Numerical simulation for the matching effect of rock parameters on explosives and rocks

Tingting Li¹, Xuefeng Niu¹*, Aiping Fei², Chunyu Zhu¹ and Mingchang Wang¹

¹College of GeoExploration Science and Technology, Jilin University, Changchun, 130026, China
²School of Civil Engineering, University of Science and Technology Liaoning, Anshan Liaoning, 114051, China

*Corresponding author’s e-mail: niuxf@jlu.edu.cn

Abstract. China’s mine blasting technology is gradually mature, but there are deficiencies in low blasting efficiency. The reasonable matching of explosives and rocks can effectively improve the blasting efficiency and is of great significance for mine blasting. Based on ANSYA/LS-DYNA, the matching effects of rock physical density, elastic modulus, Poisson's ratio, compressive strength and shear modulus in double-hole blasting were studied and verified by simulation. By comparing the length of time that the shock wave caused the rock to be crushed, the experiment shows that the longer the blasting time, the better the matching effect. Numerical simulations show that the five physical factors affecting the matching effect of explosives and rocks are: compressive strength, Poisson's ratio, density, shear modulus, and elastic modulus. It has been verified that the experimental results can provide reference for the development of blasting technology.

1. Introduction

Mine blasting technology is becoming more and more mature, and the matching between reasonable explosives and rock parameters has always been an important issue in blasting engineering. Domestic and foreign scholars have done a lot of research: the matching of explosives and rocks has impedance matching, full process matching and energy matching [1]; Zheng Changqing from the perspective of artificial intelligence, based on impedance matching, applies the neural network method is to explosives and rocks. In the matching system, an intelligent matching optimization system based on neural network and fuzzy comprehensive judgment is established [2]; Zhao Mingsheng et al. used BP neural network to establish the explosive rock matching model, and predicted the explosion characteristics and blasting design parameters from the factors of rock blasting characteristics and blasting effects [3]. Liu Maoxin et al. used the regression analysis method to explore the matching relationship between explosives and rocks. Finally, the matching coefficient of the optimal matching region was 2.50~2.58 [4]. Ye Haiwang et al. used the fuzzy characteristics of fuzzy mathematics to construct a explosive and rock matching system based on fuzzy reasoning [5]; Wang Min et al. applied wave impedance matching theory to explosive parameters matching with rock [6]; Leng Zhendong et al. proposed a new rock-explosive matching method based on blasting mechanism. Under the premise of ensuring the full fracture of the rock between adjacent blastholes, the optimal performance of the explosive blasting is determined by reasonable control of the comminution zone [7]. Wu Xianzhen obtained the best damping effect when the blast hole spacing was 4m and the differential time was...
28ms by adjusting the time difference [8]; Lou Xiaoming proposed that the extension time is 25ms, the minimum synthetic velocity peak and the most obvious vibration reduction [9]; Zhao Jianjian studied the effect of double-hole blasting under differential delay time [10]. The above research mainly optimizes the blasting scheme from the perspectives of intelligent system, wave impedance matching, full process matching, energy matching, and differential time. It does not explain the petrophysical factors that cause the explosives to match the rocks reasonably. In this paper, based on ANSYS/LS-DYNA, the influence of rock physical parameters on the matching effect between explosives and rocks is matched, which provides a reference for the development of mine blasting in China.

2. Establish a Model
Scheme: The TNT explosives were selected and simulated with granite and basalt rock, and the emulsion explosives were matched with the granite for verification. In the matching, the control variable method can be used to change a certain physical factor of rock within the range of rock physical parameters. Models are respectively TNT—granite—density 1, TNT—granite—density 2, TNT—granite—elastic modulus 1. TNT—Granite—Elastic Modulus 2, TNT—Granite—Poisson 1, TNT—Granite—Poisson 2, TNT—Granite—compressive strength 1, TNT—granite—compressive strength 2, TNT—granite—cutting Die Modulus 1, TNT - Granite - Shear Modulus 2, TNT - Basalt - Physical Parameter Model and Emulsion Explosive - Granite - Physical Parameter Model, a total of 40 models. The stress-time curves of the different locations in the respective models are extracted, namely: the direction perpendicular to the vertical direction of the first blasthole, the vertical direction of the two blastholes, and the perpendicular direction of the second blasthole, fitted according to the extracted data. The blasting-time function is used to calculate the blasting time of each model. The matching effect is determined by comparing the length of blasting time, and then the relationship between the physical parameters of rock and the reasonable matching effect of explosive and rock is obtained.

