Numerical simulation of the effect of priming methods on result of ore fragmentation in fan-patterned long hole blasting and its application

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Abstract. Fan-pattern long hole blasting is a common method which is widely applied in the sublevel or level mining methods in deposits in which the thickness of ore body is thick and the dip of ore body is steep and the country rocks are comparatively hard. The effect of priming methods on result of ore fragmentation is very important and numerically analyzing its mechanism has a theoretical and practical significance. In this paper, we investigated the damage and fragmentation grain size of ore body in according to the priming methods such as collar, middle and bottom priming by using Ansys Autody in detail. The simulation result showed that the producing rate of fine ore and boulder were 9.4% and 36.7% in the collar priming and 5.6%, 26.3% in the middle priming and 5.5% and 23.0 % in bottom priming respectively. This shows that the bottom priming method is more advantageous than the others. The practical design for field application of the fan-pattern long hole blasting was carried out by JKSimblast and the expected result has achieved.

1. Introduction
Priming method in the fan-pattern long hole blasting is an important factor to evenly distribute explosive energy along the length of blast hole charge, reduce the loss of it and to improve the quality of ore fragmentation.

Priming methods in the fan-pattern long hole blasting, which have been developed and applied to the field until now, can be divided into four types by the position of primer and direction of detonation in the blast hole. Namely, collar, middle, bottom and mixed priming type [1,2,3,4,5].

Collar priming is the method that the detonation is propagated from the collar of the blast hole to the bottom in which detonator is placed from the collar of it to the bottom. Bottom priming is the method that the detonation is propagated from the bottom of the hole to the collar, in which detonator is placed from the bottom of the hole to the collar. Middle priming is the method that the detonation is propagated in two directions to the collar and bottom at the same time, in which detonator is placed at the middle of the blast hole. Mixed priming is the method in which above three methods are combined.

Many researchers including Emilie Sarah Willoams [1,2,8,9] have analyzed and comparatively evaluated the explosive mechanism of collar and bottom priming based on the consideration of the characteristics of explosive force and concluded as follows.
Firstly, the magnitude and time of the dynamic action of stress wave and quasi-static action of explosive product on rock fragmentation are the important factors.

Secondly, in bottom priming, the strength of stress wave is larger and the time of holding the pressure of explosive product is longer than collar priming and effect of the concentrated charge is appeared.

Thirdly, specific energy and impulse are increased towards the bottom of the hole in bottom priming.

Some researchers [10,11,12,13] described on the fact that bottom priming is more effective than collar priming in the view of stress wave action.

In this paper, we investigated the damage and fragmentation grain size of ore body in according to the priming methods such as collar, middle and bottom priming by using Ansys Autodyn in detail.

2. Model for numerical simulation by using Ansys Autodyn

2.1 Geometrical model

In this paper, we assume that the 2D geometrical model for numerical simulation is symmetry on the drilling drift section and the material is continuous and isotropic.

Fig. 1 shows the layout plan of fan-pattern long blasting hole. The distance between the ends of blast holes is 2.5m and the length of blast holes is between from 12m to 15m and the diameter is 76 mm and the section of drilling drift is trapezoid with 1.6m×1.8m, where each hole is assumed to be blasted simultaneously.

![Fig. 1. Layout plan of fan-pattern long blasting hole and charge.](image)

2.2 Material model

The materials used in numerical simulation are rock and explosive.

2.2.1 Rock model. The rock is lead-zinc ore and JH(Johnson-Holmquist) – 2 model [12,14] is used. This model is assumed that the strength of material is determined by pressure, modulus of deformation and damage variable in the state before and after break.

Table 1 shows the physical and mechanical characteristic values of ore set by JH-2 model.

| Factors                        | Symbol | Value  |
|--------------------------------|--------|--------|
| Volumetric elastic coefficient | K      | 55 600 |
Shear elastic coefficient, MPa \( G \) 40 500
Modulus of deformation C 0.005
Compression strength, MPa \( T_c \) 150
Tensile strength, MPa \( T_t \) 8.25
Volumetric strength, MPa \( \gamma \) 2 800
Poisson coefficient \( \mu \) 0.3
Specific surface energy of rock, J/m\(^2\) \( G_f \) 70
Volumetric density, kg/m\(^3\) \( \rho \) 2 800

The following relationship is established between elastic coefficient of the material \( E \) and Poisson coefficient \( \mu \), Volumetric elastic coefficient \( K \) and shear elastic coefficient \( G \).

\[
K = \frac{E}{3(1-2\mu)} \\
G = \frac{E}{2(1+\mu)}
\] (1, 2)

As shown above, if rock parameters are established by JH-2 model, damage and breaking process of rock by shock load can be more accurately simulated.

