Effect of Delay Time and Firing Patterns on the Size of Fragmented Rocks by Bench Blasting

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Abstract. This paper discusses the size control method of fragmented rocks induced by bench blasting in an open pit mine, especially the effect of delay time and firing pattern. Based on the results of a series of field tests, it can be said that the delay time and firing pattern have an impact on the size of fragmented rocks. The application of two directions of firing pattern that the order of ignition of blast holes is from the center to both ends of the row of blast holes can produce a more uniform size of fragmented rocks compared with that of a one-directional firing pattern which is the order of the ignition of blast holes from one side to the other. Due to the rock mass conditions and products specification, the size of fragmented rocks and its distribution can be controlled by applying an appropriate delay time and firing pattern.

Keywords: Delay Time, Firing Pattern, Rock Fragmentation

1 Introduction

Rock blasting is the rock excavation and fragmentation technique most widely adopted in the various fields of the mining, civil and construction industries because of its efficient, and economical aspects [1]. On the other hand, in case that the blasting operation may have an obvious impact on the surrounding environment, such as ground vibration, fly rock, noise, etc. blasting standards or conditions are not appropriate [2]. Moreover, the size of fragmented rocks have an obvious impact on the open pit mining operations such as loading, hauling and crushing, and it may have a large influence of the total operation cost. Hence, one of the keys for success of safe and economical mining operations is to design an appropriate blasting standard based on the rock mass conditions.

From these points of view, this paper discusses the size control method of fragmented rocks induced by bench blasting in an open pit mine especially considering the effects of delay time and firing pattern without changing other blasting standards such as burden, spacing and/or powder factor.

2 Overview of Field Experiments

The case study Mine A used in this research is located in the southern part of Kyushu Island in Japan. This mine is an open-pit metal mine and extracts a silicic-acid ore which contains gold.

A series of blasting tests were conducted at three faces (east, west, and north) in B pit. Table 1 represents the basic blasting design used in this pit. Ammonium Nitrate Fuel Oil (ANFO) was used as the explosive and was initiated hole by hole using electric detonators. Before blasting, a photograph of the bench face was taken for evaluation of the fracture/joint state of rock mass. After blasting, a photograph of the debris was taken for the rock fragmentation analysis, and then the rock samples were collected in order to the measure mechanical properties of rock at each face.

In this test, the delay time and the firing pattern (the order of the ignition) were changed and their effects on the size of fragmented rocks were discussed.

Table 1. Basic blasting standard at Mine A.

Burden (m)	2.5
Spacing (m)	1.5
Borehole diameter (mm)	76
Bench height (m)	10
Bench angle (°)	80
Drilling angle (°)	80
Drilling length (m)	12
The number of blast hole (hole)	10
Powder factor (g/t)	170
Charge quantity (kg/hole)	23.7

2.1 Evaluation of Fracture/Joint Conditions in Rock Mass

Before blasting, a photo of each face was taken by a digital camera in order to investigate and record the fracture condition of the rock mass. As shown in Fig.1, courses of traverse were set at the face wall (every 2 m), and then the sizes and abundance ratios of each rock block separated by discontinuities and courses of traverse were calculated. This space of fracture/joint assumes the particle size of each rock block. The particle size at 50% of the gain size accumulation curve of rock blocks before blasting (Xb_{50}) was used as a representative parameter for evaluating the joint/fracture condition of rock mass at each face. Moreover, the directions of the major joint systems were measured by using a clinometer.

2.2 Fragmentation Analysis

Fragmentation assessment was achieved by the analysis of a scaled photograph taken from the fragmented rocks. Paley recommended a procedure for taking photographs of
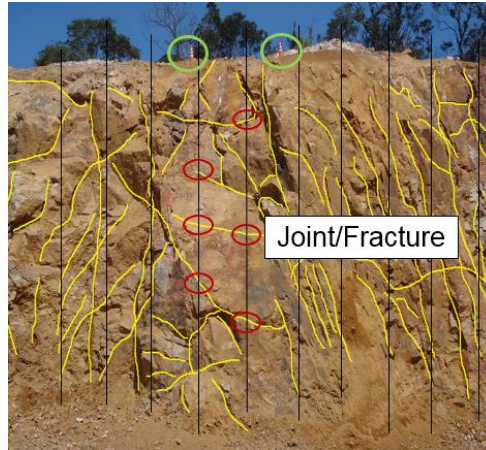
Fig. 1. Measurements of joints/fractures condition of rock mass at test face.

