**SCHOOL OF MATERIALS AND MINERAL RESOURCES ENGINEERING**

**UNIVERSITI SAINS MALAYSIA**

# EFFECT OF BLAST DESIGN ON PARTICLE BREAKAGE AT IMERYS MINERALS MALAYSIA SDN. BHD. SIMPANG PULAI, IPOH

By

**MOHAMMAD AIDIL BIN RODZALI**

**Supervisor: Dr. Mohd Hazizan Bin Mohd Hashim**

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# DECLARATION

I hereby declare that I have conducted, completed the research work and written the dissertation entitled **"Effect of Blasting Pattern on the Particle Breakage at Imerys Minerals Malaysia Sdn. Bhd. Simpang Pulai, Ipoh"**. I also declare that it has not been previously submitted for the award of any degree or diploma or other similar title of this for any other examining body or university.

Name of Student : Mohammad Aidil Bin Rodzali Signature :

Date : 21st June 2017

Witness by

Supervisor : Dr Mohd Hazizan Bin Mohd Hashim Signature :

Date : 21st June 2017

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| | |
|---|---|
| ANFO | Ammonium Nitrate Fuel Oils |
| UCS | Uniaxial Compressive Strength |
| PLT | Point Load Test |
| PF | Powder Factor |
| B | Burden |
| S | Spacing |
| D | Diameter of Blast Hole |

# LIST OF SYMBOLS

| | |
|---|---|
| $I_S$ | Uncorrected point load strength index |
| F | Correction Factor |
| $I_{S (50)}$ | Corrected point load strength index |
| % | Percent |
| n | Uniformity Index |
| A | Rock Factor |
| S | Relative weight strength of explosive (ANFO) = 100 |

**KESAN DARIPADA REKA BENTUK LETUPAN TERHADAP PEMECAHAN BATU DI IMERYS MINERAL MALAYSIA SDN. BHD. SIMPANG PULAI, IPOH**

## ABSTRAK

Kajian ini adalah untuk mengkaji hubungan antara reka bentuk letupan dan pemecahan partikel tenatng bagaimana reka bentuk letupan memberi kesan terhadap pemecahan batu dalam konteks mencapai pemecahan batu yang optimum. Pemecahan batu dengan ketara memberi kesan terhadap prestasi memuatkan, mengangkut dan proses kominusi. Berdasarkan ujian titik beban yang dijalankan, batu-batu untuk semua sesi letupan diklasifikasikan sebagai batuan yang serdahana kuat. Imerys Minerals Malaysia mengamalkan reka bentuk lubang corak berperingkat dimana ia menghasilkan tenaga letupan yang lebih seragam berbanding reka bentuk lubang segi empat dan segi emmpat tepat. Ammonium Nitrate Fuel Oil (ANFO) dipilih sebagai bahan letupan yang utama untuk setiap sesi letupan berbanding Bulk Emulsion walaupun Bulk Emulsion mempunyai sifat kalis air yang baik. Data yang diperolehi daripada hasil kajian menunjukan purata peratusan melepasi saiz 800mm adalah 72.83% dan ini menunjukkan bahawa lebihan daripada peratusan itu memerlukan pemecahan kali kedua. Purata indeks keseragaman bagi kesemua sesi letupan adalah 1.63 manakala purata D50 ubtuk kesemua sesi letupan adalah 527.18mm. Untuk purata pemecahan batu bersaiz maksimum adalah 2220.54mm. Pemecahan batu yang dicapai melalui operasi letupan tidak mencapai pemecahan yang optimum.

**EFFECT OF BLAST DESIGN ON THE PARTICLE BREAKAGE AT IMERYS MINERAL MALAYSIA SDN. BHD. SIMPANG PULAI, IPOH**

# ABSTRACT

The present study aims to investigate the relationship the blast design and particle breakage on how the blast design effects the fragmentation of rock in term of obtaining the optimum fragmentation. The fragmentation of rock significantly affects the performance of loading, hauling and comminution process. Based on the Point Load Test, rocks in all blast sessions were classified as medium strength rock. Imerys Minerals Malaysia adopted staggered pattern for blast hole pattern which produces much more uniform distribution of explosive energy rather than square and rectangular pattern. Ammonium Nitrate Fuel Oil (ANFO) was selected as a primary explosive for each session of blasting instead of Bulk Emission although Bulk Emission has a good water resistance. The data obtained from the study indicate that the average percentage passing for size of 800mm (feed opening for jaw crusher) in all blast sessions was 72.83% which means that the remaining percentage required secondary breakage. The average value of uniformity index for all blast sessions was 1.63 and the average value of D50 was 527.18mm. The average of maximum size rock fragmentation for all blast sessions was 2220.54mm. The rock fragmentation achieved during the blasting operation was far away from achieving optimum fragmentation.

# CHAPTER 1

## INTRODUCTION

### 1.1 Background Study

The four most common unit operations in exploitation for mining (quarry) are drilling, blasting, loading and haulage. The sequence of unit operations used to accomplish mine development and is repeated over and over to produce the mineral commodity. The main purpose for blasting is to obtain the desired rock fragmentation for loading, haul, dump and feeding to the primary crushing plant. The fragments that being produced form blasting should not only be suitable for loading, hauling and dumping but must be small enough to pass through the primary crushing plant. The fragmentation of rock is crucial for mining operation.

