Comparative analysis of ANFO and emulsion application on overbreak and underbreak at blasting development activity in underground Deep Mill Level Zone (DMLZ) PT Freeport Indonesia

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Abstract. Underground Deep Mill Level Zone (DMLZ) mine PT Freeport Indonesia (PTFI) is still in development stage and currently has no production activities yet. In underground DMLZ mine, a trial of emulsion explosive has conducted since March 15th, 2017 where previously used was Ammonium Nitrate Fuel Oil (ANFO) explosive for tunnel blasting. This study purposes to analyse the results and impact of ANFO and emulsion explosive in order to know the advantages and disadvantages of each explosives. In this study, an overbreak and underbreak comparison evaluation was performed by ANFO explosives and emulsion in underground DMLZ mine tunnel blasting. Furthermore, processing data based on explosives specification data, explosives quantity, heading location and time that detonated, solid design and actual tunnel DMLZ of PT. Freeport Indonesia, also cross section data. After all the data were processed and analysed, it was concluded that the emulsion explosive was more effective for use in tunnel blasting. To optimize the effective blasting results it is necessary to redesign new drilling patterns and blasting geometry by used of radial crack method, so that they can be applied to DMLZ tunnels in the future.

1. Introduction

PT. Freeport Indonesia (PTFI) is a mining company that using surface and underground mining systems. PTFI's surface mine called Grasberg is one of the largest open pit in the world, now the reserves of Grasberg will be exhausted in a few years. PTFI's underground mine has five sites: Kucing Liar, Big Gossan (BG), Deep Ore Zone (DOZ), Grasberg Block Cave (GBC), and Deep Mill Level Zone (DMLZ).

Underground mining activities require the best possible technical planning for ore retrieval. One such plan is the establishment of a tunnel (Drift) as access, Conveyor Drift, Intake and Exhaust Drift.

PTFI DMLZ underground mine is still in development stage and has not done production activities yet. One of the development stage activities is the opening of the tunnel to open the access path for employees and mining equipment. The activity is to blast the tunnel by burn cut method.

In the DMLZ underground mine, a trial of emulsion explosives has been conducted since March 15th, 2017 where previously used was ANFO for tunnel blasting. The heading is detonated with ANFO explosives, the perimeter hole using detonating cord is not filled with ANFO so that when mucking the materials of explosion and dumping in the crusher can cause explosion in the crusher. In addition,

ANFO explosives can cause excessive cracking of the tunnel.

ANFO and emulsion explosives has their respective advantages and disadvantages such as ANFO is not water resistant and emulsion is water resistant. ANFO's diameter is 2 mm and emulsion 0.001 mm where ANFO mixing is easy to do anywhere, but emulsions require enhanced sensitivity by adding a sensitizing agent (sensitizer). Since there are several consequences of using ANFO explosives in DMLZ tunnel blasting, the researchers conducted further observations on emulsion use trials as well as the effect of emulsion on overbreak and underbreak, also evaluated comparative effects of the use of ANFO and emulsions.

2. Methodology

There are literature study and data retrieval at this stage with primary data and secondary data. The data required in the final project study is obtained from Orica's direct observation as well as from UG DMLZ Engineering department in underground mine Deep Mill Level Zone PT. Freeport Indonesia.

The primary data that needed for this study are quantity of explosives used, actual tunnel condition, actual perimeter area and circumference, overbreak and underbreak area and circumference, the furthest distance of overbreak and underbreak, and actual tunnel length and volume. And the secondary data are explosive specification, the location and time of heading being detonated, tunnel solid design and actual, also drilling pattern and blasting geometry.

Explosive and rock specification data, quantity of explosives used, the location and time of heading detonated, as well as tunnel solid design and actual DMLZ PTFI be processed and obtained cross section data using Auto CAD. The cross section results will be processed again to analyze the perimeter, overbreak and underbreak, as well as the area and volume of the tunnel. Once everything is analyzed, conclusions and suggestions on effective explosives can be found to use in future DMLZ tunnels.

