Research Article
Effect of Pre-Existing Symmetrical Cracks on Propagation Behaviors of a Blast-Induced Crack

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Defects such as voids, pores, and joints will transform into big scale cracks in the rock of tunnel surrounding under dynamic load like blasting and earthquake. In this paper, three kinds of symmetrical cracks were chosen as an example, and experiments and numerical simulations were conducted to study the effect of symmetric cracks on a blast-induced crack. The relationship of main crack propagation characteristic and distribution of symmetrical cracks was investigated. Some circular specimens using two kinds of material, PMMA and sandstone, including a center hole charged with a detonator and pre-existing cracks were used in the experiments. The test system consisted of an oscilloscope and an ultradynamic strain amplifier and crack propagation gauges (CPGs) were employed in monitoring propagation velocity. AUTODYN code was applied in numerical simulation to investigate the propagation behavior of main crack between symmetrical cracks. Linear equation of state and a modified major principal stress failure criterion was utilized to describe the status of rock material. Based on experimental and numerical results, it can be concluded that (1) the pre-existing symmetrical cracks have arrest effect on main crack propagation, (2) compressive stress in y-direction plays very important roles in crack arrest, and (3) the spacing of parallel cracks has a great influence on crack propagation length and velocity.

1. Introduction

Fragmentation by drilling and blasting is widely employed in mining, quarrying, and civil construction excavations because of its effectiveness and economic efficiency. However, the blasting shock wave by explosive will cause damage of rock mass that is unnecessary, which may lead to many accidents. Therefore, the dynamic response of rock under blasting load has attracted many scholars’ attention [1–10].

The process of rock fracture and fragmentation by explosive under is very complicated, which is relevant to the characteristics of rock mass, explosive material, and charge method. Therefore, many numerical methods have been presented. Zhu et al. [11] established a surface blasting model using finite difference method in AUTODYN code and investigated the effect of different defects including voids, pores, and open joints on dynamic strength of rock and two kinds of boundary were considered in his study. Zhang et al. [12] studied the crack propagation mechanism under blasting load using numerical simulations, and his result agreed that there is a different stress state resulting in crack propagation in time sequence. Yilmaz and Unlu [13] investigated the behavior of rock under different blasting loads using a three-dimensional finite difference model and concluded that the most efficient explosive is the one with low-frequency content but with a sufficient high borehole pressure. Wang et al. [14] used a coupled method combining UDEC and LS-DYNA to study the effect of blasting wave on the faulted rock masses, and the result showed that the existence of faults influences the pattern of rock damage.
Zhong et al. [15] applied RFPA dynamic in investigating the function of loading rate, distance from the borehole to the free boundary, and size of hole between two charge holes on propagating crack. Yi et al. [16] analyzed numerically the effect of situ stress on rock fracturing under explosive load and concluded that the crack propagation is governed by explosive stress wave but influenced by the high situ stress in far field. Fakhimi and Lanari [17] simulated rock fragmentation under blasting load using the DEM-SPH method and indicated that the last stage of rock is owing to the infiltrating of explosive gas.

Experimental study is very important in studying rock dynamic response under blasting. Therefore, Hu et al. [18] investigated the propagation rule of a crack under blast loading and the results indicated that the side close to borehole will propagate toward it, but the other one will expand away from it. Liu et al. [19] tested the dynamic fracture toughness of brittle material under explosive load using PMMA plates and the crack propagation gauge and concluded that dynamic propagation toughness is greater than initiation toughness. Yu et al. [20] studied the effect of blasting on the mechanical behavior of sandstone and agreed that the mechanical parameters of sandstone will change after blasting. He and Yang [21] explored the effect of two holes on propagating crack and analyzed the crack arrest mechanism of empty holes. Yang and Ding [22] used digital image correlation method to study granite dynamic response under blasting load with different lateral pressure coefficient $K$ and the results indicated that the radius of the crush zone decreases with the increment of lateral pressure coefficient. Yang et al. [23] investigated the dynamic behavior of jointed rock under blasting in high-stress condition by caustics method and agreed that, in the crack initiation stage, the high stress influences a little, and in the propagation stage, it can change the crack propagation speed, and by the same method, Wang et al. [24] explored the interaction of a running crack and blasting wave and concluded that a blasting wave can influence dynamic stress intensity factor at the tip of a propagating crack.