fragmented rocks as to minimize errors due to distortion [3]. Two balls with a diameter of 24 cm were used as a scale in the photograph. The balls were placed in the same vertical line down the fragmented rocks, preferably with one ball near the top of the fragmented rocks and the other near the bottom. The balls should not be placed randomly in the fragmented rocks nor in a horizontal line across them. The camera was held such that the long axis of the photograph was vertical. The photograph was then taken with the camera as perpendicular to the surface of fragmented rocks as possible. By having two balls on the surface of fragmented rocks, allowance was made for a variable scale within the photograph when the camera could not be positioned perpendicular to the surface of the fragmented rocks.

The scaled fragmentation photographs were manually digitized from the original photograph on the computer screen by software known as Split-Desktop, developed by Split Engineering, as illustrated in Fig.2 [4]. The outlines of visible rocks above a certain minimum resolution, 3 mm in diameter on the photograph, were traced by a mouse. After the digital image was analyzed, the particle size distribution of fragmented rock was derived, as shown in Fig.2. The representative particle size at 50% of the gain size accumulation curve, Xp_{50}, was used in this research.

3 Results and Discussions.

3.1 Effect of Delay Time on Distribution of Rock Fragmentation

Delay blasting is generally conducted in order to control blast-induced ground vibration. In addition, it influence on the fragmented effect since it creates a new free face. Fig. 3 illustrates the blasting pattern discussed in this section. By using MS electrical detonators, two types of delay time: 25 ms and 50 ms were set in the field experiment. In addition, firing direction was also discussed. One was firing from edge to edge of the blasting hole and the other one was firing from the center to the edges of the holes.
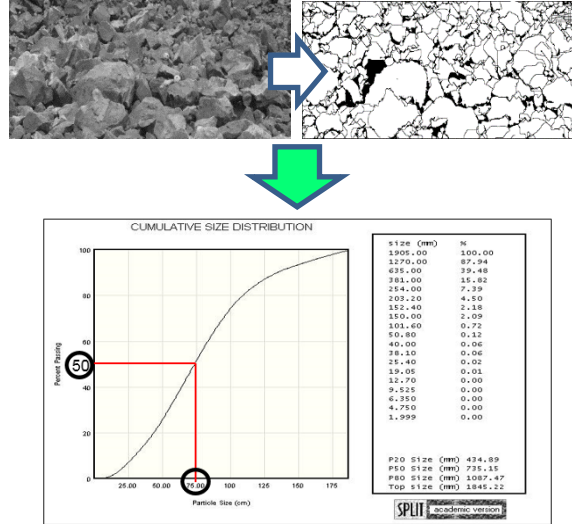
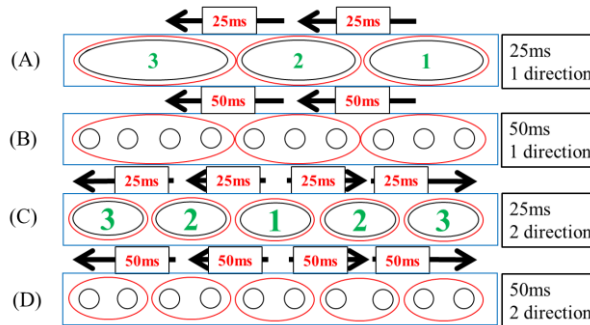**Fig. 2.** Procedures of fragmentation analysis.

Fig. 3. The illustration of blasting pattern.

Example photographs of muck pile in each blasting pattern are shown in Fig. 4. As shown in these photographs, size distribution of rock fragmentation is different from each blasting pattern. In the case of blasting patterns (A) and (B) in Fig. 3, firing from edge to edge of the row, the size of rock fragmentation is obviously different depending bench face. In other words, the size tends to be big around the area of start of firing point and the one is likely to be small around the area of the end of firing point.

