STUDY ON THE DYNAMIC DAMAGE EVOLUTION DURING COAL SEAM PULSE WATER INFUSION

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Abstract:

Dynamic damage evolution during coal seam pulse water infusion is simulated through secondary development of ABAQUS software in this paper in order to obtain the rule of dynamic damage evolution 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. Therefore, the effect of different parameters of pulse water infusion on dynamic damage evolution of coal around the infusion hole was analyzed and numerical simulation results show that the quantity of coal damage is significantly increased by increasing water infusion frequency under constant water infusion pressure and time rate. Based on these research results, the rule of accurate dynamic damage field distribution around water infusion holes was obtained. It provides, thus, a theoretical basis for both optimizing technological pulse water infusion parameter design and raising water infusion effect.

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, to provoke 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 the process of coal seam high pressure pulse water infusion, and water is injected in the coal to its maximum limit, to different fracture and pore of coal seam so that the fracture, pore and permeability coefficient around infusion hole of coal seam are improved. This technology of mixing water infusion, hydraulic fracturing and hydraulic extrusion in one can reduce the danger of outburst flooding effectively. With reference to this, static pressure coal seam water infusion has the following features: permeability coefficient around the infusion hole of coal seam is improved through periodic changes of high pressure water. So, 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 also changed, and the effect of coal seam

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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 was loaded by periodic changing of water pressure, which caused a damage cumulative effect of the coal body around water infusion borehole, so that by increasing damage accumulation of coal, the permeability coefficient around coal drilling also changed. Flow field and stress field are mutually influenced and there is also a mutual restriction in the process of high pressure pulse water infusion. Without regard to the change of its permeability, its coefficient yields greater errors when it is in the state of high stress, especially in the process of high pressure pulse water infusion; since stress and flow fields have strong coupling effects, the coal damage increases during the water infusion process, and the permeability coefficient of coal changes dynamically. So, the coupling effects of stress field and flow field must be considered in the process of coal seam high pressure pulse water infusion [4-6]. During this process, the fluid-solid coupling law of water and coal is analyzed using ABAQUS software. The research result of coupling effect of pulse water pressure field and stress field has an important theoretical value and practical significance in revealing the mechanism of increasing permeability and enhancing the effectiveness of both water infusion parameters and their field application.

2 Numerical simulation

In the process of coal seam pulse water infusion, the coal seam around water infusion holes has different damage degrees because on the one hand, damage is caused by permeate volume stress, and on the other, it by pulse water pressure which also causes 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 and due to the periodic changes of pulse water pressure, the mathematical model of the strain accumulation model is embedded in the SOIL module of ABAQUS software [8,9,17]. In this way, the /effect/rule of different parameters of high pressure pulse water infusion on the damage of coal around infusion hole is gotten.

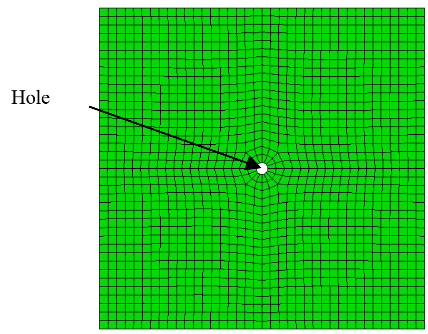


Figure 1. The one - dimensional simulation model.

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

2.1 The rule of damage accumulation with respect to coal under cyclic loading

The plastic hysteretic loop of coal body around water infusion hole will appear in each infusion cycle during the process of coal seam pulse water infusion. During an early stage of coal seam pulse water infusion, the hysteresis loop area is larger, and by increasing pulse rate, the hysteresis loop area produced by pulse water pressure becomes smaller. The plastic strain will be generated by pulse water pressure so that the rule of plastic strain change reflected damage evolution of the coal body. The predecessors have done a lot of research into materials damage evolution under periodic loading. 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 rule of materials damage evolution provided the parameters are easily determined and engineering applications are convenient. Nonlinear axial strain damage accumulation model shown in Eq. (1) is used in this simulation, where p is instability speed factor, the value range is [2,8]. α represents the instability of the scaling factor, and the value range is [0,1]. β is instability factor, and β is nonlinear function of p and α. ε is axial strain, ε' is axial strain extreme of coal under periodic load.