As is known well, there are many voids, pores, and joints in rock masses of tunnel surrounding, which can transform into big scale open precracks in the later period of construction owing to repeated blasting. These big cracks certainly will have an effect on the propagation of blasting-induced cracks and there will be different functions for precracks with different orientations. In this paper, three kinds of symmetric precracks were chosen to study its effect on a propagating main crack.

In this study, some big scale circular plates using two materials, PMMA and sandstone, with a center charge holes, three radial main cracks, and three pairs of symmetric secondary cracks were applied in the experiments and an electrical detonator was used to generate blasting load. Crack propagation gauges (CPGs) were employed in measuring the main crack propagation speed. The explicit dynamic software AUTODYN [24] was applied in the numerical study, which is a highly nonlinear dynamic software and can solve the dynamic problems of solid, liquid, gas, and its coupling; similarly, AUTODYN code has good adaptability in simulating the process of rock fracturing [25–27]. According to experimental and numerical study, the behavior of a propagating crack between secondary cracks could be obtained.

2. Experimental Study

Rock contains a plenty of joints and cracks; when a moving crack encounters these cracks, they will affect the moving crack dynamic propagation behavior. In this study, a pair of symmetric cracks about the horizontal axis as shown in Figure 1 was considered and the effect of these two cracks on a moving crack was investigated.

2.1. Specimen and Its Dimension. Three types of large circular specimens with a centralized charge hole as shown in Figure 2 were applied in this study. Three radial main cracks were designed in each specimen, and the angle between them was $120^\circ$. There is no effect between the three main cracks, and such design can save materials. There was a pair of cracks designed in front of each main crack, and the angle between the pair of cracks was designed as $0^\circ$ (parallel), $20^\circ$, $50^\circ$, $80^\circ$, $-20^\circ$, $-50^\circ$, and $-80^\circ$, as shown in Figure 2.

Two materials, sandstone and polymathic methacrylate (PMMA), were selected to make the specimens. Sandstone material was obtained from Zigong area in China where the sandstone has the property of homogeneity and high density. An experimental study by Rossmanith [28] showed that PMMA has a similar fracture characteristic with homogeneous rock under dynamic loads. PMMA has the property of transparency so that crack propagation patterns after blasting can be observed easily. Therefore, PMMA was also selected to make the specimens in the blasting tests.

For all the specimens, the distance $b$ between the main crack tip and the center point A of the line connecting the two crack center was $30$ mm; the diameter of the charge hole was $8$ mm; the outer diameter, the inner diameter, and the length of the electric detonator were $7$ mm, $6$ mm, and $50$ mm, respectively.

In order to make sure that main crack can propagate successfully and the distance $a$ from the center of the borehole to the main crack tip was $20$ mm for sandstone and $30$ mm for PMMA. The length of main cracks and the pair of cracks were, respectively, $70$ mm and $40$ mm for sandstone and $30$ mm and $40$ mm for PMMA.

Two groups of PMMA specimens were tested. In the first group, the pair of cracks was parallel, and the crack spacing was designed as $20$ mm, $35$ mm, $50$ mm, $65$ mm, $80$ mm, and $95$ mm, respectively, to make sure that the existence of parallel cracks has an obvious influence on main crack propagation. In the second group, the distance between the pair crack centers was kept as a constant $40$ mm, and the angle $\theta$ was designed as $20^\circ$, $50^\circ$, $80^\circ$, $-20^\circ$, $-50^\circ$, and $-80^\circ$, as shown in Figures 2(b) and 2(c).

For sandstone specimens, the pair of cracks was parallel to the main crack, and the spacing of the pair of cracks $S$ was only one variable. The spacing was designed as $20$ mm, $30$ mm, $40$ mm, $50$ mm, $60$ mm, $70$ mm, $80$ mm, and $90$ mm,
respectively. In addition, the tests by using the sandstone specimens without the pair of cracks were also conducted for comparison. The density of sandstone and PMMA was 2370 kg/m\(^3\) and 1180 kg/m\(^3\), respectively, and their elastic wave velocity is obtained by the SonicViewer-SX system as shown in Figure 3, and according to the speed of \(P\)-wave and \(S\)-wave, the dynamic parameters such as elastic modulus and Poisson ratio can be calculated by the following equation:

\[
E = \frac{\rho c_p^2 (3c_p^2 - 4c_s^2)}{c_p^2 - c_s^2},
\]

\[
\nu = \frac{c_p^2 - 2c_s^2}{2c_p^2 - 2c_s^2},
\]

where \(c_p\) and \(c_s\) are the speed of \(P\)-wave and \(S\)-wave, and \(E\), \(\nu\), and \(\rho\) are the elastic modulus, the Poisson ratio, and the density, respectively. The measured dynamic material parameters have been listed in Table 1.