On the other hand, in the case of blasting patterns (C) and (D) in Fig. 3, firing from the center to the edges, overall of the size tends to be homogeneous. Hence, as a next step, the photograph of the muck pile is divided in to 3 parts as shown in Fig. 5; the photographs are analyzed by Sprit-Desktop software again. The percent passing of the size of fragmentation of patterns (A) and (C) is shown in Figs 6 (a) and (b), respectively. The results described above are successfully seen in these figures. In case of one direction firing pattern, the size tends to be big around the area of start of firing point since

stress wave interference is hard to occur around the area and at the end of firing point, stress wave interference help to reduce the size of rock fragmentation. On the other hand, because stress wave interference equally occurred overall blasting area, resulting in homogenous size distribution.
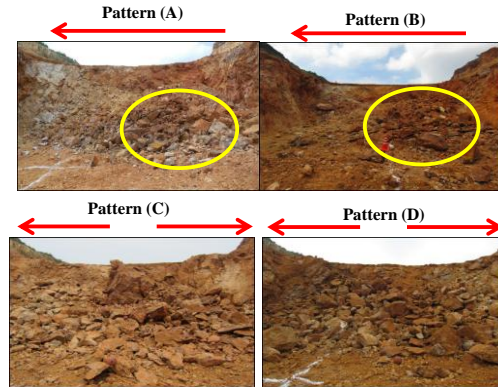

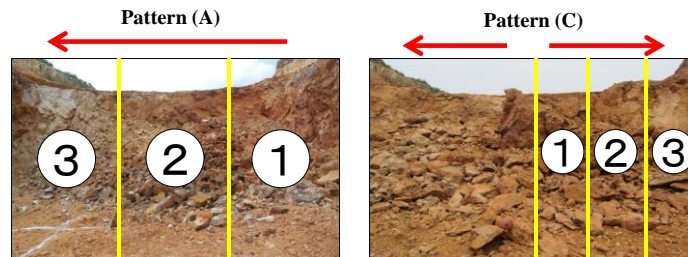**Fig. 4.** The muck pile after blasting in each blasting pattern.

Fig. 5. The divided photographs for discussing the effect of blasting pattern (a) dividing pattern for Pattern (A) and (B) and (b) dividing pattern for Pattern (C) and (D).
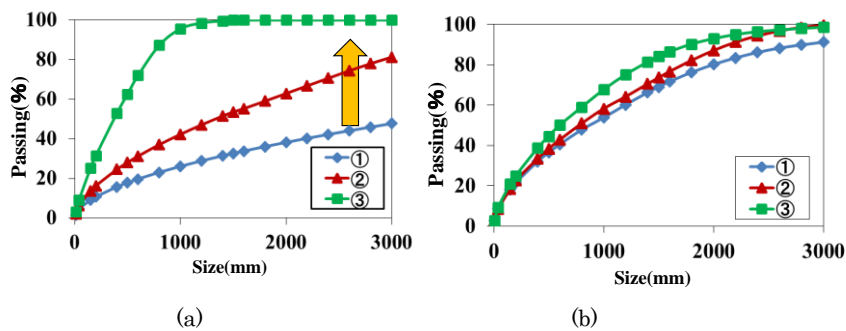

Fig. 6. The accumulation curves obtained from divided photograph (a)the result of Pattern (A) and (b) the result of Pattern (C).

6

3.2 Prediction of Distribution and Size of Fragmentation in Delay Blasting

Based on the discussion described above, the prediction of fragmentation size in delay blasting is established in this section. In order to access the distribution, the homogeneity of the distribution have to be quantitatively evaluated. Therefore, the uniformity coefficient is defined on a basis of uniformity coefficient which is generally used to classify the soil [5] as follow:

$$n = \frac{X_{p60}}{X_{p10}} \qquad (1)$$

Where, n is uniformity coefficient, X_{P60} and X_{P10} are the particle size at 60% and 10% of the gain size accumulation curve, respectively. In the field of soil classification, the range of the size distribution is classified as wide when $n \geqq 10$. On the other hand, the soil is judged as uniform when n is less than 10. Representative distributions and their uniformity coefficients are shown in Figs 7 (a) to (c). By visual observation, the distributions are divided into three ranks in this study. The divided rank is listed in Table 2. In addition, the result of uniformity coefficient in each firing pattern is shown in Fig. 8. Moreover, the averages of uniform coefficient of patterns A, B, C and D are 27.7, 15.1, 5.65 and 7.98. Based on the results, it can be said that two directions of firing pattern can make the distribution more uniform. This might be because the formation of stress wave interference and free face occur symmetrically in the case of two directions of firing pattern. On the other hand, the behavior of superposition of stress waves is different depending upon the place in the case of one direction of firing pattern, which result in un-uniform size distribution.

