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Effect double-primer placement for improving the fragmentation on harder material in stemming column: a case study

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Abstract. The fragmentation is one of the indicator of the successful blasting operation, because the next step is loading the blasted material which is the equipment productivity is depend on the bucket fill factor. Greater size of material loaded means lower bucket fill factor. Lower bucket fill factor, lower equipment productivity. More crack due to blasting, easier loading equipment to dig it up. The explosive energy transferred to the surrounding caused radial crack first. Then the shock wave formed and travel through the crack. Higher Velocity of Detonation (VoD), higher detonation wave produced. Then, increasing distance from the source of VoD the energy is getting lower. The simply way to improve fragmentation is increasing the Powder Factor (PF), but it has any side effects. The double-primer placement with double deck method will improve the fragmentation while using the same value of PF.

Keywords: double primer, double deck, fragmentation, excavator productivity, explosives energy.

1. Introduction

Fragmentation is one thing that indicates the overall blasting result. This affected by some factors and process. Why fragmentation is being very important? Because the next step of the cycle is loading the material-blasted by excavator and then hauled by hauling unit (truck or conveyor). Due to this is a cyclic process, when one step is in slow-motion, the whole cycle is being slower. Some customers use the fragmentation as the base for allocating the blasting cost.

The explosive chemical reaction produces the detonation waves as the energy. This is called store energy in explosive. This wave travels along an explosives column explains the speed of fully reaction of explosive, the velocity is called VoD (Velocity of Detonation). The higher of VoD will be the higher of bore hole pressure developed. When this shock reach the bore hole wall, it will form radial crack and fragmentation begin. The shock wave will decrease while enter the media. The more longer the column charge, the shockwave is being greater. Greater shockwave will generated more radial crack that will be the way for gas expansion. Clearly, more explosive will gain finer fragmentation.
But in some condition the effect of using more explosive is not accepted by regulations or by company blasting budget. The amount of explosive using is usually express by Powder Factor (PF) which is ratio of total explosive used and total blasted material. More PF is being used, better fragmentation aimed and higher cost budgeted.

Zhang (2005) said that using double primer has many purposes, such as for ensure that the main charge will be detonate perfectly (backing up for the other initiator), maintaining the ground vibration and improving the fragmentation. Because of the stemming is vital to contain the explosive energy within the rock mass for fragmentation as opposed to escaping out the top of the blast hole and energy distribution is a particular problem in the upper part of the bench where explosive has been replaced by stemming, this paper will deal with the last purpose; improving the fragmentation.

Base on theory of breakage due to blasting, shock wave is produced by the gas pressure (pressure and temperature was so high) as the results of detonation. The test did by Dawes et al shows that the stress wave amplitude on rock mass due to using double primer (in blast hole) is higher than two amplitudes of stress wave that is produced by single primer. It takes effect on using non electric detonator and electronic detonator.

2. Method
2.1. Study Area
The study was conducted in one of the branches of PT DNX Indonesia located in the district of Berau, East Kalimantan. Blasting is done on the overburden layer. The overburden layer on which the study was located is a "batuputih" layer that is often a problem in the production department due to the inadequate blasting characterized by an unexpected target of excavator production, particularly on the first layer.

Based on lithologic data, this layer is a sandstone layer (very fine grain size) that inserts on the shale-muds layer. The color is gray, very compact, crystalline texture, containing iron and quartz. Thickness 30-50 cm. at the study site, the thickness of this layer is approximately 80 cm and in some Blast holes are in the stemming column (relatively in collar), so the explosive energy is not enough to dismantle this layer. Fragmentation is excellent near the charge and gets worse as the distance away from energy source increases.

![Figure 1. The Lithology of the Site](image-url)

The blasting designs used on the condition as following below. This blast design was use daily, on each location. There were no special adjustment for special case happen.
Table 01. Data of Blast Geometry

| Items            | Amount | Unit of Measurement |
|------------------|--------|---------------------|
| PF Maximum       | 0.23   | -                   |
| Burden           | 9      | Meter               |
| Spasi            | 10     | Meter               |
| Hole Depth       | 9      | Meter               |
| Hole Diameter    | 200    | Mm                  |
| Charge           | 186.3  | Kg                  |
| Length of Charge | 4.8    | Meter               |
| Stemming height  | 4.2    | Meter               |

The figure 2 below attached the energy distribution within the design above. This figure use the program of 2dBenck by JK Simblast.