The main factors that influence the performance of blasting are drilling, explosives and geology. All of these factors play an important role in producing the desire rock fragmentation. In this study, the investigation will be more focusing in term of effect of the blast design in particle (rock) breakage.

The degree of rock fragmentation depends on varies of blasting design. Some common parameters which will affect the performance of blasting are spacing, burden, stemming, powder factor, sub-drilling, diameter of the hole and length of the hole. Other factors that influence the outcome of the blasting performance are properties of explosive, blast hole patterns and firing patterns. Blasting is one of the most crucial operations in mining sector which will influence the economics of mining.

**1.2 Problem Statement**

This study will investigate the effect of blast design on the particle breakage which means it will cover the type of blast hole pattern used, firing pattern (blast timing) and other specification in the blast design (burden, spacing, stemming and etc.) that might affect the outcomes of the blasting (rock fragmentation). Blast design is one of the most important and crucial factor in blasting besides geological features. Both are important in producing the desired fragmentation for further process for example excavation can be easier if the rock small and fit to the bucket of the excavator. Thus, decreasing the working time and cost. For information, geological factors are uncontrollable factor which makes it cannot being changed while explosive (blast design) factors are controllable factor which means that changes can be made to the design of the blast for further improvement in blasting performance.

One of the scenarios that have been a routine in Imerys's quarry after blasting is the usage of breaker (a powerful percussion hammer fitted to an excavator) to break the oversize rock produced after blasting. . The efficiency of the mine transport and crushing can be adversely affected by poor fragmentation. All of these problems will increase the cost of mine production and time consuming.

The significance of optimum rock fragmentation is to reduce the cost of operation in the crushing and grinding thus improves the economics of the quarry. Therefore, the outcome of this study will help the industry to improve their blasting performance in order to achieve an optimum fragmentation. By improving the performance of blasting, the efficiency of other processes for example loading, hauling and crushing will also being improve.

**1.3 Objective**

Blasting is one of the fundamental elements for the mining cycle. Below stated the main objective throughout the whole research:

•To study the relationship between the particle breakage and blast design(firing pattern) on how the blast design(firing pattern) effect the particle breakage in term of size reduction.

•To summarize the result from each of blast design (firing patterns) which one of the blast hole patterns produce the best fragmentation that suitable for loading, hauling, dumping and tipping to the feed of the primary crusher.

**1.4 Scope of Research Work**

The study was carried out in Imerys Mineral Malaysia which located in Keramat Pulai, Perak. Imerys Mineral Malaysia own two quarry which are Zain Liew and Honaik. All the mining operations are actively conducted in Zain Liew quarry. Both quarries are located at Gunung Terundum which located at the castern side of the Kinta Valley.

It took about 5 weeks to collect the data from the blasting. In Imerys, blasting will be conducted from Monday to Thursday depend on the weather. This study consist data collection of drilling record and blasting parameters. Additionally, the study on the rock strength was conducted for each sessions of the blasting operation by using Point Load Test which the will be correlated with the Uniaxial Compressive Strength.

For fragmentation analysis, photos of muck pile and a scale as size reference were taken after each of blast sessions. Next step is to analysis the photo of muck pile by using Wipfrag software to measure the size of fragmented rocks. Wipfrag software will analyze the size of the muck pile and produce particle size distribution graph based on the size of fragmented rocks.

### 1.5 Thesis Outline

This thesis contains five main chapters which are Introduction, Literature Review, Methodology, Discussions and Conclusions. The first chapter is Introduction that briefly explains about background of study, problem statement, objectives of research and scope of research work. In the second chapter, Literature Review is the foundation of study. Citation from journals and articles are review in this chapter in order to accomplish this project. The knowledge about blasting principle and rock breakage mechanism are also been discussed in this chapter. For Chapter 3, it more directly focus on the method of study. This project involves the usage of Wipfrag software which function as fragmentation analysis that produce graph of particle size distribution. Method of collecting blast design, collecting picture of muck pile, collecting samples of rock and point load test were been discussed in this chapter. Chapter 4 which is Discussion will cover the outcomes of the study in term of blast design, particle size distribution and point load test (strength of rock). The relation between these outcomes will be analyzed in this chapter. For the last chapter which is Conclusion, it will conclude the overall of this study and suggest some of recommendation to improve the efficiency of blasting in order to achieve a desired size of fragmentation.

# CHAPTER 2

## LITERATURE REVIEW

### 2.1 Introduction

This chapter discussed theory of blasting in all aspects and reviewed the previous research or study that related to effect of blast design or blasting parameters, properties of explosive and mechanisms of rock fragmentation. Theory and knowledge of blasting are crucial in order to select the right combination of explosive to achieve a reliable performance without sacrificing the elements of safety and environment.

### 2.2 Blast Design

Figure 2.1 illustrates the blast-pattern parameters concept of blast design. All of terminologies in figure 2.1 are very essential for a shot-firer to understand for a proper blast design that will yield adequate fragmentation.