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

Fig. 2 shows the curve of ultimate strain-relative cycle at different α of Baodian mine coal sample cycle load experimental data by Yang Yongjie [11] when the $p = 8$, $\varepsilon' = 1.1\%$. It can be seen from Figure 2 that the acceleration section proportion of curve ultimate strain-relative cycle is mainly influenced by the parameter α. When $\alpha = 0.3$, the acceleration section proportion of the curve representing the ultimate strain-relative cycle is smaller than $\alpha = 0.8$ m. So, the greater the value of α, the larger the acceleration section proportion. According to the Baodian mine coal mine sample experimental data fitting, the suitable value of α is 0.5, i.e., it is the reference value in the process of this numerical simulation.

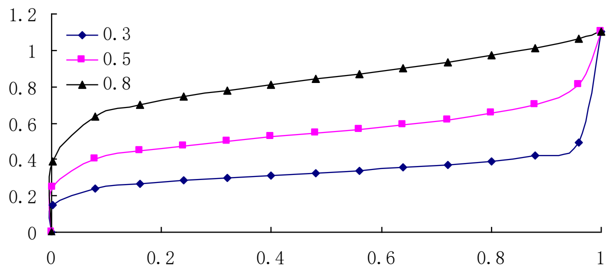


Figure 2. The curve of ultimate strain-relative cycle at different α (p = 8).

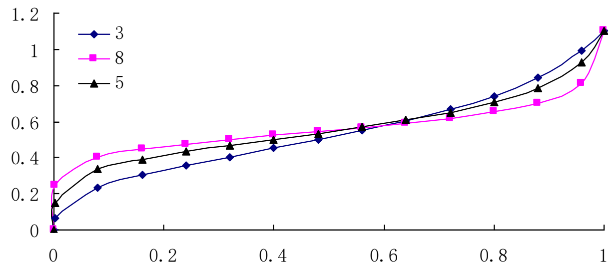


Figure 3. The curve of ultimate strain-relative cycle at different p (α = 0.5).

Figure 3 is a curve of ultimate strain-relative cycle at different p of Baodian mine coal sample cycle load experimental data by Yang Yongjie [11] when the $\alpha = 0.5$, $\varepsilon' = 1.1\%$. It can be seen from Fig.3 that 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, i.e., it is the reference value in the process of this numerical simulation.

2.2 Boundary conditions

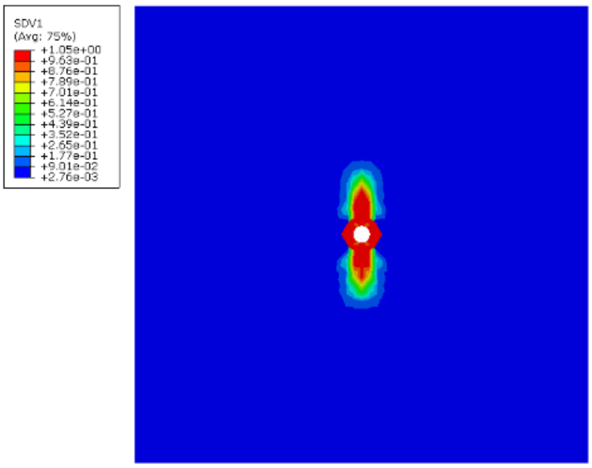
The main parameters need to be set in the process of numerical simulation: the bulk density of coal $\gamma = 14000$ N/m^3, elastic modulus $E = 1$ GPa, Poisson's ratio $v = 0.36$, cohesive strength $c = 2$MPa, friction angle $\varphi = 25°$. The upper and lower boundary of Fig.1 is constrained, and the entire boundary is 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.