From the figure 2, we know that the last energy reach at the collar of blast hole was at 0.713-1.325 Mj/m³. With this design, production report says that the productivity often below the target at 1.425 BCM/Hour.

2.2. Analysis Tools
To determine the amount of energy released by explosives was developed by Cole in 1965. Energy sources are divided into 2, namely: a. Strain Energy-ET, energy from strain wave b. Bubble Energy,
energy from detonated gas. When a wave moves faster than the local speed of sound in a fluid, it is a shock wave. Like an ordinary wave, a shock wave carries energy and can propagate through a medium. Just as waves in general shock wave have energy and can develop / spread through a medium.

Based on the theory of one-dimensional shock wave, when one shock wave (with pressure P1) meets with another wave (pressure P2), the final pressure (P3) generated will be greater than the sum of P1 and P2 (P3 > P1 + P2).

![Figure 3. Shock Wave Collision Theory](image)

This is called Shock Collision. A shock wave collision is different from the elastic wave collision. In one-dimensional conditions, the elastic stress wave (with stress σ1) meets with another elastic stress wave (with stress σ2), then the final stress produced equals the overall amount of stress (σ3 = σ1 + σ2).

In shock wave collision, the final pressure depends on two initial shock pressure and material conditions.

Drilling the hole is carried out prior to blasting by using a specific geometry. The geometry of drilling are: diameter of bore hole, depth of bore hole and incination of bore hole. The geometry of blasting are: Burden (B), Spacing (S), Bench Height (H), Length of Column of Charge, Subdrilling (J) and Stemming Column (T).

![Figure 4. Blast Geometry](image)

Equation for volume of blasting is

\[
V = B \times S \times H \text{ (BCM)}
\] (1)
**Powder factor** is the ratio of explosives and volume of blasting, is

\[ PF = \frac{\text{Total Explosives Used (Kg)}}{\text{Total Volume of Blasting (m}^3) \]  \tag{2}

\[ PF = \frac{\text{Total Explosives Used (Kg)}}{\text{Total Tonage of Blasting (Ton)}} \]  \tag{3}

**Explosives Energy**

The effects of the energy released by the explosives in the rock media and measured as fragmentation, ground movement, and vibration among others, are dependent on the characteristics of the explosive products. (Lusk, et al., 2018)

When energy is released, oxidation reaction occurs, the consequence is a significant amount of heat is generated, they increase the temperature and expanding rapidly causes high pressure. Depend on the (confining) media, it causes deformation, movement, rock damage and fracturing, among others.

The explosive characteristic to estimate the level of energy stored in the explosive are (1) density, (2) detonation velocity, and (3) detonation pressure.

The actual energy released by explosives and manifested as high pressure and high temperature gas product will act on the surrounding rock to initially produce expansion work, that energy is the sum of: fragmentation energy, Seismic energy, kinetic energy, fragment rotation energy, energy in forms that vary difficult to measure (i.e : to expand the borehole, produce cracks in the fragments, to heat the rock mass, etc).

**Explosive density**

\[ \text{Density} = \frac{\text{Weight of Explosives (g)}}{\text{Volume of Explosives (m}^3) \]  \tag{4}

For example the density of ANFO is 0.8 g/m³. The higher density of explosives will provide more energy for breaking the rock. If the density is too low, the explosives is more sensitively to detonating cord. If the density is too high, it will more difficult for initiating. So there were death density.

**Velocity of Detonation (VoD)**

Velocity of Detonation (VoD) is also named Detonation Velocity which is refers to the speed of detonation wave is propagated through the explosive and therefore is the parameter which defines the rhythm of energy release (Jimeno, et al., 1995). It affected by charge density, confinement, initiation and aging of explosive. In other hand, Lusk (2018) said that variables affecting the VOD are (a) the relationship between VOD and density; and (b) the diameter of the charge and its relationship to VOD are of particular interest for practical applications.

In general a reduction in the VOD will cause a reduction in the detonation pressure as well as in the availability of the released energy of the explosive (Lusk, et al., 2018).

**Explosives pressures**

The blasting reaction produces a very high temperature gas called detonation pressure. It is the function of the density and the square of the detonation velocity. Jimeno (1995) gives the equation below:

\[ PD = 432 \times 0,000001 \times \rho e \times \frac{VoD^2}{1+0.8xpe} \]  \tag{5}

Where: \( PD = \)Pressure of Detonation (MPa), \( VoD = \)Velocity of Detonation (m/s), \( \rho e = \)Density of Explosive (g/cc).