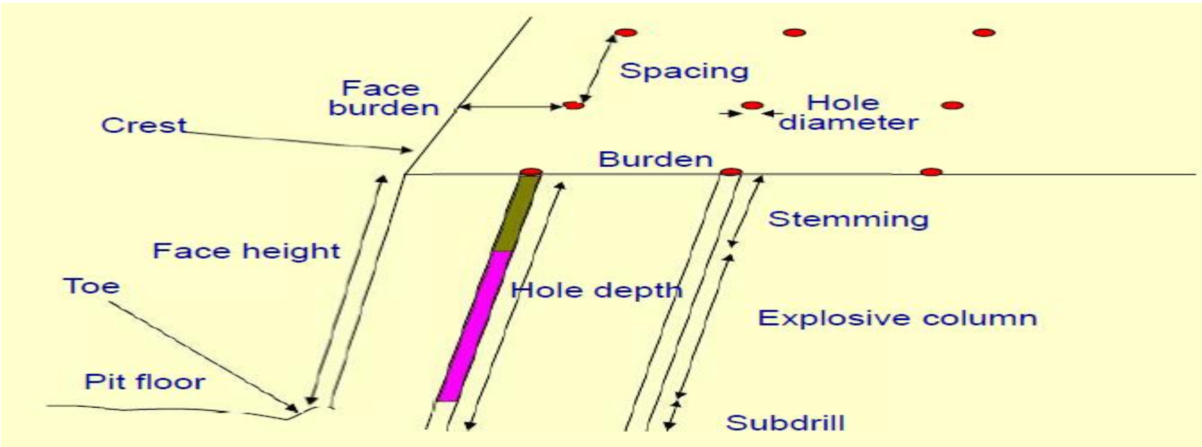


**Figure 2.1:** Blast-Pattern Parameter (Mohd Lip, 2015)

Blast Parameters:

- Burden
- Spacing
- Powder Factor
- Bench Height
- Hole Diameter
- Hole Depth
- Sub-drill
- Stemming Sequence

Terminologies in Blasting

- Free Face:

  An exposed rock surface towards which the explosive charge can break out during blasting.

- Bench Height:

  A vertical distance between top and floor of the bench is called bench height. A recommended bench height is at least twice of burden

- Blast Hole Diameter:

  The blast hole diameter depends on the geology, desired fragmentation, face height and economics. Basically, geological aspect is one of uncountable factor that cannot be changed. Normally for hard rock, smaller diameter of blast hole is applied to the blast design to make the blast hole pattern become closer. Thus, explosive charge will be more distributed hence improve the fragmentation. For economical purpose, larger diameter of blast hole is applied to the blast design. The cost of drilling and blasting decreases as blast hole diameter increases.

The relation between blast hole diameter and face height is:

D = 0.001 - 0.02 H (Bench Height) ……………………………….. (Equation 2.1)

- Blast Hole Inclination

Inclined drilling will provide better charge distribution and produce good back break. Energy of blast is directed towards the free face and only small part will cause the back break. Besides, less toe problem since less constriction in the bottom of the hole.

- Burden:

Burden is the distance from blast hole to the nearest free face. Burden is calculated by considering blast hole diameter, rock density and type of explosive. The value of burden will affect the calculation of spacing, stemming and sub-drilling. Inadequate burden will lead to air blast and fly rock problems. Larger burden can causes poor fragmentation, toe problems and excessive ground vibrations

Burden = ( 25 – 45 ) × Blast Hole Diameter ………………………. (Equation 2.2)

For hard rock use ratio of 25D to 30D

For medium rock use ratio of 30D to 35D

For soft rock use ratio of 25D to 30D

- Spacing:

Spacing is the distance between adjacent blast hole in row and measured perpendicular to burden. Optimum energy distribution result from the spacing equal to 1.15B (Burden) with staggered pattern (Nobel, 1996). Larger spacing will produce poor fragmentation while close spacing causes toe problems. Other assumption of spacing for example 1.6 to 2.0 times burden is also a good starting point in deciding the spacing of the blast hole. According to Mustapha Mohd Lip, 1.2 times burden is commonly applied in Malaysia.

- Sub-drill

  Sub-drilling is the distance drilled below the floor level to ensure that the full face of the rock is capable of being removed to the desired excavation level. Sub-drilling is important in order to achieve a smooth pit floor. Over drilling will produce higher vibration while less drilling will cause toe problems. Sub-drill = Burden / 3 …………………………………………….. (Equation 2.3)

- Stemming:

  Stemming acts to contain the explosive energy within the blast hole to avoid the possible of fly rock. Size crushed rock, chipping, sand or mud can be used as stemming material. The materials are filled between the explosive charge and the collar of the blast hole.

  The optimum stemming length is calculated based on the following formula:

  $T_s = (12Z / A) \times (QS / 100)^{1/3}$ …………………………………….. (Equation 2.4)

  where, Z = Fly rock Factor (1 for normal blasting and 1.5 for controlled blasting)

  A = Rock Factor

  Q = Mass of explosive in 8 hole diameters or if the charge length is less than 8 hole diameters, the total mass of explosive

  S = Relative weight strength of explosive (ANFO) = 100

- Explosive Column:

Charge length of explosive column in the blast hole. If the explosive column inadequate, the optimum energy cannot be produced thus lead to poor fragmentation of rock.

- Powder Factor:

Powder factor (PF) in term of blasting is a quantity/weight of explosive per unit volume of rock blasted ($kg/m^3$).