2.2.2 Explosive model. JWL model is used for explosive model. JWL model is mathematical model which is referred to the explosion characteristics of explosive by the shock wave theory based on the relationship of Rankne-Hugoniot and gas expanding theory based on JWL (Jones - Wilkins - Lee) state equation.

The relationship of Rankne-Hugoniot is as follows. [12]

\[
\begin{align*}
  u &= \sqrt{\left(p - p_0\right)\left(\nu - \nu_0\right)} \\
  D &= \nu_0 \sqrt{\frac{p - p_0}{\nu_0 - \nu}} \\
  E - E_0 &= \frac{p + p_0}{2} \left(\nu_0 - \nu\right)
\end{align*}
\] (3)

Where \( u \)- moving velocity of particles, m/s; \( D \)-propagation velocity of shock wave, m/s \( p_0 \), \( p \)-pressure of material before and after the propagation of shock wave, Pa; \( E_0 \), \( E \)-internal energy before and after the propagation of shock wave, kJ;

\[
\nu_0 = \frac{1}{\rho_0} \quad \nu = \frac{1}{\rho}
\]

\( \rho_0, \rho \)-volumetric density of material before and after the propagation of shock wave, kg/m\(^3\)

The state equation of JWL is as follows. [2, 5, 9]

\[
P = A\left(1 - \frac{w}{R_1\nu}\right)e^{-R_1\nu} + B\left(1 - \frac{w}{R_2\nu}\right)e^{-R_2\nu} + \frac{wE}{\nu}
\] (4)
Where $P$-pressure of detonation production, Pa; $E$- initial specific energy, kJ; $v$-volume per unit mass of detonation production, $m^3/kg$; $A$, $B$, $R_1$, $R_2$, $W$- characteristic values given according to the kind of explosive.

In ANSYS [7] is reflected the physical and mechanical characteristics of explosive based on above equations, these are called JWL model and selected as a kind of material library.

The result of modeling on the physical and mechanical characteristics of some kinds of explosives by using the state equation of JWL is given in Table 2.

| Table 2. physical and mechanical characteristics of some explosives by JWL |
|-----------------------------|-------|------|------|-----------------------------|
| Factors                    | ANFO  | TNT  | RDX  | Ammonite №7                 |
| Density $\rho$, Kg/m$^3$   | 931   | 1 630| 1 865| 950                         |
| Factor A, GPa              | 49.46 | 373.77| 907.3| 47.6                         |
| Factor B, GPa              | 1.891 | 3.747| 10.4 | 5.29                         |
| Factor $R_1$               | 3.907 | 4.15 | 4.7  | 3.5                          |
| Factor $R_2$               | 1.118 | 0.9  | 1.0  | 0.9                          |
| Factor W                   | 0.333 333 | 0.35 | 0.4  | 0.3                          |
| Propagation velocity of shock wave $D$, m/s | 4 160 | 6 930| 8 520| 3 600                        |
| Initial specific energy $E$, kJ/kg | 2 484 | 6 000| 10 500| 4 500                        |

2.2.3 Calculation model. The size of model for calculation is 24 000mm×42 000mm, the charging diameter is 76mm and the detonation point is placed at the collar, middle and bottom of the hole and the explosive is selected the ammonite №7.

3. Numerical simulation by Ansys Autodyne
Since preprocessing such as geometrical modeling and mesh cannot be properly performed with Ansys Autodyne, we performed the numerical simulation in combination with the partial program Explicit Dynamics of ANSYS Workbench.

① Mesh
The mesh is carried out by importing the geometrical model built in SolidWorks into Geometry function of ANSYS Workbench and by transferring into Mesh and with Medium method.

The size and number of finite elements are 30mm×30mm and 630 000 respectively with reference to the accuracy and capacity of computer.

② Initial Condition
Model is set up with lead-zine ore and the factors of the material attributes are set up with the given value of Tables 1 and 2.

③ Boundary Condition
The rest of surfaces except for the free surface of drilling drift is set up with constraint boundary condition as the displacement boundary condition.

Since the external force exerting on the model is the ground pressure which is exerted on the drift, the gravity and the lateral pressure are exerted on the upper and side faces of the model and the bottom face is constrained as the stress boundary condition.

If they are calculated under the condition of the ore body,
$$\sigma_z = \gamma H = (2 800 \times 9.8) \times 70 = 1.921 \times 10^6 \text{ Pa}$$
\[ \sigma_z = \sigma_y = \frac{\mu}{1-\mu} \gamma H = \frac{0.3}{1-0.3} (2800 \times 9.8) \times 70 = 0.823 \times 10^6, \text{ Pa} \]

Where \( \sigma_z, \sigma_y, \gamma, H \) - vertical and lateral stress, Pa; \( \gamma \) - specific gravity of ore body, N/m³; \( \mu \) - Poisson coefficient of ore, \( H \) - occurrence depth of ore body, m

4. Interaction

Interaction is set up with Euler/Lagrange. Since there is the simultaneous detonation, detonation point is set up with the point way.