3 Results and discussion

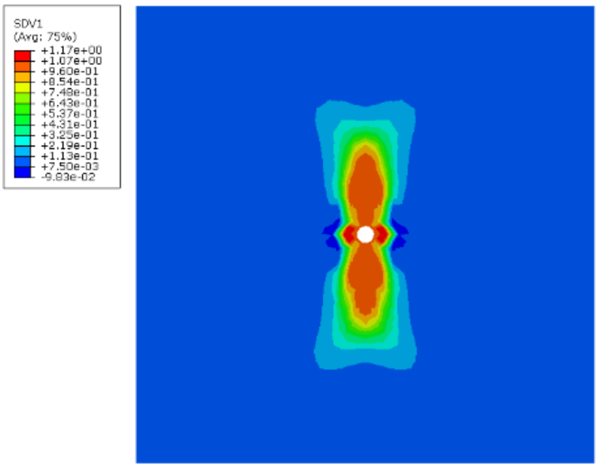
3.1 The impact of infusion time on coal damage quantity

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

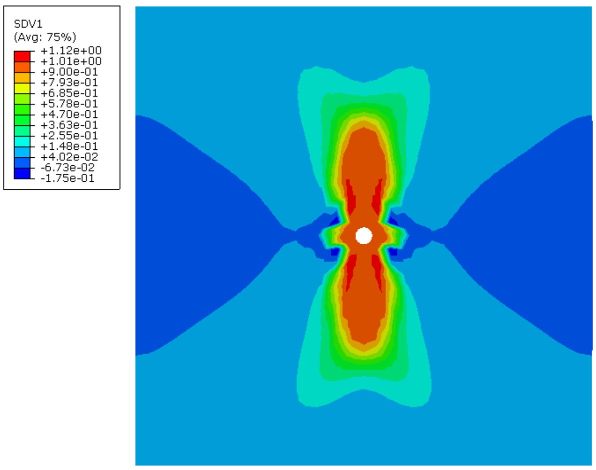
Figure 4 shows dynamic damage evolution distribution at different time rates around water infusion holes, which are of 1 min, 3 min, 5 min and 10 min, respectively. It can be seen from it that with the increase in water infusion rate, the damage quantity around the water infusion hole exhibited a dynamically increased law of change, and continued generating radiation spread around the infusion hole. Figure5 presents a 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 that with an increase in infusion time rates damage quantity displayed a nonlinear increasing trend, the reason of which is coal seam crack caused by pulse water pressure which continued to expand. The greater the change in coal damage quantity, the larger the water infusion impact radius can be gotten.