PF = (Weight of Explosive) / (Burden × Spacing × Bench Height) ... (Equation 2.5)

The value of powder factor depends on the hardness of rock. For example, the softer the rock that being blasted, the smaller value of powder factor.

**Table 2.1:** Classification of powder factor based on the hardness of rock (Sharma, 2009)

| General Category | Rock type | Powder factor ($kg/m^3$) | Rock factor A |
|---|---|---|---|
| Hard (+200) | Andesite<br>Dolerite<br>Granite<br>Ironstone<br>Silcrete | 0.70 | 12 -14 |
| Medium (100 – 200) | Dolomite<br>Hornfels<br>Quartzite<br>Serpentinite<br>Schist | 0.45 | 10 -11 |
| Soft (50 – 100) | Sandstone<br>Calcrete<br>Limestone<br>Shale | 0.30 | 8 - 9 |
| Very soft (-50) | Coal | 0.15 – 0.25 | 6 |

The value of powder factor influences the fragmentation of rock. Inadequate powder factor will produce poor fragmentation in other words producing larger boulder which required secondary blasting. The calculation powder factor is very essential in order to yield adequate fragmentation.

- Blast Hole Pattern:

  For commercial blasting in mining section, there are 3 most common patterns which are square pattern, rectangular pattern and staggered pattern. Operating experience and blast modeling results have shown that fragmentation and productivity are generally greater with staggered patterns compare to rectangular or square patterns (Orica Group Companies. 2008). According to Orica, staggered pattern provide an optimum distribution of explosive charge.

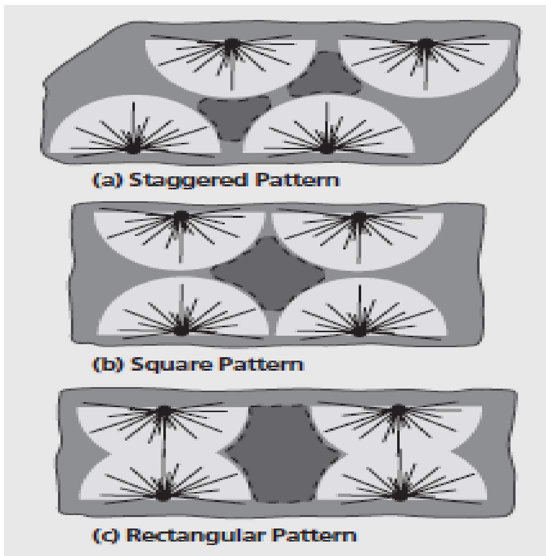


**Figure 2.2:** The Effect of Blast Hole Patterns on Distribution of Explosive Energy (Orica Group Companies, 2008)

i) Square Pattern

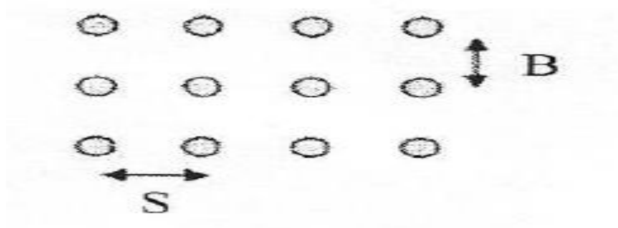


**Figure 2.3:** Square Blast Hole Pattern

For square pattern, the main characteristic is the distance between burden and spacing are equal. Burden = Spacing

ii)Rectangular Pattern

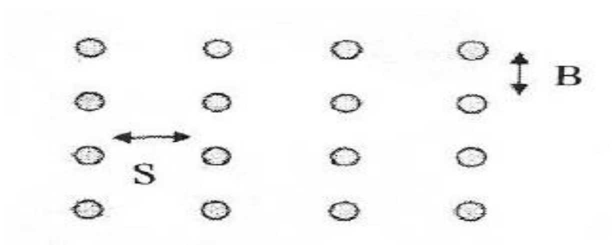


**Figure 2.4:** Rectangular Blast Hole Pattern

Generally, rectangular pattern has drilled Spacing about 1.2 Burden

iii)Staggered Pattern

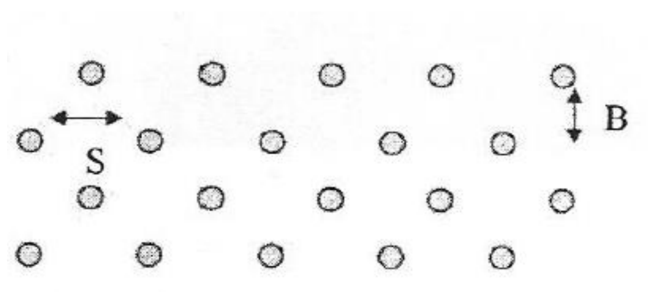


**Figure 2.5:** Staggered Blast Hole Pattern

The last one is a staggered pattern which the drilled Spacing of each row are offset such that holes in one row are positioned in the middle of the Spacing of the holes in preceding row. The Spacing is larger than the Burden.

**2.3 Properties of Explosive**

Explosive is a solid, liquid or mixture of substances that has the ability of developing a sudden high pressure by the rapid formation or liberation of stable gases at high temperature.