5. Execute

Here, the number of rotary is less than 1 000 000 and the time for simulation is more than 5~ 10ms, which are set up in the Control item.

The time step is reasonably selected in the Output item and then numerical simulation is carried out by selecting the Run item.

6. Result

After the numerical simulation, the process and result of ore break are analyzed according to each priming method by damage variable. (Fig. 2)

The red color marked in the figure means the complete breakage of ore body.

Fig 2. Result of numerical simulation analysis by damage variable.

4. Effect of priming methods on result of ore body fragmentation

Priming method gives a large influence on the blasting effect, especially on the fragmentation grain-size by blasting, because the interaction of stress field induced by blasting of the explosive is different with the same elements for blasting.

We investigated the changing characteristics of fragmentation grain-size by blasting according to the priming methods under the same elements condition for blasting, where the drill hole burden \( W \) is 3.0m, the distance between the bottom of hole \( a \) is 2.5m, the 70% of the hole length is charged with ammonite No7 by zigzag pattern and one column is blasted simultaneously.

The layout for drilling and blasting made based on the given blasting elements is shown in Fig. 1.

4.1. Case of collar priming

The changing relationship between damage distribution of ore body and fragmentation grain-size by blasting according to the size of drill hole burden in the collar priming is shown in Fig. 3 and Table 3.

As shown in the figure and table, grade rate in which the grain-size is less than 100mm takes about 50% and more than 1 000mm takes 28 to 47% and the grain-size between them is 3 to 12%. The grade
rate in which the grain-size is 100 to 750mm takes only 2 to 5%, which shows that collar priming is very disadvantageous in the view of blasting fragmentation.

![Damage distribution of ore body by collar priming](image)

**Fig. 3.** Damage distribution of ore body by collar priming.

### 4.2 Case of middle priming

Fig. 4 and Table 3 are shown the changing relationship between damage distribution of ore body and fragmentation grain-size by blasting according to the size of drill hole burden in the middle priming under the same condition as the above drilling pattern.

As shown in the figure and table, grade rate in which the grain-size is less than 20mm takes 12.5 to 15% and more than 1000mm takes 47% and the grain-size between them is 8.3 to 50%, which is very large as compared with the collar priming. The grade rate in which the grain-size is 100 to 750mm takes 41%, which shows that middle priming is very advantageous as compared with collar priming but the product rate of boulder is comparatively large as 47%.

![Damage distribution of ore body by middle priming](image)

**Figure 4.** Damage distribution of ore body by middle priming

### 4.3 Case of bottom priming

Fig. 5 and Table 3 are shown the changing relationship between damage distribution of ore body and fragmentation grain-size by blasting according to the size of drill hole burden in the bottom priming under the same condition as the above drilling pattern.

As shown in the below figure and table, grade rate in which the grain-size is less than 20mm and more than 1000mm takes 5.0~9%, 12~20% respectively and the grain-size between them is 12~20%. The grade rate in which the grain-size is 100~750mm takes 45~47%, which shows that bottom priming is very advantageous as compared with collar and middle priming.

As a result, the producing rate of dust ore and boulder of more than 750mm in diameter are 9.4% and 31.4% respectively in the collar priming, which is very higher than the other priming methods and in the bottom priming, they are 0.1% and 3.3% smaller than the middle priming respectively.
Form the above investigation, applying the bottom priming method in fan-patterned long hole blasting shows that it is very effective in reducing the producing rate of boulder as well as dust ore.

**Fig 5.** Damage distribution of ore body by bottom priming

**Table 3.** Fragmentation grain-size by blasting according to the priming (%)

| Priming Method   | Fragmentation grain-size, mm |
|------------------|------------------------------|
|                  | < 20 | 20-100 | 100-750 | 750-1000 | >1000 |
| Collar priming   | 9.4  | 25.2   | 28.7    | 5.3      | 31.4  |
| Middle priming   | 5.6  | 24.1   | 44.0    | 4.6      | 21.7  |
| Bottom priming   | 5.5  | 23.8   | 37.8    | 4.4      | 18.6  |

5. Case Study

The result of research is applied to the sublevel stopes between -500m ~ -710m level in a lead-zinc mine.

The length and height of the stope which is set up by the given mining and geological characteristics are 55m respectively. The explosive used is ammonite No7, the size of drill hole burden W is 3.0m, the distance between the end of blast hole is 2.4m, the drilling diameter is 76mm and the long holes are drilled using the disk type rock driller FJY25 and the are charged by the bisector method and it is detonated with simultaneous blasting one by one column.