**Bore Hole Pressure**

Pressure on the wall of the borehole due to the high explosive temperature (explosive pressure = Pe) is only half of the detonation pressure.

The blasting results have special provisions relating to fragmentation when associated with transport of material (transport-loading and hauling) (Hustrulid, 1999) are: diggability, muckpile size,
average distribution of fragmentation and amount and size of fragment.

**Excavator Loading Cycle**
A complete loading cycle of an excavator are: dig, swing, dump, return swing and bucket spot. Dig process has the strong relation with the blasted rock. Mining manuals provide loading cycle times or production rates of excavators as function of the volume of the bucket and a qualitative description of the ease of excavation of the rock or its diggability.

3. **Results**

3.1. **Blasting Design**
Blasting done with Burden: 9 meters, Spacebar: 10m, depth: 9 meters. The explosive used is the emulsion blend type (T4070). It has VoD 4,600-5500 m/s in 200 mm hole diameter (Maksimum VoD on proper condition). Powder factor has been designed on 0,23.
Blasting will be done using double-primer engineering with double deck. The goal is that explosive energy can dismantle the "batuputih" layer present in the stemming column. The following is the blasting plan data.

| Items                  | count | Unit of Measurement | Description   |
|------------------------|-------|---------------------|---------------|
| PF Maximum             | 0.23  | -                   | -             |
| Burden                 | 9     | Meter               | -             |
| Spasi                  | 10    | Meter               | -             |
| Hole Depth             | 9     | Meter               | -             |
| Hole Diameter          | 200   | Mm                  | -             |
| Charge                 | 186.3 | Kg                  | Total Charge  |
|                        | 110   | Kg                  | Lower Deck    |
|                        | 86.3  | Kg                  | Upper Deck    |
| Length of Charge       | 3     | Meter               | Lower Deck    |
|                        | 2.1   | Meter               | Upper Deck    |
| Stemming height        | 2.9   | Meter               | Collar stemming|
|                        | 1     | Meter               | Middle stemming|
From the figure, we know that the last energy reach at the collar of blast hole was at 1.325-1938 Mj/m³. With this design, production report says that the productivity reach the theoretical target (see table 3).

3.2. Delay time
Blasting is done by hole by hole method using non electric detonator. Delay on 25ms row control and echelon row 67ms. The blasting design used was echelon - box cut. In hole delay detonator (IHD) used on the same top and bottom decks, which is 500ms.

3.3. Excavator Productivity
Below attached the result of the observation of digging time related to the productivity based on MCR. The data recorded randomly at the same type of excavator used.
### Table 03. Data of Excavator Productivity

| No | Average Digging Time (sec) | Time of Observation | Excavator Unit ID | Layer | Productivity Report from MCR (BCM) |
|----|---------------------------|---------------------|-------------------|-------|-----------------------------------|
| 1  | 9.97                      | Day 1               | 09:00-09:40       | PC3600-07 | 1                                | 1,716 |
| 2  | 9.58                      | Day 2               | 10:00-10:28       | PC3600-07 | 1                                | 1,736 |
| 3  | 11.73                     | Day 3               | 09:40-10:00       | PC3600-07 | 1                                | 1,860 |
| 4  | 10.46                     | Day 4               | 10:00-10:24       | PC3600-07 | 1                                | 1,488 |
| 5  | 9.97                      | Day 5               | 10:10-10:40       | PC3600-07 | 1                                | 1,488 |
| 6  | 12.19                     | Day 6               | 15:30-16:30       | PC3600-07 | 2                                | 1,603 |
| 7  | 12.23                     | Day 7               | 14:15-15:15       | PC3600-07 | 2                                | 1,488 |

The average digging time seems has no linear relation with the productivity caused by the aspect of influencing productivity is not only by the digging time. But the shorter digging time, will increase the productivity in some condition.

![Figure 7. Resume of Productivity Report on Trial Location](image)

The red line was the target line. From these it show that the productivity was greater than 1.425 BCM/Hour.

4. **Discussion**

4.1. **Stemming material**

Commonly, stemming is the material (not the explosives) placed on the top of blasthole which has the purpose to confine the gasses. Optimum grade of stemming is important to transfer energy to the material around the blast hole, if the gas escape from blast hole (in a large amount), the energy transferred was getting lower.