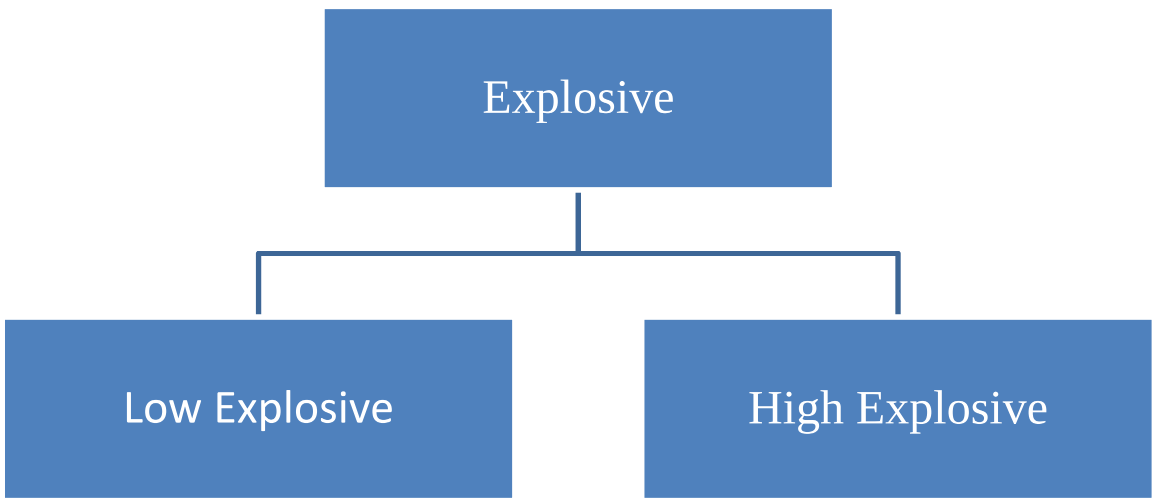


**Figure 2.6:** Type of Explosive

Low explosive can be defined as an explosive that does not require a detonator to initiate it. This kind of explosive is usually started off by a flame, heat, or a spark which is provided by the spit of a safety fuse, a wick or an electric fuse head. The examples of low explosive such gun powder or black powder. Gun powder was manufactured during 13$^{th}$ century and has been used as military explosive and rock blasting explosive in the past.

The components of gun powder are charcoal, saltpeter and sulphur. Nowadays, gunpowder mainly used in safety fuse, as a propellant and other pyrotechnic applications.

High explosive is being classified into two groups which are primary explosives and secondary explosives. Primary explosives have been used as a starter explosive in detonator and extremely sensitive to shock, heat and friction. Lead azide, mercury fulminate and lead styphnate are the examples of primary explosive. For secondary explosives, it is insensitive to shock, heat and friction and being added to detonator to boost power. The examples of secondary explosive are dynamites, bulk emulsion and water gel.

The main parameters which influence the performance and the selection of an explosive are:

- Velocity of detonation
- Sensitivity
- Fume Characteristic
- Water Resistance
- Storage Properties
- Detonation Pressure
- Physical Characteristic
- Density

The rate of which the detonation travels along an explosive column or explosive charge is called velocity of detonation. The power and shattering effect of an explosive are affected by the value of velocity of detonation. The value for velocity of detonation increases as the hardness of rock increases. High velocity of detonation used for hard rock while low velocity of detonation suitable for soft rock. Basically, explosive that has lower value of velocity of detonation will produce gas over a longer period and have more heave. Normally, the range of velocity of detonation in commercial explosive is 2500m/s to 6500m/s (Mather 1997).

**Table 2.2:** Classification of Velocity of Detonation

| Type of explosive | Velocity of detonation (m/s) |
|---|---|
| NG based explosive | 3500-5500 |
| Watergels | 3500-5000 |
| Emulsions | 4500-6100 |
| ANFO | 2200-4400 |

The gases produced during the blasting activity mostly non-toxic carbon dioxide, nitrogen and steam. But, a small amount of toxic gases such carbon monoxide and oxides of nitrogen are produced by the detonation of explosive. Carbon monoxide is colorless, odorless, flammable and highly toxic gas. At the concentration in the air of 200 ppm, mild headache, fatigue, nausea and dizziness may commence. The oxide of nitrogen contains nitric oxide, nitrous oxide and nitrogen dioxide. Long-term exposures to nitrogen oxides make a person become more susceptible to respiratory infections (Atlas, 1997)

For detonation pressure, a higher detonation pressure is one of the desirable characteristic in a primer (Atlas, 1987). Detonation pressure can be described as the pressure in the reaction zone as explosive detonates. It also indicates the ability of the explosive to produce the desired rock fragmentation.

The term of water resistance for explosive can be defined as the ability of the explosive to resist water and maintain the properties of explosive in the present of water or wet condition. Water resistance is one of the key factors for optimum and efficient blasting. For example, ammonium nitrate fuel oil (ANFO) has no water resistance compare to bulk emulsion and slurries which have great water resistance. Water resistance is one of the crucial factors in the selection of the explosive.

The density of the explosive plays an important role in the procedure of charging which decides the charge weight of explosive per meter of blast hole. The range density of commercial blasting in mining is between 0.8-1.6 g/cm$^3$. The table below state the optimum density range based on type of explosive (Atlas, 1997).