2.1. Overbreak and Underbreak

Many previous studies have been conducted to examine overbreak and underbreak in mining operation actvities. Overbreak and underbreak have been known as the main causal of hazards and damages to mining industry management, especially in underground mining. Refer to some previous studies, factors that causing overbreak and underbreak in mining industry can be catagorized into two points. Geological and blasting factors were the two major points that play a big role for overbreak and underbreak occurences in tunnel [1], [7].

Blasting geometry are changeable components. In modern underground blasting, smooth blasting and presplitting methods are reasonably organized techniques with advanced final wall blasting methods. Final wall customized explosives and computer base drill operating systems significantly minimize the possible failures on blasting operations. However, geological factors are unchangeable and they have a significant influence on the overbreak and underbreak phenomena. In fact, if the rock is not strong enough to support itself, possibly no blasting techniques can stop the occurrence of overbreak and underbreak. Overbreak is a surplus blasted area of rock beyond the theoretical contour in a blasting activity that can occur in any kind of underground development method. Otherwise, underbreak is rock remaining (a minus blasted area) within a specific blasting perimeter that should have been thrown out by the blast and needeed secondary blasting or excavation. The form of overbreak and underbreak in a tunnel developmnet after blasting are shown in **Figure 1.**
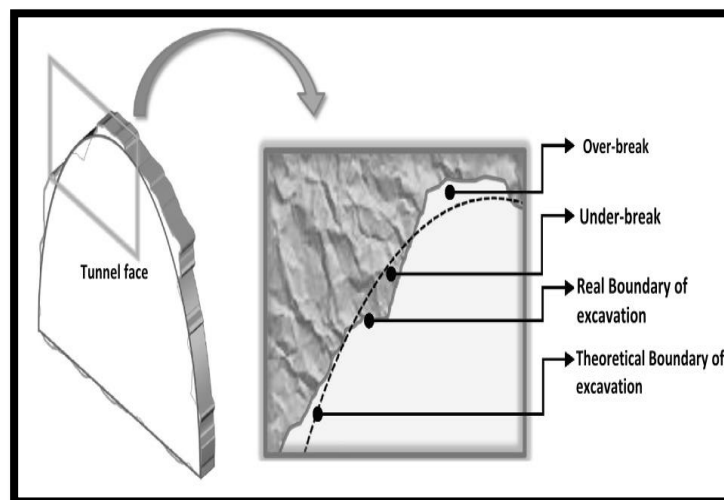
Figure 1. Forms of overbreak and underbreak in the tunnel after blasting activity [8]

2.1.1. Parameters of blasting. Overbreak can be managed by set these parameters because parameters of blasting are able to be changed. The parameters of blasting include blasting geometry, sub-drilling, firing sequences, guide holes, cut design, blasting hole, deviation, explosive characteristics, charge concentrations, powder factors, coupling ratio, blast-induced shock wave, energy levels, and others. Within just a few milliseconds, all blasting parameters affect overbreak in complex mutual correlation. Accurate blasting and drilling design should take priority and play role the selection of other blasting parameters to obtain a smooth (minimum) fracture plane without any wall damage. For example, [6] has been done model and field blasting tests to define the optimal delay time between contour holes in lock blasting by comparing instantaneous and micro-sequential initiation systems. Instantaneous initiation system was shown to be superior in minimizing overbreak. Field tests indicated the maximum radial crack length into the remaining rock mass of instantaneous initiation systems created a 1.3–9.0 times less than the micro-sequential initiation system which had only 1 ms firing delay between contour holes.

2.1.2. Geological Parameters. Geological parameters are unchanging factors and almost of them such as the strength of rock mass, discontinuous characteristics, stress and water conditions, as well the topography of the surrounding area have importance impact on the overbreak and underbreak phenomena. For example, Hagan [5] emphasised the importance of beddings and pre-existing joints on in-situ rock. In accord with his study, fractures in the rock tend to predominate the nature of the blast-induced fracture pattern and it commonly affect the overbreak more than the physical and mechanical characteristics of the rock.