2.1. Calculation model
Modeled with 2D Solid 162, the blasting media model measures 1000 cm*1000 cm. Both crater radii are 20 cm, the blast hole spacing is 780 cm, the numerical model unit system: cm-g-μs, the model is divided into 2 material parts, 60552 nodes, 61269 calculation units. The model is shown in Figure 1.
2.2. Material model

2.2.1. Explosive model

(1) Material model

The explosive material uses the high-energy explosive detonation combustion material model (MAT_HIGH_EXPLOSIVE_BURN) to describe the nature of the explosive. The specific model equation is as follows:

\[ F = \max(F_1, F_2) \]

\[ F_1 = \begin{cases} 
2(t-t_1)D_Ae_{\max} & t > t_1 \\
0 & t \leq t_1
\end{cases} \]

\[ F_2 = \beta = \frac{1-V}{1-V_{CJ}} \]

Where \( V_{CJ} \) is the C-J relative volume; \( t \) is the current time; \( t_1 \) represents the minimum time required for the detonation wave to pass from the detonation point to the centroid of the current cell. If \( F > 1 \), set \( F = 1 \).

(2) Equation of state

The flow behavior of the detonation product after the blasting of the explosive will lead to changes of the detonation product after the blasting of the explosive will lead to changes in its pressure and volume, using the JWL (Jones-Wilkins-Lee) equation of state [11]. The equation of state is as follows:

\[ P = A \left( 1 - \frac{\omega}{R_1} \right) e^{-R_1V} + B \left( 1 - \frac{\omega}{R_2} \right) e^{-R_2V} + \frac{\omega E_0}{V} \]

In the equation: \( P \) —press, \( A,B,R_1,R_2,\omega \) —Material constant, \( V \) is the relative volume; \( E_0 \) —initial specific internal energy. In this paper, the matching problem of explosive and rock is studied, which involves two kinds of explosive, TNT explosive and emulsion explosive. The parameters of the two explosives are shown in Table 1.

Table 1. The parameters of TNT materials and EOS [12]

| Name          | \( p/\text{(kg} \cdot \text{m}^{-3}) \) | \( D/\text{(m} \cdot \text{s}^{-1}) \) | \( R_1/\text{GPa} \) | \( A/\text{GPa} \) | \( B/\text{GPa} \) | \( R_2 \) | \( \omega \) | \( E_0/\text{GPa} \) | \( V_{CJ} \) |
|---------------|-----------------------------------|---------------------------------|-----------------|----------------|----------------|--------|--------|----------------|----------|
| TNT           | 1630.000                          | 6930.000                        | 21.000          | 371.200        | 3.231          | 4.150  | 0.950  | 0.300          | 7.000     |
| Emulsion [13] | 1310.000                          | 5500.000                        | 9.000           | 214.400        | 0.182          | 4.200  | 0.900  | 0.150          | 4.190     |

2.2.2. Blasting medium model

The model isotropic bilinear elastoplastic model (MAT_PLASTIC_KINEMATIC) used in this simulation describes the constitutive relationship of blasting media. The elastoplastic properties of rock media are considered, along with failure strain [14]. There are two kinds of rock media in this simulation: granite and basalt, and their physical parameters are shown in Table 2.

Table 2. Rock physics and mechanics parameter

| Rock species | Density/\( \rho/\text{kg} \cdot \text{m}^3 \) | Elastic Modulus/\text{GPa} | Poisson's ratio | Compressive strength/\text{MPa} | Shear modulus/\text{MPa} |
|--------------|------------------------------------------|---------------------------|----------------|-------------------------------|--------------------------|
| Granite      | 2400—3100                                | 50—100                    | 0.1—0.3        | 37—379                       | 15—30                    |
| Basalt       | 2600—3300                                | 60—120                    | 0.1—0.35       | 150—350                      | 10—20                    |

2.3. Algorithm

ANSYS/LS-DYNA is a large-scale nonlinear finite element program based on display. It is based on the Lagrange algorithm and has both ALE and Euler algorithms [11]. In this paper, the Lagrange grid is used to construct the rock medium. The unit adopts the multi-substance ALE algorithm. The joint between the explosive and the rock is common, and the boundary is the non-reflective boundary condition.

2.4. Time control

The two holes are simultaneously detonated, the time is 15000 \( \mu \text{s} \), and the output is 100 unit time. The time step is the same as the minimum unit length of 4 and the time step factor is 0.6.
3. Simulation Data

3.1. Data extraction
In the blasting medium, the stress-time data at different position units are extracted separately, and the vertical line of the two blastholes is extracted from the center point by 0~500 cm, and the first blasthole is 0~500 cm from the first shot. The unit is 0~500 cm from the second blasthole on the vertical line of the blasthole. Figure 2 shows the position of the analog data extraction unit. The shock wave peak is extracted and a stress-time function fit is performed.

![Figure 2. Presents the location of the data unit](image)

3.2. Data fitting
The explosion speed is extremely fast, and the power function is decremented. The function fitting follows the following principles: the peak value data is mandatory, and the regression coefficient $R^2 > 0.80$. The fitting function represents the maximum stress of the unit at different times and positions in the blasting process, namely $F = ct^a$; $F$-stress, unit: MPa; $a$-constant; $t$-time, unit: μs.