**Table 2.3:** Classification of Density

| Explosive | Density (g/cm$^3$) |
|---|---|
| ANFO | 0.8-1.0 |
| Bulk Emulsion | 1.1-1.3 |
| Nitroglycerine Based | 1.3-1.6 |
| Watergels | 1.2-1.4 |

Ammonium nitrate-fuel oil (ANFO) is one of the common explosive in mining industry. Due to ammonium nitrate which is the cheapest source of oxygen available and an essential ingredient in commercial explosive, it acts as an oxidizer in ANFO. Basically oxidizer is ammonium nitrate and calcium nitrate, the chemical which provides oxygen for the reaction. Fuel oil acts as a chemical that reacts with oxygen to produce heat. Sensitizer such as nitroglycerin and TNT are used to produce an explosive or in conjunction with fuels oils.

Sensitizer acts as heat source (hot spot) to mix the reaction between fuel and oxidizer. Sensitizer usually small air bubbles or pocket within the explosive. The range proportion of fuel oil is between 5.5%-6.0% weight. Different ratio of fuel oil will affect the velocity of detonation and energy of explosive. Adding too much fuel oil increases the production of carbon monoxide and insufficient fuel oil will increase the proportion of oxides of nitrogen. The ideal mixture of ammonium nitrate and fuel oil is stated below:

**$3NH_2NO_3 + CH_2 \rightarrow 3N_2 + 7H_2O + CO_2$ (3900 kJ/kg)**

**(Ideal – 94.3% AN: 5.7% FO)**

ANFO has density of 0.8 to 0.85 g/cm$^3$ which is low density. That means the strength of the bulk is relatively low. But, the density of ANFO can be increased by using pneumatic loading which can be increased up to 1.0 g/cm$^3$. This method which is pneumatic loading increases the relative effective energy and the velocity of detonation (ICI, 1997).

One of the disadvantages of ANFO is poor water resistance. ANFO which contains more than 10% of water usually fails to detonate (ICI, 1997). One of the characteristic of ammonium nitrate is the ability to absorb water from the surrounding. In other words, ANFO is only suitable for dry holes. ANFO can still be used in the wet hole but it must be packed in the water proof container but it will increase the cost of blasting.

One of the advantages using ANFO is that it is safe and convenient to use. Besides, it cannot be initiated on its own by shock, friction, heat or by detonator. It must be detonated by primer which is a cartridge of high explosive with detonator. A primer which called Emulex is a detonator sensitive packaged emulsion explosive which is designed for priming application in blasting activity. Emulex is one of the common products used to prime the blast hole. The detonation strength is increased by addition of 5% aluminum in the explosive. Emulex works well for wet or dry blast holes for blasting. The technical properties stated below

**Table 2.4:** Properties of Emulex

| | |
|---|---|
| Density | 1.13-1.24 g/cc |
| Velocity of Detonation | 4500-5500 m/s |
| Explosion Energy | 4.08 MJ/kg |
| Water Resistance | Excellent |

One of the ways to overcome the poor resistance of water for ANFO is by using bulk emulsion which has excellent properties of water resistance. Bulk explosive is an emulsion bulk mixes with between 30-40% of ANFO. Bulk emulsion has a good water resistance which means that the blast hole that contains water does not require water flushing. For information, the density of bulk explosive is higher compared to water thus it will replace water in the blast hole. In term of strength, bulk explosive has higher bulk strength compared to ANFO thus some adjustment on the blast design such as spacing, burden and length of explosive column must be done. Basically, none of the ingredients of bulk explosive is explosive until the addition of gas bubbles in the blast holes. Emulsion blasting agent is a water-in-oil emulsion consisting of a super saturated solution, wax or paraffin fuel and stabilized with emulsifying agent. Entrapped air, in the form of air bubbles, dispersed throughout the emulsion, acts as sensitizer (Mather, 1997). The mechanism of initiation for bulk explosive is started with shock wave of explosive causes the air bubbles to compress at high speed then creating a heat source and lastly causes the bulk emulsion to detonate. The velocity of detonation for bulk emulsion is between 4500-6100 m/s and the detonation pressure is 10-12000 MPa. In term of stability, the blasting agent of bulk explosive is normally stable in the holes for 4 days (Mather, 1997).

### 2.4 Mechanical Properties of Rock

#### 2.4.1 Point Load Test

One of the ways to determine the rock strength indexes in geotechnical practice is by using the method of point load test. Point load test is an economical testing of core or lump rock samples (irregular shape) and an acceptable rock mechanics testing procedure for the calculation of the rock strength index. The main advantage of the point load test is that point load test is portability of the press which allows its use in the laboratory or at the site. Besides, the value of the point load test can be transform into uniaxial compressive strength by conversion factor. The procedure for point load test is very simple which involves compressing of rock sample between the platens plate until the failure occur. For point load test, specimen can be in varies form depending on size and shape. Different method will be applied for different form of size and shape for example diametral test, axial test, blocks test and irregular lump test. Normally, point load test is conducted for cylindrical specimen which the diameter of 50 mm thus obtaining corrected point load index for standard core size of 50 mm diameter. For the specimen that has different diametric load from 50 mm, used below formula to find $I_{S\,(50)}$ :

Uncorrected point load strength index, $I_S = (P\times1000)/ D_e^2$ ……………….. (Equation 2.6)

Correction Factor, $F = (D_e / 50)^{0.45}$ ………………………………………… (Equation 2.7)