The orientation of discontinuity is one of the main factors affect the overbreak phenomena. According to the study by Hoek and Brown [4], a discontinuity plane having strike parallel to the tunnel axis is considered to have an unfavorable effect on overbreak. In general, less overbreaks and underbreaks are discovered where the strike of the discontinuity is nearly vertically to the tunnel axis and contrary greater when they are nearly parallel. In specific of other oriented, drives with dip are more gainful than drive against dip where the strike of discontinuity is vertically to tunnel axis and fair and very unprofitable for dip with angle of 20 to 45° and 45 to 90°, respectively, when the strike is parallel to tunnel axis [2].

2.2. Radius Crack Propagation

Radius crack propagation is the optimum distance where rocks can be ruptured by explosives, so with the determination of radius crack propagation can be determined from the location of the blast hole and the distance between the blast holes. According to Oucterlony [3], the equation to determine the magnitude of radius crack propagation that can be used is:

$$Q = \text{E eff ANFO x } 10^6 \text{ x REEws} \tag{1}$$

$$\gamma = \sqrt{\left(1 + D^2/Q\right)} \tag{2}$$

$$K_{Ic} = \text{Tensile Strength x } \sqrt{\pi \; x \; crack \; length} \tag{3}$$

where Q is explosion energy (J/kg); REEws is relative weight energy of explosive; γ is exponential of adiabatic expansion; D is explosive VOD (m/s); K_{Ic} is cracked strength of rocks (Pa.m$^{0.5}$). Blast hole pressure can be determined as follows:

$$Ph = \gamma^\gamma / (\gamma + 1)^{(\gamma+1)} \cdot \rho_e \cdot D^2 \cdot (f)^{2.2} \tag{4}$$

$$Ph = \gamma^\gamma / (\gamma + 1)^{(\gamma+1)} \; \rho e \; D^2 \left(\Phi e / \Phi h\right)^{2.2} \tag{5}$$

where Ph is blast hole pressure (pa) ; ρe is explosive density (kg/m^3); Φe is charge diameter (m); Φh is blast hole diameter (m). Blast hole pressure with crack using following the equation:

$$P_{h,crack} = 3{,}30 Klc \Big/ \sqrt{\Phi_h} \tag{6}$$

where, $P_{h,Crack}$ = blast hole pressure with crack (pa). Rco = radial crack (m) can be determined as follows:

$$Rco = 0{,}5 \; x \; \Phi h \; x \left(P_h / P_{h,crack}\right)^{2/\left[3\left(D/c\right)^{0.25}-1\right]} \tag{7}$$

3. Result and Discussion

3.1. Rock Specification

The physical, mechanical, and dynamic properties of an intact rock are important to know the behavior of rocks against the detonation process of explosives. The study area of diorite rock type has a uniaxial compressive strength are 156.5 MPa, tensile strength are 11.5 MPa, and density are 2.6 gr / cm^3 (see **Table 1**.).

Table 1. Rock mechanics and physical properties [9]

Rock Type	Diorite (Fresh)
Uniaxial Compressive Strength (MPa)	156.5
Tensile Strength (MPa)	11.5
Modulus Young (GPa)	51.66
Poisson Ratio	0.296
Friction Angle (^{0})	38.6
Cohesion (MPa)	6.3
Density (kg/m^3)	2703.5
Velocity (m/s)	5730.24

The blasting process in rock mass is very important to be studied in order to know how far the effect of these rock characteristics on the effectiveness of blasting activity. Based on data from UG

DMLZ Geology PTFI, obtained RQD value between 70% to 100% so it shows good rock quality in Drainage Level has been shown in **Table 2.**, Truck Haulage Level in **Table 3.**, Extraction Level in **Table 4.**, and Undercut Level see **Table 5.**