Because the length of the base charge of the detonator is larger than the thickness of both the sandstone and the PMMA specimens, a circular rubber ring was employed to fix the detonator in the blasting experiments so that the loads produced by explosive could fully apply to the face of the boreholes as Figure 4 shows.

The base charge of the detonator is hexogen (C\(_3\)H\(_6\)N\(_6\)O\(_6\)), and the length and density are 16 mm and 1.8 g/cm\(^3\), respectively; no coupling and no stemming were applied, and the location of the detonators is shown in Figure 4.

When stress waves encounter a free boundary, reflection will happen. The reflected tensile wave will affect the dynamic stress intensity factor (DSIF) at crack tip, and accordingly, the propagation behavior of the crack will vary [29]. Therefore, the size of the specimen should be large enough to weaken the effect of the reflected tensile wave from the boundary, and the corresponding test results could be, therefore, similar to the reality of blasts in infinite rock mass. In this study, the diameter of the circular specimens for the sandstone and PMMA was 600 mm and 500 mm, respectively. The thickness was 15 mm for sandstone specimens and 10 mm for PMMA specimens, shown in Figure 4.

2.2. Measuring Systems. Measuring systems, as shown in Figure 5, consists of an ultradynamic strain amplifier, a bridge box, a constant voltage source, an oscilloscope, a strain gauge stuck near borehole, a crack propagation gauge (CPG) circuit, and a computer. The ultradynamic strain amplifier is used to amplify the dynamic voltage signal and convey the signal to the oscilloscope. The constant voltage
source offers a voltage of 16 V for the crack propagation
gauge (CPG) circuit, and the CPG was connected with two
resistors of 50 $\Omega$. The CPG consists of 21 fine wires, and it is
40 mm in length, and 10 mm in width as shown in Figure 5.
In the tests, the CPG was stuck along the main crack
propagation path to measure crack propagation speed. The
oscilloscope and the computer were applied in storing the
experimental data, and the acquisition time of the oscillo-
scope was set as 1.2 ms which was enough to record the
complete data.

When the detonator is fired, the detonation pressure
exerted on the borehole wall sets off a shock wave in the
adjacent rock mass, but it soon decays to a high-amplitude
stress wave propagating at the longitudinal wave speed in the
rock mass. When the stress wave encounters the main crack
tip, dynamic stress intensity factor (DSIF) at crack tip will be
developed. And if it exceeds dynamic fracture toughness of
materials, which is called as threshold value to predict crack
status, the crack initiation and propagation will happen
which will result in the fine wires of the CPG breaking one by
one. The corresponding voltage signal recorded by the os-
cilloscope will jump step by step due to the changing of the
CPGs’ resistance. By calculating the derivatives of the CPGs’
voltage signal with respect to time, the breaking times of the
wires $T(n)$ can be obtained. The spacing between two wires
was 2 mm, so the average crack propagation speed can be
calculated by $2 \text{ mm}/(T(n+1)−T(n))$.

2.3. Crack Propagation Patterns under Parallel Symmetrical
Cracks. Blasting results when the pair of symmetrical cracks
is parallel are shown in Figure 6 for sandstone specimens and
Figure 7 for PMMA specimens. For sandstone, every main
crack has propagated successfully and travelled through
zones between the parallel cracks. When the spacing was less
than 50 mm, main cracks propagated until it connected one
of the parallel cracks. When the spacing is longer than
50 mm, main cracks just propagated forward.

Table 1: Dynamic parameters of PMMA and sandstone.

| Classification | P-wave speed $c_p$ (m/s) | S-wave speed $c_s$ (m/s) | Elastic modulus $E_d$ (GPa) | Poisson’s ratio $\mu_d$ | Density $\rho$ (Kg/m$^3$) |
|----------------|--------------------------|--------------------------|----------------------------|------------------------|---------------------------|
| Sandstone      | 2430                     | 1450                     | 12.19                      | 0.22                   | 2370                      |
| PMMA           | 2160                     | 1260                     | 4.65                       | 0.24                   | 1180                      |

Figure 4: Sketch of the location of the detonator charge and the specimens. (a) Sandstone specimen. (b) PMMA specimen.