With use of proper stemming material and amount of stemming these pressure losses can be minimized, increasing the efficiency of explosive comminution (CJ Konya, et al 2018). Proper stemming was shown to increase explosive efficiency by over 40%. There was three mechanism of stemming material: inertia-resistance (the weight of the stemming acting downward), stem-wall shearing along the borehole wall and internal resistance to flow of the material (similar to viscosity). The last point is most critical mechanism; interlocking ability to prevent stemming blowout.
In this study, the stemming material used was drill cutting, the type is free flowing solids which has mechanism inertia-mechanism that only has weight and viscosity and does not lock in to place and typically blows out. But, not only in this study of using the drill cutting, daily blasting practice was using this drill cutting. So, the trial was closer with the real condition. Some blasting activity has limitation about the cost that expressed with the powder factor (PF) value. This trial was limited by 0.23 of PF. To achieve the energy distribution and the PF at equilibrium, this method can be applied. This is likely of two “normal” hole (stemming is at the top) in one blasthole paralelly.

4.2 Blasting Energy Used

The main problem in this site is, the “batuputih” layer at the collar (stemming column), it is caused the blasting energy cannot reach the layer. It can be the problem for excavation unit (Back hoe). The material under the stemming column was good result, but the excavate process begin from the top. Based on the result, there was no under-productivity. The highlight is in first layer. The record says that the productivity was above 1.425 BCM/Hour. We can get the conclusion that this method suitable for deal with the “batuputih” layer lie on collar. Because, this method will reduce the distance between the charge and the “batuputih” layer, so the explosive energy that reach the top of collar greater than conventional method. Figure 2 shows maximum explosive energy reaches the “batuputih” is 3.163 MJ/m³. Besides, the trial method shows that maximum explosive energy reaches the “batuputih” is up to more than 5.000 MJ/m³ (Figure 5).

Even though, the second layer needs to be evaluated, because there is explosive gap due to the decking placement. Table 3 shows the excavator productivity achieved the target, there were not the problem.

Using double primers allows shock wave collision from two primers. It is different with elastic wave collision, shock collision produces higher final pressure than two initial shocks (Dawes JJ, 1983 in Zhang ZX, 2014). The application for these theories in this paper is in the gap between two column of explosive charge that stemmed.

Due to the shock collision theory (Zhang, 2016), when one shock wave (with pressure P1) meets with another wave (pressure P2), the final pressure (P3) generated will be greater than the sum of P1 and P2 (P3> P1 + P2). The pressure used to break the rock.

Zhang (2016) in his study did double-primer placement was in sublevel caving and rock break in the roof of a drift using electronic detonators, the result is rock fragmentation looks much finer or better according to field observations. This procedures could be better if use non electronic detonator too.
Figure 9. Stress distribution in the plane of a sublevel caving ring. Explosive is charged in the blasthole between F1 and F2, and the primers are placed at D1 and D2.

The explosive was fully charged. There were not middle stemming. the final stress is greater than either of the initial two stresses starting from D1 and D2.

Yamamoto et al. propose that while two primers detonate in same delay time, two shock wave will collide in the place with no free face, the tensile waves will meet then form the cracks, it will happen at the mid section of the spacing of blast hole.

This method not only can be applied for double primer blast hole, but shock collision also occur in the adjacent (single primer) blast hole, based on Johnson, C (2018).

Measuring and observing two shocks wave collide in strata is difficult. It is assumed that the same basic relationships occur, but how the additional parameters of shear and tensile strengths, density and unavoidable fractures in the rock mass, affect the process is more difficult to quantify (Johnson C, 2018). Simultaneously detonating charge, shock wave collides happens in mid between two adjacent hole.

Figure 10. interaction from two simultaneous detonating blast hole.

The figure was proposed by Rossmanith, P is P wave and S is S wave, F is denote the source of wave from, and E is end of wave. The collision is happen between blasthole #1 and blasthole #2. So along the spacing the rock breakage is still occur due to shock wave collide.

5. Conclusion

Rock fragmentation is not only caused by explosive energy, but also there were shock energy (strain energy) worked too. The first layer that there were “batuputih” layer is broken by more explosive
energy, but the second layer that there were explosive separated by stemming material is brokenby more shock wave collision.

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