Table 2. Rock mass data in drainage level [9]

Rock Type	Parameters	Lowest Values	Middle Values	Highest Values
Diorite	Q-System	5.83	8.89	13.33
	RQD (%)	70-90	80-90	90-100
	Joint spacing (m)	1	2	3
	Number of joint sets	One Joint Set	Two Joint Sets	Two Joint Sets Plus Random
	Joint alteration (ja)	3	5	6

Table 3. Rock mass data in Truck Haulage Level [9]

Rock Type	Parameters	Lowest Values	Middle Values	Highest Values
Diorite	Q-System	5.83	8.89	13.33
	RQD (%)	70-90	80-90	90-100
	Joint spacing (m)	1	2	3
	Number of joint sets	One Joint Set	Two Joint Sets	Two Joint Sets Plus Random
	Joint alteration (ja)	3	5	6

Table 4. Rock mass data in Extraction Level [9]

Rock Type	Parameters	Lowest Values	Middle Values	Highest Values
Diorite	Q-System	5.83	10	14.965
	RQD (%)	70-90	80-90	90-100
	Joint spacing (m)	1	2	3
	Number of joint sets	One Joint Set Plus Random	Two Joint Sets	Two Joint Sets Plus Random
	Joint alteration (ja)	3	5	6

Table 5. Rock mass data in Undercut Level [9]

Rock Type	Parameters	Lowest Values	Middle Values	Highest Values
Diorite	Q-System	6.67	10.585	20
	RQD (%)	70-90	80-90	90-100
	Joint spacing (m)	1	2	3
	Number of joint sets	One Joint Set	Two Joint Sets	Two Joint Sets Plus Random
	Joint alteration (ja)	3	5	6

3.2. Overbreak and Underbreak Analysis
From the results data of Drainage, Truck Haulage, Extraction, and Undercut Level that has been averaged, then **Table 6.** showed results data of ANFO and emulsion application for area and

circumference of overbreak and underbreak. Afterwards, **Table 7.** showed results data of ANFO and emulsion application for the furthest distance of overbreak and underbreak from design.

Table 6. Results data of ANFO and Emulsion application for area and circumference of overbreak and underbreak average at study area

Number	Location	Explosive	Overbreak Area (m²)	Underbreak Area (m²)	Overbreak Circumference (m)	Underbreak Circumference (m)
1	Drainage Level	Emulsion	5.4959	0.9468	35.6423	7.5315
		ANFO	9.0302	0.4324	39.8952	5.1857
2	Truck Haulage Level	Emulsion	8.3949	1.3237	35.4118	8.3723
		ANFO	7.7661	1.0388	34.2499	11.1498
3	Extraction Level	Emulsion	2.0389	0.414	21.4225	8.4789
		ANFO	8.612	0.9720	24.9592	4.0931
4	Undercut Level	Emulsion	1.808567	0.374422	20.04629	7.393733
		ANFO	1.196072	0.994789	16.27197	12.62942

Table 7. Results data of ANFO and Emulsion application for the furthest distance of overbreak and underbreak average from design at study area

Number	Location	Explosive	The Furthest Distance of Overbreak from Design (m)	The Furthest Distance of Underbreak from Design (m)
1	Drainage Level	Emulsion	0.7275	0.35495
		ANFO	0.86665	0.26915
2	Truck Haulage Level	Emulsion	1.2175	1.945
		ANFO	1.23745	0.94665
3	Extraction Level	Emulsion	0.36	0.22025
		ANFO	1.354	0.330238
4	Undercut Level	Emulsion	0.320333	0.154533
		ANFO	0.293	0.235333