Figure 5: The measuring system applied in the blasting tests.
Figure 6: Crack propagation patterns under parallel symmetrical cracks in sandstone specimens. (a) $S = 20$ mm. (b) $S = 30$ mm. (c) $S = 40$ mm. (d) $S = 50$ mm. (e) $S = 60$ mm. (f) $S = 70$ mm. (g) $S = 80$ mm. (h) $S = 90$ mm. (i) No existing parallel cracks.

Figure 7: Crack propagation patterns under parallel symmetrical cracks in PMMA specimens. (a) $S = 20$ mm. (b) $S = 35$ mm. (c) $S = 50$ mm. (d) $S = 65$ mm. (e) $S = 80$ mm. (f) $S = 95$ mm.
Crack propagation patterns for PMMA specimens are shown in Figure 7, and it can be found that all main cracks branch in the propagation process in the first and one of the branches keeps propagating in the later, and this is because the fracture toughness of PMMA is lower than rocks and crack branch will take place easier when stress at crack tip is strong enough.

To comparing results for different models, crack propagation length for sandstone and PMMA specimens was measured and the function of crack propagation length and the spacing of parallel cracks is shown in Figure 8. It can be observed that the main crack will propagate for a longer distance with the spacing of parallel cracks, and according to Figures 6 and 7, when there are no parallel cracks, crack propagation length is the longest among all the models. Therefore, the existence of parallel cracks can arrest main crack propagating, which is related to the spacing of parallel cracks.

2.4. Crack Propagation Velocity in Sandstone Specimens. To study main crack propagation in details, crack propagation gauges (CPG) were applied in measuring the main crack propagation speed in sandstone specimens for $S = 40$ mm, 60 mm, 80 mm, and no existing parallel cracks, and voltage signals of CPGs and its derivatives are shown in Figure 9.

2.5. Blast Results under Oblique Symmetrical Cracks in PMMA Specimens. For investigating main crack propagation between oblique symmetrical cracks, just PMMA specimens were designed because it is earlier to make by the laser technique. Crack propagation patterns of these models are shown in Figure 9.

When parallel cracks exist, main crack arrest occurs at different times and different locations for different secondary spacings, and arrest location is near 11th fine wire for $S = 40$ mm, near 16th wire for $S = 60$ mm, and near 18th wire for $S = 80$ mm, respectively. Their arrest times are 127.80 $\mu$s, 152.40 $\mu$s, and 179.36 $\mu$s, respectively. From Figures 9(a), 9(b), and 9(c), after the crack arrest, main cracks keep propagating for a while. From Table 1, the $P$-wave speed of sandstone is $2430$ m/s. The shortest distance that explosive stress wave travels from borehole to the free boundary and back to the running crack tip is about $460$ mm. Thus, it will spend at least 189.30 $\mu$s so that the reflected wave from a free boundary can affect main crack propagation. Because all arrest times for three models are less than 189.30 $\mu$s, crack arrest is unrelated to the reflected wave, but which leads to main crack propagation again. When there are no parallel cracks, the time of 21th wire fracturing is $146.48 \mu$s, and the CPG voltage signal is not influenced by the reflected wave.

Main crack propagating speeds can be obtained based on CPGs voltage signals, as shown in Figure 10, and it is the function of crack propagation speed versus crack extending distance. When parallel cracks exist, main crack propagation speeds have a tendency of decreasing gradually until it arrests and it will continue to propagate for a while when reflected waves reach, but later crack propagation speeds are much lower than previous propagation speeds. There is a different trend of the change of crack speed when the spacing changes. For $S = 40$ mm, the velocity of the main crack seriously decreases with crack propagating, and for $S = 60$ mm, crack propagation speed varies fluctuantly at first and then decreases gradually, and for $S = 80$ mm, crack speed diminishes fluctuantly during the whole process. Therefore, main crack arrest takes place earlier with the decrease of the spacing of parallel cracks. When there are no parallel cracks, crack speed varies fluctuantly, but has no tendency to decline.

When $\theta$ is negative, crack branching can be observed for all models, and the longest propagation lengths are 26.5 mm, 29.5 mm, and 23.5 mm, respectively, for $\theta = -20^\circ$, $-50^\circ$, and $-80^\circ$. When $\theta$ is positive, the longest propagation distances are 29 mm, 22.5 mm, and 18.5 mm, respectively, for $\theta = 20^\circ$, 50’, and 80’. So, the included angles of symmetrical cracks have an effect on main crack propagation and the function mechanisms are more complex compared to that under parallel cracks.

