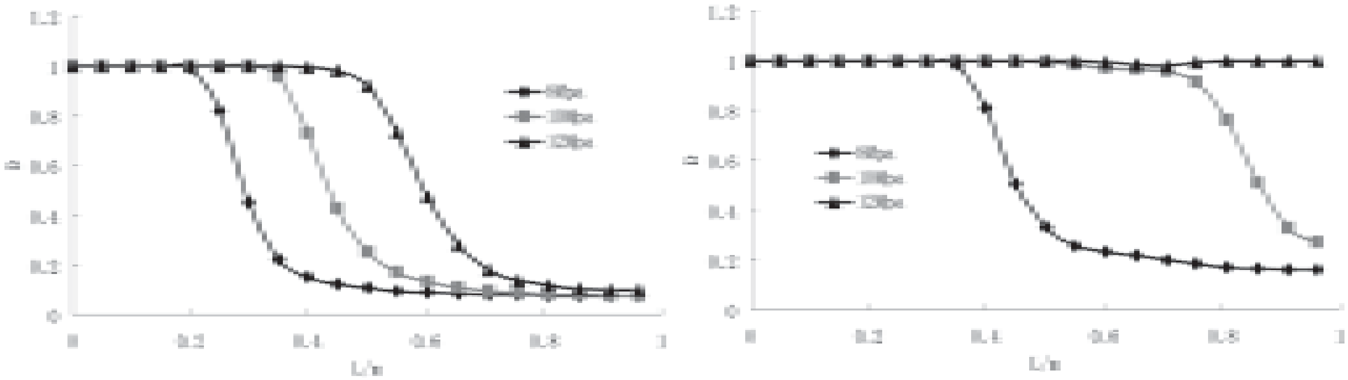


Fig.7 Curve of length-damage at different pressure

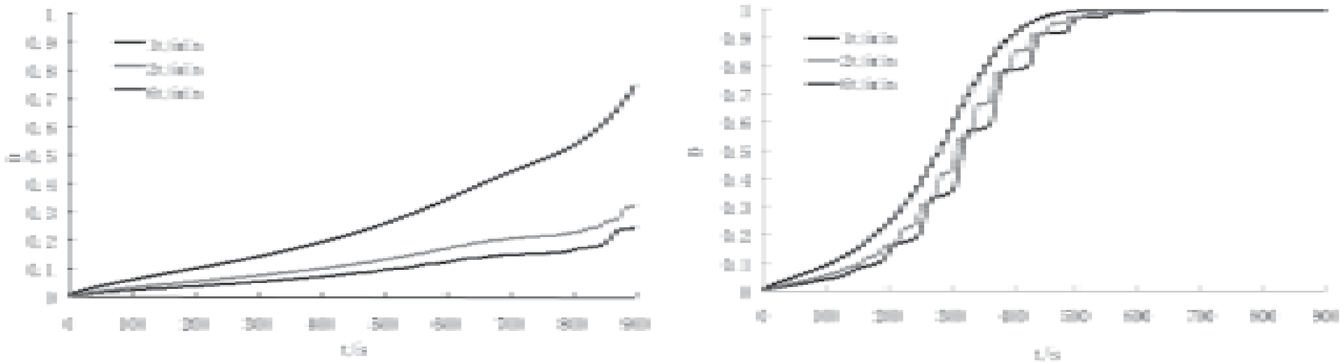


Fig.8 Curve of time-damage at different frequency

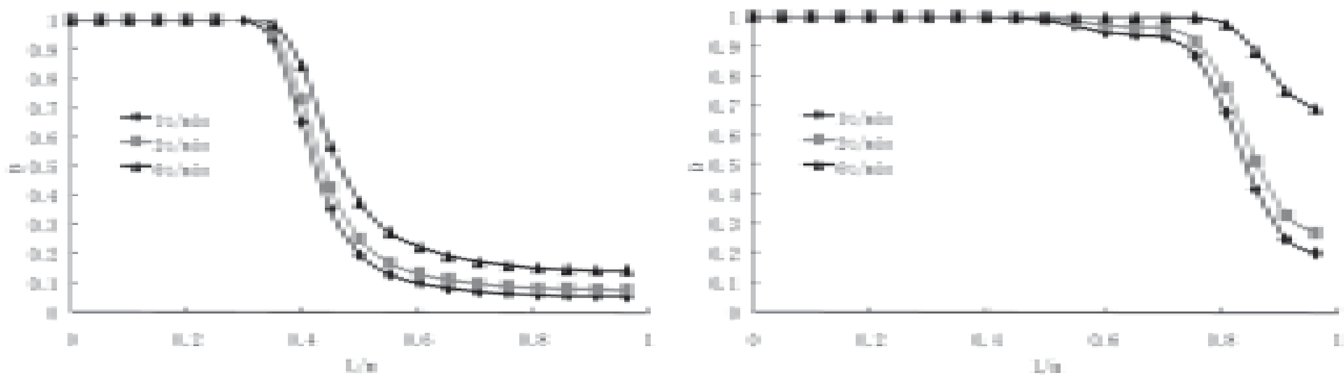


Fig.9 Curve of length-damage at different frequency

min, 2 t/min and 6 t/min at the bottom of water hole 0.5 m and 0.95 m. It can be seen that when other conditions are constant, under different pulse water infusion frequency, the coal damage quantity change law with water infusion time have same change rule between Fig.8 and Fig.6. It can be seen from Fig.8 that, other conditions remain constant, on the same water infusion time, the bigger water frequency; the greater coal damage quantity can be gotten. It shows infusion frequency has significant effects on the damage quantity. The frequency of high pressure pulse water infusion needs to improve under the existing technical conditions, in order to get a better effect of preventing coal and gas outburst.

Fig.9 is curve of location distance of water infusion hole dynamic damage evolution at two infusion frequency are respectively 1 t/min, 2 t/min and 6 t/min when pulse water infusion time are respectively 5min and 15min. It can be seen that when other conditions are constant, under different pulse water infusion frequency, the coal damage quantity change law with pulse water infusion frequency have same change rule between Fig.9 and Fig.7.

It can be seen from Fig.9 that, other conditions remain constant, on the same location distance of water infusion hole, the higher infusion pressures frequency, the greater coal damage quantity can be gotten. It shows water infusion frequency has significant effects on the coal seam damage quantity. That is to say the bigger the water infusion frequency is, it can effectively increase the influence of coal seam water infusion, and the better effect of pulse water infusion can be gotten [14-16].

3. Conclusions

Based on the basic principle of liquid-solid coupling, the dynamic damage evolution rule during coal seam pulse water infusion is simulated through secondary development of ABAQUS software, during this process the mathematical model of the strain accumulation model due to the periodic changes of pulse water pressure is embedded in SOIL module of ABAQUS software in this paper, in order to obtain the dynamic damage evolution rule of coal seam around the pulse water infusion hole. It provides a new quantitative method of determining coal seam pulse water infusion parameters and location. The law of different parameters of pulse water infusion on the dynamic damage evolution of coal around the water infusion hole is gotten. This research results contribute to obtain accurate dynamic distribution law of damage fields around water infusion holes. It provides theoretical basis for optimizing pulse water infusion technological parameters design and raising water infusion effect.

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