Corrected point load strength index, $I_{S\,(50)} = F \times I_S$ ……………………….. (Equation 2.8)

The mechanics of point load test causes the rock to fail in tension. The point load test's accuracy in predicting uniaxial compressive strength depends on the ratio between uniaxial compressive strength and the tensile strength (Hoek 1977). The ratio depends on the rock's hardness. For this study, the relationship between point load test and uniaxial compressive strength can be expressed as below:

$UCS = 24 \times I_{S\,(50)}$ MPa …………………………………………………….. (Equation 2.9)

### 2.4.2 Compressive Strength

Compressive strength can be defined as a capacity of material or structure to detain loads that tend to reduce size and being expressed in newton or pounds per square inch. It can be calculated by plotting applied force against deformation in a testing machine. For some material, it fractures at its own compressive strength limit; others deform irreversibly which amount of deformation may be assumed as the limit for compressive load. Compressive strength is one of the important element for design the structures. Compressive strength is totally different from tensile strength which tensile strength is the resistance or ability of the material a material to retain a pulling (tensile) force.

### 2.4.3 Young's Modulus

Young's modulus also known as elastic modulus is a measure of the stiffness of the rock material. It is defined as the ratio of the stress (force per unit area) along an axis and the strain (ratio of deformation over initial length) along the axis in the range of stress. The value of Young's modulus can be obtained experimentally from the slope of a stress-strain curve during the tensile or compressional test. Young's modulus of rock materials varies according on the rock type.

## 2.5 Classification of Rock Materials for Strength

According to Brown (1981), point load test can be used to determine the point load index which can be related to the uniaxial compressive strength of the intact rock. Point load test is an alternative way to find the uniaxial compressive strength. The value of point load test can be correlated with the value of uniaxial compressive strength by using the conversion factor that varies depending on type of rock.

**Table 2.5:** Classification for Strength of Intact Rock Material (Palmstrom, 1995)

| Term | Point Load Strength Index, MPa | Uniaxial Compressive Strength, MPa |
|---|---|---|
| **Low Strength** | 1-2 | 25-50 |
| **Medium Strength** | 2-4 | 50-100 |
| **High Strength** | 4-10 | 100-250 |
| **Very High Strength** | >10 | >250 |

## 2.6 Physical Properties of Rock

### 2.6.1 Density and Porosity

Density can be defined as mass per volume of the substance. The density of rock is normally expressed as specific gravity which is the density of the rock relative to the density of water. Density of rock is various and some suggestion state that the minerals that compose a particular rock are one of the elements that influence the density of rock.

Rocks are porous and porosity is much related with the density. Porosity is the percentage of void space in the rock and it describes how compact and denser the material is packed. It is defined as the ratio of the volume of the pore or void space divided by total volume. For common rock, porosity varies from 1% to 40%. Density and porosity are much related to the strength of rock. A low density and high porosity indicates that the rock has low strength (Zhao, 2010)

### 2.6.2 Permeability

Permeability is the properties and abilities of rock for fluids (gas or liquid) to flow through rock. High permeability indicates that the rock allow the movement of fluid passing through rock rapidly. Most rock including igneous, sedimentary and metamorphic rock has low permeability. Permeability also governed by porosity. Porous rock such sandstone usually has high permeability compared to granite which have low permeability. Another factor affecting the permeability is the properties of pore fluid. Pore fluid is the fluid that occupy the voids space in soil or rock. Permeability is directly proportional to the unit weight of the pore fluid and inversely proportional to the viscosity of pore fluid.

## 2.7 Mechanism of Rock Breakage

The chemical reaction occurred when an explosive charge is detonated which very rapidly turns the solid or liquid explosive mass into a hot gases. The reaction begins at the point of initiation where the detonator is connected to the explosives and produces a convex like compressive wave that acts on the borehole wall and propagates through the explosive column. The undetonated explosive products are ahead of the reaction zone while expanding hot gasses are behind the reaction zone. The whole blast hole is occupied with the gaseous detonation products at very high temperature and pressure after the explosive detonates. This pressure is responsible for producing radial compressive stress on the wall of the blast hole (Sharma, 2011).

### 2.7.1 Explosive Energy Release and Rock Breakage

The fragments that being produce in mines are fragments formed by the new fractures created by the detonating explosive charge, in-situ blocks that have been liberated from the rock mass without further breakage and lastly is fragments produced by extending the in-situ fractures in combination with other new fractures.

Rock fragmentation by blasting is produced by dynamic loading introduced into the rock mass. The explosive loading can be classified into two phases with are shock wave and gas pressure phase.