Let $F = ct^a = \text{compressive strength}$, and $t$ is the blasting time at which the rock can be crushed. The shock wave makes the rock blasting time longer, the blasting range is wider, and the blasting block shape is more uniform, which is beneficial to mine development.

3.3. Data sorting
Table 3 shows the blasting time statistics of the shock wave breaking the rock when the TNT explosive is matched with the granite under a certain physical parameter of the rock.

| Physical parameter | Distance from the first blasthole time /μs | Vertical time in two blastholes /μs | Distance from the second blasthole line /μs |
|--------------------|------------------------------------------|-----------------------------------|------------------------------------------|
| Compressive strength | 779.88                                    | 21088.00                           | 666.08                                   |
| Poisson's ratio     | 644.03                                    | 1056.71                            | 652.04                                   |
| Density             | 636.29                                    | 977.21                             | 610.68                                   |
| Shear Modulus       | 638.37                                    | 915.91                             | 571.74                                   |
| Elastic Modulus     | 623.19                                    | 948.95                             | 544.04                                   |

Table 4 shows the blasting time statistics of the shock wave breaking the rock when the TNT explosive is matched with the basalt under a certain physical parameter of the rock.

| Physical parameter | Distance from the first blasthole time /μs | Vertical time in two blastholes /μs | Distance from the second blasthole line /μs |
|--------------------|------------------------------------------|-----------------------------------|------------------------------------------|
| Compressive strength | 614.54                                    | 1124.24                           | 637.95                                   |
| Poisson's ratio     | 572.33                                    | 1116.93                           | 521.01                                   |
| Density             | 552.82                                    | 921.26                            | 515.09                                   |
| Shear Modulus       | 540.72                                    | 922.45                            | 501.66                                   |
| Elastic Modulus     | 526.64                                    | 722.40                            | 501.41                                   |

Table 5 shows the blasting time statistics of the shock wave breaking the rock when the emulsion explosive is matched with the basalt under a certain physical parameter of the rock.
Table 5. Blasting time statistics of emulsion explosives for crushing granite

| Physical parameter | Distance from the first blasthole time /μs | Vertical time in two blastholes /μs | Distance from the second blasthole line /μs |
|--------------------|------------------------------------------|-----------------------------------|------------------------------------------|
| · Compressive strength | 527.27 | 1226.19 | 493.00 |
| · Poisson's ratio | 449.85 | 896.46 | 422.46 |
| · Density | 432.08 | 767.95 | 431.53 |
| · Shear Modulus | 388.64 | 759.91 | 349.96 |
| · Elastic Modulus | 331.00 | 714.39 | 329.88 |

4. Data Analysis
According to the blasting funnel theory, the position of the vertical direction of the two blastholes is the most unfavorable position of the blasting [15]. In the analysis of the blasting time causing the rock crushing, the blasting time in the vertical direction of the two blastholes is the main distance. The blasting time of the unit in the direction of the vertical line of the two blastholes is supplemented, and comprehensive analysis is carried out within the error tolerance.

The data in Table 3 shows that the blasting time of the vertical blasting direction of the two blastholes from the largest to the smallest is compressive strength, poisson's ratio, density, elastic modulus, and shear modulus. The blasting time from the vertical direction of the first blasthole to the crushing time of the rock is compressive strength, Poisson's ratio, shear modulus, density, and elastic modulus. The blasting time from the vertical direction of the second blasthole to the crushing of the rock is compressive strength, poisson's ratio, density, shear modulus and elastic modulus.

The data in Table 4 shows that the blasting time of the vertical direction of the two blastholes causes the crushing time of the rock to be compressive strength, poisson's ratio, density, elastic modulus and shear modulus. The blasting time from the vertical direction of the first blasthole to the rock is from compressive strength, poisson's ratio, density, shear modulus, and elastic modulus. The blasting time from the vertical direction of the second blasthole to the crushing of the rock is compressive strength, poisson's ratio, density, shear modulus and elastic modulus.

The relationship between the rock physical parameters and the reasonable matching effect of the rock in the range of error tolerance is compressive strength, poisson's ratio, density, shear modulus and elastic modulus.

In order to verify the authenticity of the conclusions, reading the data from table 5, within the scope of the error, the above conclusions are reasonable.

5. Conclusion
A reasonable match between explosives and rock parameters can improve mine blasting efficiency. In this paper, numerical simulation is carried out to obtain the relationship between the effects of various physical factors of rock. The most influential effect is the compressive strength. The smallest is the elastic modulus, that is, the order of influence of matching effect is compressive strength and Poisson's ratio, density, shear modulus and elastic modulus, providing a reference for the development of blasting technology.

Acknowledgments
This work was supported by the National Natural Science Foundation of China Grant No: 41472243; the Open Fund of Key Laboratory of Urban Land Resources Monitoring and Simulation, Ministry of Land and Resources, Grant No. KF-2018-03-020.

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