3. Numerical Study

Owing to the complexity of oblique symmetrical cracks, we will focus on exploring the function mechanism of parallel cracks on main crack propagation behaviors. In this section, numerical models are established based on the explicit dynamic software AUTODYN according to experimental specimens and stress distribution versus time in the specimen can be obtained.

3.1. Numerical Model. In the numerical simulation, the numerical model included two parts: sandstone and explosive, in which quadrilateral element and Lagrange calculation method were applied. According to the specimen dimension shown in Figure 2(a), some numerical models of

![Figure 8: Main crack propagation length versus the spacing of parallel cracks.](image-url)
sandstone were established in AUTODYN code, as shown in Figure 12, and it is 1 mm in width for every crack.

The dynamic mechanic parameter of sandstone has been shown in Table 1, and linear equation of state (EOS) was used to describe the state of sandstone under explosive stress wave, and it can be written as follows:

\[ P = k \left( \frac{\rho}{\rho_0} - 1 \right), \]  

where \( P \) is pressure, \( k \) is the bulk modulus, and \( \rho/\rho_0 \) is the ratio of the present density and the initial present. Because sandstone belongs to brittle material, linear elastic strength model was employed to express the relation of its strain and stress. And a modified principle stress failure criterion [30] was applied in predicting whether an element fails, which can be written as follows:

\[ \sigma_1 \leq \sigma_T (\dot{\varepsilon}) \quad \text{or} \quad \tau_{\max} = \frac{\sigma_1 - \sigma_3}{2} \leq \tau_C (\dot{\varepsilon}), \]  

where \( \sigma_1 \) is the maximum principal stress, \( \sigma_3 \) is the minimum principal stress, \( \tau_{\max} \) is the maximum shear stress, \( \sigma_T (\dot{\varepsilon}) \) is the dynamic tensile strength, and \( \tau_C (\dot{\varepsilon}) \) is the dynamic shear strength. The failure criterion means that when the maximum principal stress exceeds the dynamic tensile strength, or the maximum shear stress exceeds the dynamic shear strength, the element of sandstone will fail, which is not able to sustain any tensile or shear loading, but still be able to sustain compressive loading.

For explosive material, hexogen in the detonator is used in AUTODYN code, and its density, C-J pressure, velocity of detonation, and detonation energy per unit volume are 1.891 g/cm³, 42 GPa, 9110 m/s, and 1.05 × 10⁷ kJ/m³, respectively. Johns Wilkins Lee (JWL) is applied in describing

\[ \text{Figure 9: The voltage signal recorded by CPGs and its derivative.} \]

(a) \( S = 40 \text{ mm} \). (b) \( S = 60 \text{ mm} \). (c) \( S = 80 \text{ mm} \). (d) No existing parallel cracks.
The state of explosive and it can be described by the following equation:

\[
P = A \left(1 - \frac{\omega}{R_1 V}\right) e^{-R_1 V} + B \left(1 - \frac{\omega}{R_2 V}\right) e^{-R_2 V} + \frac{\omega E}{V},
\]

where \(P\) is the pressure, \(V\) is the specific volume, \(E\) is the total initial energy, and \(A, B, R_1, R_2, \) and \(\omega\) are constants. For hexogen explosive, \(A = 778.3\) GPa, \(B = 7.071\) GPa, \(R_1 = 4.2, \) and \(R_2 = 1.0, \omega = 0.3.\) The erosion criterion was applied in the explosive material to avoid grid distortion, which says that when the geometric strain of explosive element exceeds 1.8, the element will vanish.

3.2. Numerical Results. The dimensions of models in numerical simulations are the same as that in experiments, and there are 9 models in all, and numerical results are shown in Figure 13. Shear failure and tensile failure occurred in
Figure 12: Meshing of a sandstone specimen by using quadrilateral elements.

Figure 13: Continued.
simulations, and the first is near borehole, and the second occurred in further location and propagation paths of main cracks. According to the simulation results, the propagation length of main cracks increases with the spacing of parallel cracks and it is less than that without parallel cracks. When $S<40\text{ mm}$, main crack propagates toward the free surface of parallel cracks in the later period, which agrees with experiment results.