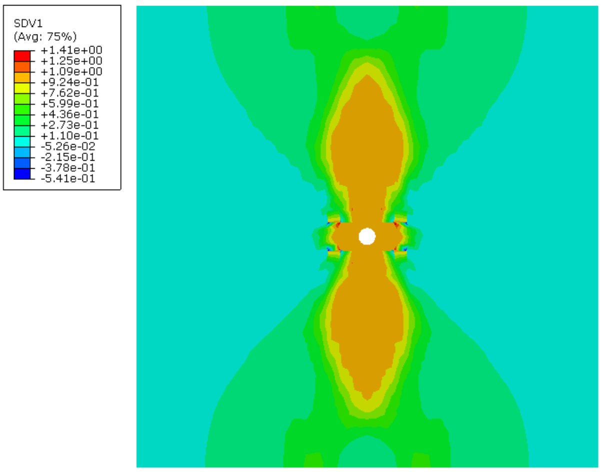
(1) 1min



(2) 3min

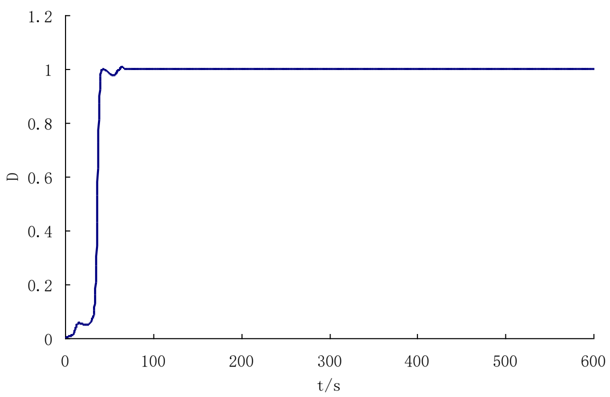


(3) 5 min

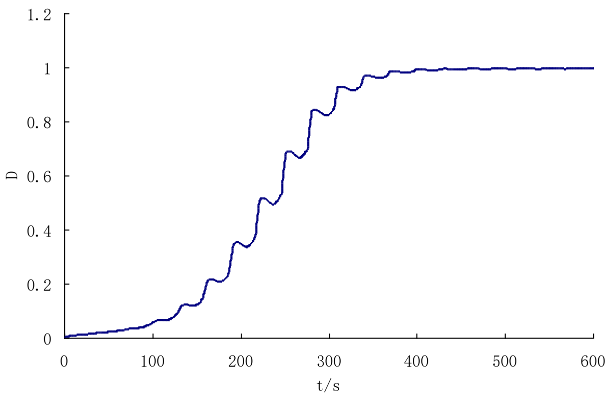


(4) 10 min

Figure 4. Damage distribution at different time rates.



(1) 0.2 m



(2) 0.5 m

Figure 5. Curve of time-dynamic damage evolution.

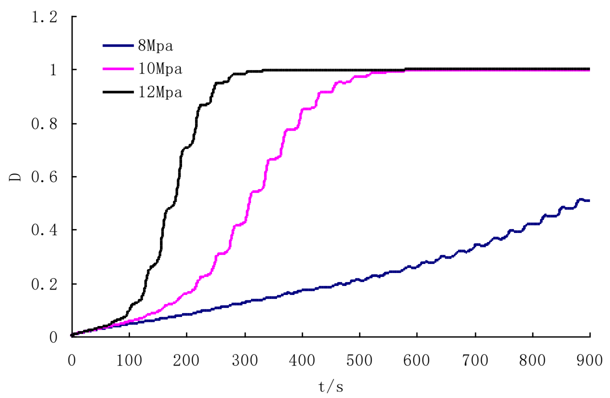
3.2 The impact of water pressure on coal damage quantity

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

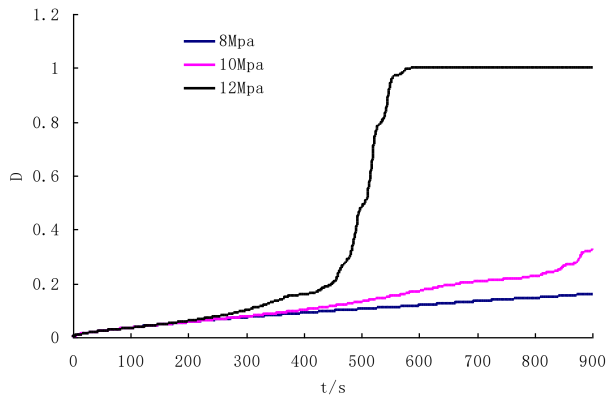
Figure 6 shows the curve of time-damage quantity at various pressures when the water infusion pressures at the bottom of the water hole of 0.5 m and 0.95 m. are 8 MPa, 10 MPa and12 MPa, respectively. It can be seen that when other conditions are constant, under different pulse water pressures, the coal damage quantity obtains with time uniform change. The damage quantity is increased with an increase in infusion rate, whereas the coal damage quantity changes greatly only in its initial stage. After a certain water infusion rate, damage quantity change rate becomes slow. Lastly, the coal damage quantity increases to a certain degree, the damage quantity increases rapidly, and it tends to become stable. Overall, the evolution of coal damage quantity under high pressure pulse water infusion shows the rule of a typical development of three nonlinear sections. The initial damage quantity change stage, the damage quantity constant change stage and accelerated damage stage, because the change of coal damage quantity is mainly due to the damage of coal, so the rule of coal damage quantity change is consistent with the 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 the coal body itself and the stress state are 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]. Figure 7 presents a curve of distance location of the water infusion hole, namely dynamic damage evolution at two water infusion time rates with 5min and 15min at the bottom of the water infusion hole. From Figure 7 it can be seen that other conditions remain constant, but at the same water infusion time rates, the higher the water pressure, the greater the coal damage quantity can be gotten. It shows that water infusion pressure has significant effects on the coal seam damage quantity.