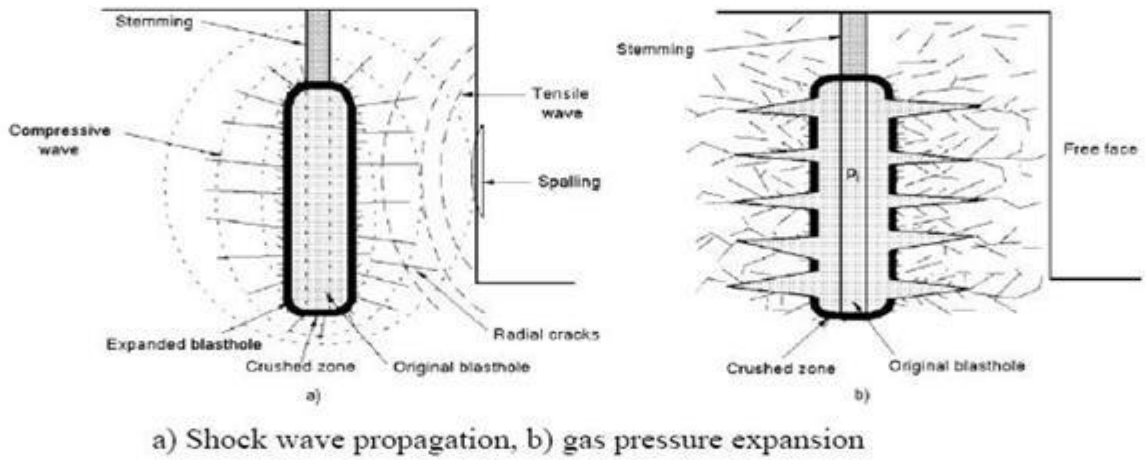


**Figure 2.7:** Shock Wave Propagation and Gas Pressure Expansion

The quickness of the energy release from the explosive mass depend on how rapid the detonation process. More precisely, the faster or quicker the detonation velocity of the explosive, quicker energy applied to the borehole wall makes it shorter time period. On the other hand, the slower the detonation velocity of the explosive will caused the energy applied to the borehole much slower and makes it a longer time period. The degree of coupling between explosive and the borehole wall will be affected on how efficiently the shock wave is being transmitted into the rock.

One of the best ways to transmit a better transmission of energy is by pouring or pumping the explosive into the blast hole instead of using the cartridge product which will leave a space between the cartridge product and the borehole wall. The pressure that builds up in the borehole depends on the explosive composition and physical characteristic of the rock. Strong competent rock will result in much higher pressure compared to weak rock, compressible rock (Sharma, 2011).

The fragmentation process begins when the shock wave reaches the borehole wall. The shock wave that begins out at the detonation velocity of the explosive will decrease rapidly as it enters the rock and in short distance it is reduced into the sonic velocity of the particular rock. Once the shockwave encounters with the borehole wall, the compressive strength of the rock is exceeded by the shockwave and the zone of that area around the borehole is crushed.

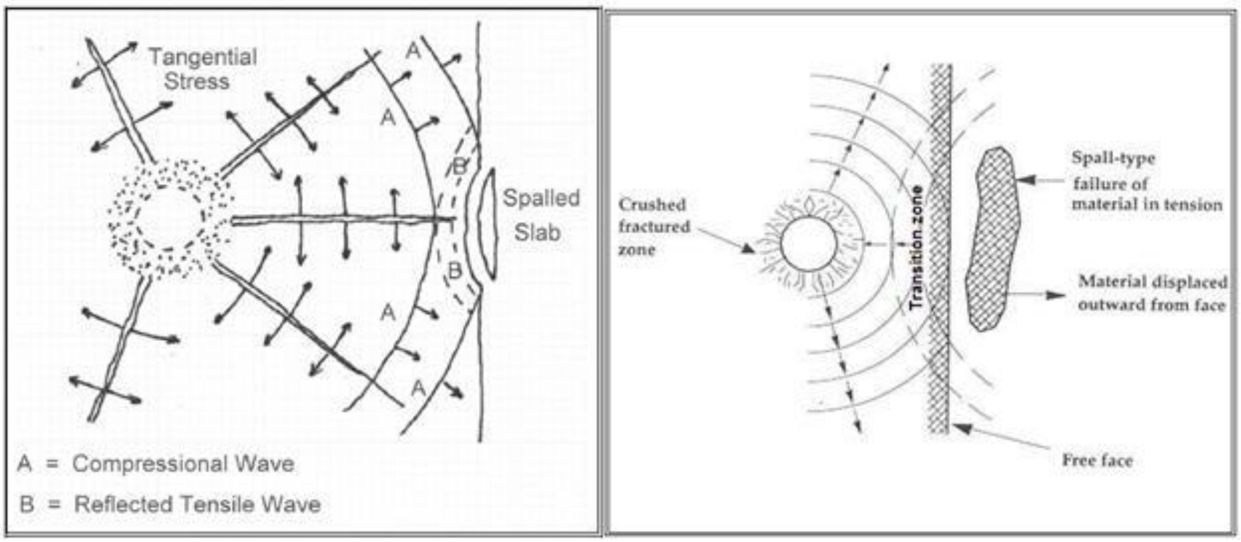


**Figure 2.8:** Compressional and Reflected Tensile Wave

While the shockwave emits outward at declining velocity, the intensity of the shockwave decreases below the compressive strength of the rock thus compressive crushing stops. The area/radius of the crushed zone varies with the compressive strength of the rock and the intensity of the shockwave. Beyond the crushed zone, the intensity of shockwave is exceeded the tensile strength of the rock and causes the rock mass to expand and fail in tension. Thus, radial cracking occurred on the rock.

If the compressive shockwave radiating outward from the hole encounter a fracture plane, discontinuity or a free face, it is reflected and becomes a tension wave that approximately the same energy as the compressive wave. The tension wave can possibly break a slab of rock. The reflection rock breakage mechanism depends on these three requirements (Sharma, 2011):