According to the distribution of pressure during the whole process, as shown in Figure 14, when explosive stress wave encounters free boundary, it will reflect and change to tensile wave, which can enhance the stress at crack tip. In the case of small space of parallel cracks, main crack arrest occurs earlier according to experiment results, and reflected wave will make crack propagate again, but this moment crack tip is different from that in initial circumstance, so crack propagation route will be easier to deviate.

3.3. Stress Distribution between Parallel Cracks. To explore the mechanism of main crack arrest between parallel cracks, a target point was set in the location of 30 mm ahead of main
Figure 14: Continued.
crack tip to record the compressive stress in $y$-direction for models when $S \geq 40$ mm and no existing parallel cracks, as shown in Figure 15, and tensile stress is positive and compressive stress is negative. Comparing two kinds of models, there is much larger tensile stress from 42.5 $\mu$s to 52.5 $\mu$s and much larger compressive stress from 52.5 $\mu$s to 62.5 $\mu$s than that without parallel cracks, which says that bigger tensile stress and compressive stress occur in crack propagation path when parallel secondary cracks exist.

Stress contour of model with $S \geq 40$ mm is shown in Figure 16, and there is strong compressive stress between parallel cracks at first, but which is not able to influence main crack propagation. When main crack propagates to the zone between parallel cracks, a strong compressive stress occurs, which can result in crack arrest.

3.4. Effect of the Spacing of Parallel Crack. In order to investigate the difference among models with different spacings, nine target points were set along crack propagation path to record the maximum compressive stress in $y$-direction, as shown in Figure 17.

It can be found that there is obvious compressive stress between parallel cracks for all the models. However, some differences exist for different models according to these curves. For models of $S = 20$, 30, 40, 50, and 60 mm, the maximum compressive stress in $y$-direction firstly increases and then decreases with distance from initial main crack tip. However, it rises steadily, and the location corresponding to peak value is further from the initial main crack tip. When $S$ is less than 35 mm, the maximum compressive stresses at target points increase with the spacing of parallel cracks, which leads to different arrest effects on main crack. When the spacing is small enough, the compressive stress between parallel cracks is very large, and the arrest function, therefore, is very large.

**Figure 15:** The stress history curves of the target points.
4. Discussion

Based on the foregoing analysis, main crack will arrest between parallel cracks and it is related to the spacing of them. The smaller the spacing, the more obvious the arrest effect on main crack propagation. In reality, the arrest effect is caused by the reflected compressive wave of the rarefaction wave.

For parallel cracks as shown in Figure 18(a), on the one hand, with the spacing increasing, the reflected angle will be increasing and it will can enhance the magnitude of stress component in $y$-direction, which suggests that stress component in $y$-direction is increasing with the reflected angle; however when the spacing is small, the compressive stress in $y$-direction is still big according to Figure 17, which is because that wave’s travelling route is short and stress waves...
keep strong enough. When the spacing of parallel cracks is increasing, the compressive stresses in y-direction decrease obviously firstly and then keep almost invariable according to Figure 17.

For oblique symmetrical cracks, there still exists arrest effect on main crack propagation according to the results in experiments. When the included angle is toward inside as shown in Figure 18(b), the mechanism of crack arrest is similar to that of parallel cracks and it is also owing to the reflected compressive wave of rarefaction waves. When the included angle is toward outside as shown in Figure 18(c), the mechanism changes because the reflected wave is away from propagation path of main cracks, which is not able to have an effect on main crack propagation. In this situation, explosive waves are reflected on the face of symmetrical cracks so that blast energy which drives crack propagating
decreases, and the strength of diffraction wave between secondary cracks will decline sharply; therefore, crack propagation length is smaller than that in the model without symmetrical crack.

5. Conclusions

This paper explored the effect of two symmetric cracks on the propagating crack using PMMA specimens and sandstone specimens, and crack propagation gauges were used to measure the main crack propagation speed in the sandstone blasting experiments. The explicit dynamic software AUTODYN was employed in doing explicit dynamic analysis for models and acquiring stress distribution between parallel cracks. Combining experimental and numerical results, the following conclusions can be obtained:

1. The pre-existing symmetrical cracks have arrest effect on main crack propagation under blast loads and it weakens with the spacing between them
2. Compressive stress in y-direction plays very important roles in crack arrest and it is caused by the reflected waves of rarefaction wave
3. As parallel cracks spacing increases, the terminal propagation length of main crack is increasing and crack propagation velocity declines slower

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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