The simulation results were compared with the similar coal and gas outburst and with coal seam experimental data obtained from field measurements.The measured wetted radius is 1.5 m and simulated wetted radius is greater than 1m. When comparing, it may be observed that the relative error between the experimental and simulation results is very small. A similar study on ABAQUS software on the hydraulic progressive damage [19] also observed good agreement between the ABAQUS simulation results and experimental data obtained.

The results show that the damage quantity of coal is increased significantly by improving the water infusion pressure under constant water infusion time and frequency. So, the pulse water infusion pressure needs to be improved under the existing technical conditions and not cause big coal fissure if coal and gas outburst is to be prevented.



(1) 0.5 m



(2) 0.95 m

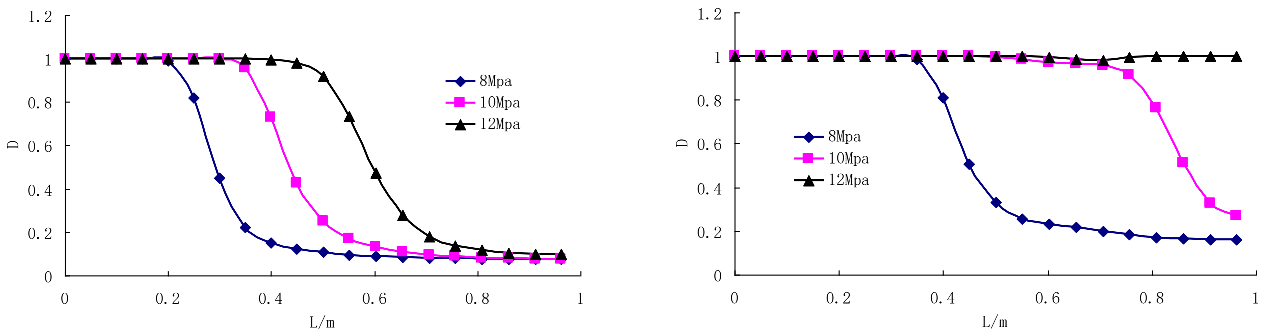
Figure 6. Curve of time-damage at different pressures.

3.3 The impact of pulse frequency on coal damage quantity

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

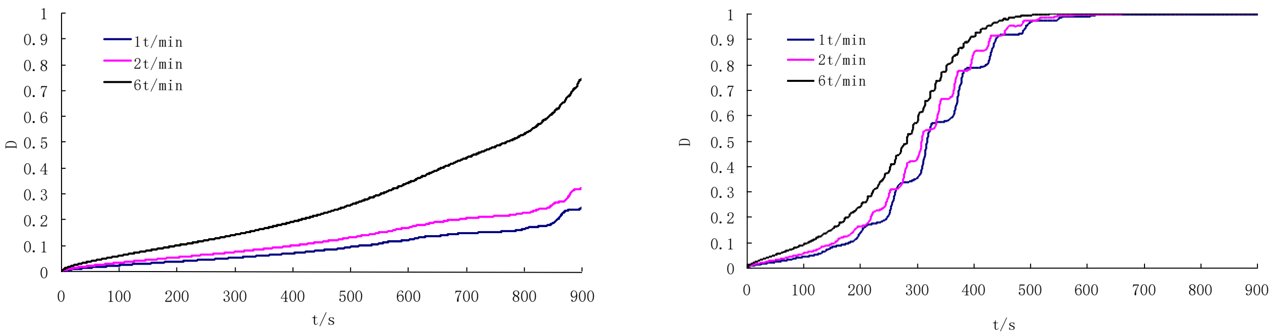
Figure 8 shows the curve of time-damage quantity at different frequencies when the infusion frequencies are 1 t/min, 2 t/min and 6 t/min, respectively, at the bottom of the water hole of 0.5 m and 0.95 m. It can be seen that when other conditions are constant, under different pulse water infusion frequencies, the rule of coal damage quantity change with water infusion time rate has the same change rule presented in Fig. 8 and Fig. 6. It can be seen from Figure 8 that other conditions remain constant at the same water infusion time rates. Consequently, the bigger the water frequency, the greater the coal damage quantity can be gotten. It shows that infusion frequency has significant effects on the damage quantity. The frequency of high pressure pulse water infusion needs to be improve under existing technical conditions so that coal and gas outburst could be prevented.