Based **Table 6.**, then get ANFO and emulsion application chart at study area for area and circumference of overbreak and underbreak average showing the ANFO and emulsion overbreak and underbreak area and circumference is fluctuated, but ANFO's more than emulsion's [9]. See **Figure 2**.
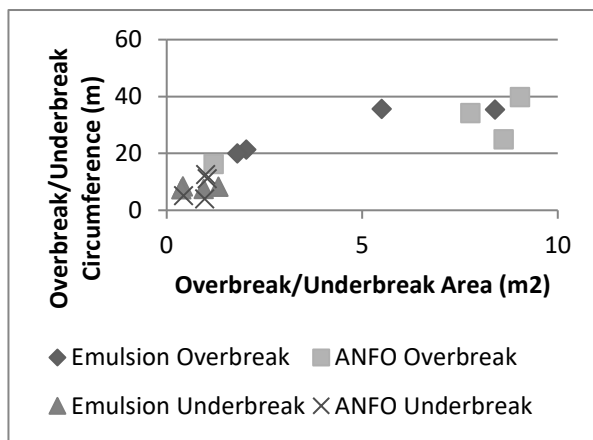
Figure 2. ANFO and Emulsion chart for area and circumference of overbreak and underbreak average at study area
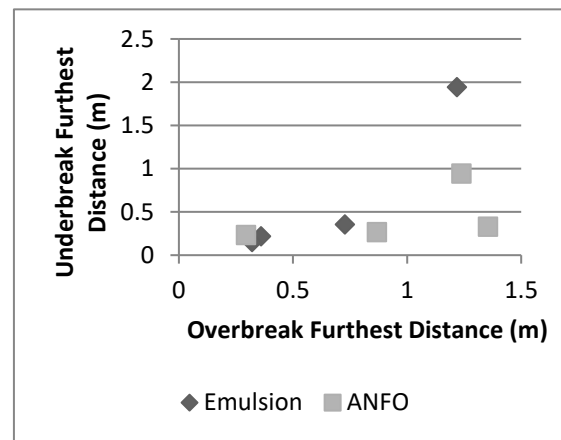

Fig 3. ANFO and Emulsion chart for the furthest distance of overbreak and underbreak from design average at study area

ANFO and emulsion application chart at Undercut Level for the furthest distance of overbreak and underbreak from design based on **Table 7.** has been shown in **Figure 3.** The result of ANFO and emulsion overbreak and underbreak furthest distance from design fluctuated and then ANFO overbreak increased so that more than emulsion's. However, emulsion underbreak more than ANFO's [9].

Review from result that has obtained at Drainage Level, Truck Haulage Level, Extraction Level, and Undercut Level without average all or based in all data, can be concluded that emulsion application produced some undebreak and few of overbreak. However, ANFO application produced more overbreak than emulsion and some underbreak. The result has been shown in **Table 8**. There is one of sample heading that blasted with ANFO at Extraction Level in **Figure. 4.** and blasted with emulsion at Undercut Level in **Figure. 5.**

Table 8. Final results data of ANFO and Emulsion for highest value of overbreak and underbreak

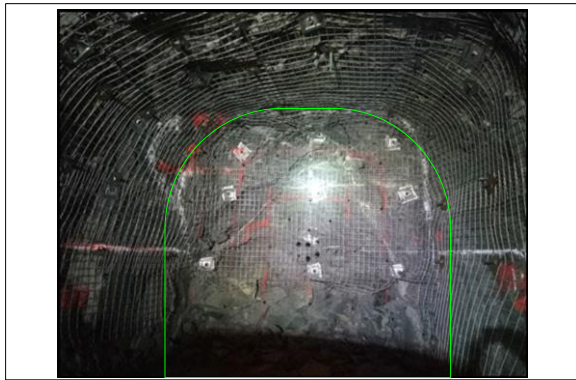| Number	Location	Explosive	Overbreak Area	Underbreak Area	Overbreak Furthest Distance from Design	Underbreak Furthest Distance from Design
1	Drainage Level	Emulsion	-	√	-	√
		ANFO	√	-	√	-
2	Truck Haulage Level	Emulsion	-	√	-	√
		ANFO	√	-	√	-
3	Extraction Level	Emulsion	-	-	-	-
		ANFO	√	√	√	√
4	Undercut Level	Emulsion	√	-	-	-
		ANFO	-	√	√	√