(a)   (b)   (c)

Fig. 7. The representative distribution of fragmented rock in uniformity coefficient (a) 2.1 (b) 15.1 (c) 20.3.

Table. 2. The rank of distribution in each uniformity coefficient.

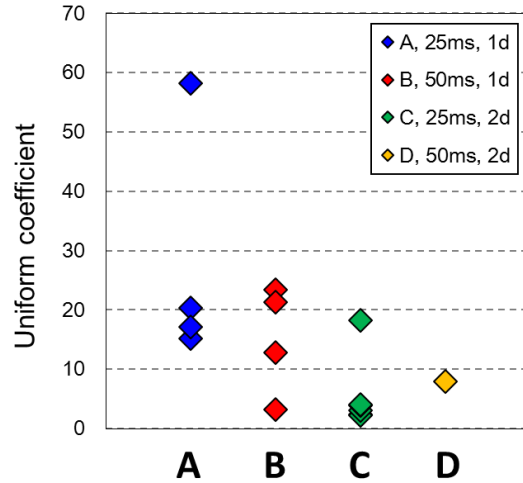| Rank	Uniformity coefficient
good	0～10
normal	10～20
bad	20～

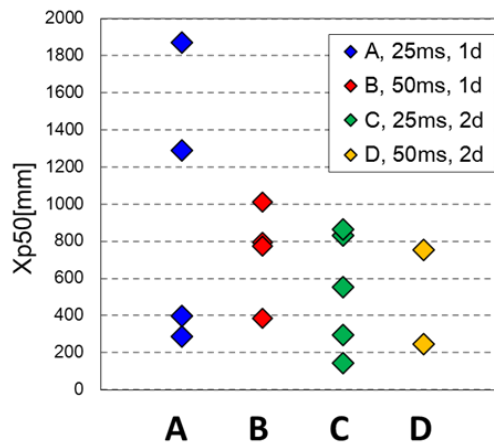**Fig. 8.** Uniformity coefficient in each firing pattern.

Fig. 9. The relationship between firing pattern and X_{P50}.

Furthermore, the effect of delay time and firing pattern is discussed. The relationship between firing pattern and X_{P50} is illustrated in Fig. 9. As can be seen in this figure, X_{P50} in the case of 50 ms looks like small. Hence, the average of X_{P50} of each firing pattern is calculate. The average X_{P50} of pattern A, B, C and D are 961.3 mm, 742.1 mm, 537.6 mm and 500.7 mm. This result suggested that the size of fragmented rock can be reduced by applying 50 ms of delay time in this mine. There might be certain delay time which can reduce the size of fragmented rock. On the contrary, the average X_{P50} of one direction (A and B) and two directions (C and D) of firing pattern are 851.2 mm and 528.3 mm, respectively. Moreover, the average X_{P50} of 25 ms (A and C) and 50 ms (B and D) of delay time are 707.0 mm and 661.7 mm, respectively. It can be seen that although delay time influence on the mean size of fragmented rock, the influence

of firing direction is more significant than that of delay time. Two directions of delay time have good dependent advantage of both distribution and mean size of fragmented rock. Although the required size is depending upon the operation, two directions of firing pattern is better to apply basically in terms of uniformity and delay time should selected depending upon the operation in order to control the size of fragmented rock.

4   Conclusions

Delay time has an obvious impact on the size and distribution of blast-induced fragmented rocks. Firing direction strongly influence on both the distribution and size of blast-induced fragmented rocks. Homogeneous size of blast-induced fragmented rocks can be obtained by conducting two directions firing pattern and one direction firing pattern make the size distribution heterogeneous. On the other hand, delay time influence on the size of fragmented rocks, but the influence of the firing direction on the size is larger than that of delay time.

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