Figure 9 shows the curve of distance from location of water infusion hole-dynamic damage evolution at two infusion frequencies which are 1 t/min, 2 t/min and 6 t/min respectively when pulse water infusion time rates are 5 min and 15 min. It can be seen that when other conditions are constant, under different pulse water infusion frequencies, the rule of coal damage quantity changes with pulse water infusion frequency and have the same rule of change in Figure 9 and Figure7 . From Figure 9 it can be seen that other conditions remain constant at the same location distance from the water infusion hole. So, the higher the infusion pressures frequency, the greater the coal damage quantity. It shows that water infusion frequency has significant effects on the coal seam damage quantity. That is to say that higher frequency of water infusion can effectively increase the influence of coal seam water infusion so that consequently the better effect of pulse water infusion can be gotten [14-16].



(1) 5 min (2) 15 min

Figure 7. Curve of length-damage at different pressures.



(1) 0.5 m (2) 0.95 m

Figure 8. Curve of time-damage at different frequencies.

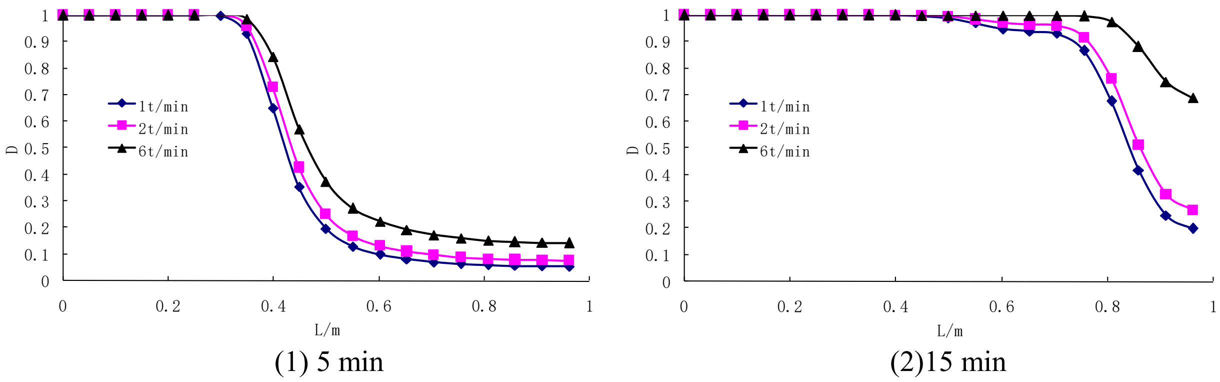


Figure 9. The curve of length-damage at different frequencies.

4 Conclusion

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

Numerical simulation results show that, during the process of coal seam high pressure pulse water infusion, the stress field and flow field are mutually influenced and mutually restricted. The coupling of the stress and flow field has an impact on physical and mechanical properties of coal so that these factors can effectively prevent coal and gas outburst. The coal damage quantity is significantly increased with water infusion rate under constant water infusion pressure and frequency. The coal damage quantity is significantly increased by increasing water infusion pressure under constant water infusion rate and frequency.

The coal damage quantity is significantly increased with an increase in water infusion rate under constant water infusion pressure and frequency. The coal damage quantity is significantly increased by increasing water infusion pressure under constant water infusion time rate and frequency. The coal damage quantity is significantly increased by increasing water infusion frequency under constant water infusion pressure and time rate. So, the pulse water infusion (time) rate needs to ensure a better effect of preventing coal and gas outburst. Meanwhile the pulse water infusion pressure is to be improved under existing technical conditions. The frequency of pulse water infusion is also to be improved under existing technical conditions.

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