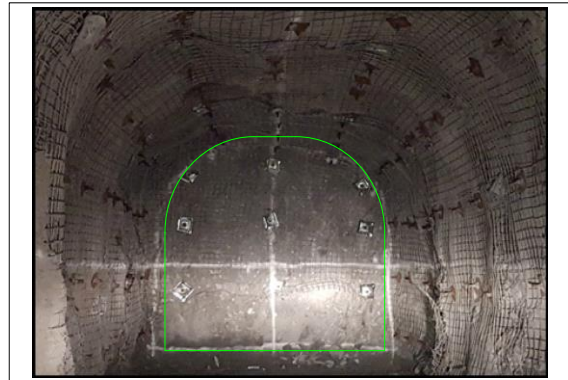**Figure 4.** Heading at P#6 DP#12 East Blasted with ANFO

Figure 5. Heading at MAD 2 DD#8 EN Blasted with Emulsion

4. Conclusion

From results that has obtained at Drainage Level, Truck Haulage Level, Extraction Level, and Undercut Level, can be concluded that emulsion application produced some undebreak and few of overbreak. However, ANFO application produced more overbreak than emulsion and some underbreak. The impact of overbreak is excessive usage of ground support and the impact of underbreak is doing blasting again that's mean disadvantageous and also dangerous in geotechnical side. The advantages of ANFO are inexpensive or economic, easy to create, safe handling. However, ANFO also has disadvantages i.e. low density and density can't be adjusted, not water resistance, so using cartridge emulsion at lifter hole, and usually leaving detonating cord at perimeter hole. Afterwards, the advantages of emulsion are water resistance, safe handling, not using detonating cord at perimeter hole, and density can be adjusted depend the type of gasser used. However, the disadvantages of emulsion are expensive, emulsion consumption more than ANFO because have to do QA (Quality Assurance) and QC (Quality Control) before loading at blast hole, and not easy to create. Thereby, the explosives that effective to use in blasting development at underground Deep Mill Level Zone (DMLZ) PT. Freeport Indonesia is emulsion. However, it should be redesign drill pattern and blasting geometry for emulsion. To use emulsion in blasting development UG DMLZ PTFI, be recommended to redesign drill pattern and blasting geometry using radial crack method.

References

[1] Mahtab, M.A., Bostald, D.D., Alldredge, J.R. *and* Shanley, R.J. 1972. *Analysis of Fracture Orientations for Input to Structural Models of Discontinuous Rock*. USBM-RI 7669: USA
[2] Bieniawski, Z.T. 1973. *Engineering Classification of Rock Masses*. Wiley: Trans. South Africa.
[3] Ouchterlony, Finn. 1977. *Analysis of Crack Related to Rock Fragmentation*. Springer-Verlag Wien: Stockholm, Sweden
[4] Hoek E. and Brown, E.T. 1980. *Underground Excavation in Rock*. London
[5] Hagan, T.N. 1992. *Personal Communication, Blasting*. Queensland, Australia.
[6] Rustan, A. 1998. Rock Blasting Terms and Symbols. CRC Press: Rotterdam.
[7] Mandal, S.K., and Singh M.M. 2008. Analysis of Blast Pattern to Evaluate Extent and Causes of Overbreak in Large Cavern. Blasting and Fragmentation 2. Page 1-26. ISSN 1937-6359.
[8] Jang H 2012 *Optimizing Overbreak Prediction Based on Geological Parameters Comparing Multiple Regression Analysis and Artificial Neural Network*. Australia. 161-162.
[9] PT Freeport Indonesia 2017 Underground DMLZ Geo-technical Services and Geology