The layout plan for drilling and blasting of the object is designed by using JKSimBlast.

**Table 4.** Characteristics of the objective ore body

| №   | Index                        | Unit  | Value   |
|-----|------------------------------|-------|---------|
| 1   | Thickness of ore body        | m     | 13~18   |
| 2   | Dip                          | °      | 55~60°  |
| 3   | Ore name                     |       | Galena  |
| 4   | Strength coefficient of ore  | f      | 8       |
| 5   | Strength of hanging wall rock| f      | 9       |
| 6   | Strength of footwall rock    | f      | 14      |
| 8   | Grade of ore                 | %      | 15~18   |
The flow chart to design the fan-patterned long hole blasting by using JKSimBlast[6] is given in the Fig. 6 and the layout plan based on it is given in the Fig. 7.

![Flow chart for designing the fan-patterned long hole blasting](image_url)

Fig 6. Flow chart for designing the fan-patterned long hole blasting
By applying the bottom priming in the fan-patterned long hole blasting based on the above layout plan for drilling and blasting, the producing rate of boulder is lowered as 17.1% from the former 26.2% and we achieved a considerable economic profit.

6. Conclusion

We can achieve the following conclusions from the above research results.

Firstly, the damage of ore body and the changing characteristics of fragmentation grain-size by blasting can be solved according to the priming methods under the same condition as blasting elements by Ansys Autodyn.

Secondly, in the view of fragmentation grain-size by blasting, the bottom priming is more effective than the other priming methods in the fan-patterned long hole blasting.

References

[1]. Emilie Sarah Willoams 2002 A Controlled Blasting Approach to Dilution Control in Narrow-Vein Mining (Canada) p 34–70
[2]. Rick Tavas, 2001 Determination of Blast-Induced Dynamic Soil Response Using Axisymmetric Boundary Elements (University of California) p. 20–70.
[3]. N.F. Mott 2006 Fragmentation of Rings and Shells (Springer-Verlag Berlin Heidelberg, Germany) p 23–230,
[4]. Optimizing the blast process. 56–57, www.MiningMagazine.Com., September, 2015.
[5]. Forward Charge. 46–52, www.MiningMagazine.Com., November, 2015.
[6]. JKSimBlast Manual (Version 2.0) 2005 QLD, Australia, p 1–79,
[7]. ANSYS 18.1 Help, 2017.
[8]. Ali Fakhimi et al. 2014 DEM–SPH simulation of rock blasting. Computers and Geotechnics (55), 158–164.
[9]. Thierry Bernard et al. 2014 The Digital Simulation of Blasts: A Major Challenge for Mines in the 21st Century. Procedia Engineering (83), 100–110.
[10]. G. R. Liu et al. 2003 Smoothed Particle Hydrodynamics (World Scientific Publishing Co. Pte. Ltd) p 1–389.
[11]. Egon Krause et al. 2007 Computational Science and High Performance Computing III. (Springer-Verlag Berlin Heidelberg) p 206–223
[12]. Qiang Wu et al. 2015 SPH-Based Simulations for Slope Failure Considering Soil-Rock Interaction. Procedia Engineering (102) 1842~1849.
[13]. Christian Heckotter et al. 2015 Experimental investigation and numerical analyses of reinforced concrete structures subjected to external missile impact. Progress in Nuclear Energy (84) 56~67.
[14]. Houfu Fan et al. 2016 A hybrid peridynamics–SPH simulation of soil fragmentation by blast loads of buried explosive. International Journal of Impact Engineering (87) 14~27.
[15]. Sun Zhaochen et al. 2015 A two-phase simulation of wave impact on a horizontal deck based on SPH method. Procedia Engineering (116) 428~435.
[16]. John F. MOXNES et al. 2015 Strain rate dependency and fragmentation pattern of expanding warheads. Defence Technology (11) 1~9.
[17]. John F. MOXNES et al. 2014 Experimental and numerical study of the fragmentation of expanding warhead casings by using different numerical codes and solution techniques. Defence Technology (10) 161~176.
[18]. W. Riedel et al. Hypervelocity impact damage prediction in composites: Part II—experimental investigations and simulations. International Journal of Impact Engineering (33) 670~680. 2006.
[19]. W. Riedel et al. 2010 Transient stress and failure analysis of impact experiments with ceramics. Materials Science and Engineering B (173) 139~147.
[20]. Rajarshi Das et al. 2008 Studying the Effect of Rock Shape on Brittle Fracture Pattern Using a Mesh-free Method SPH. Proceedings of the World Congress on Engineering (11) 173~178.