COMPARISON ANALYSIS OF ROCK FRAGMENTATION AFTER BLASTING BETWEEN IMAGEJ ANALIZER AND WIPFRAG SOFTWARE

NURHANISAH BINTI ABDUL JALIL

UNIVERSITI SAINS MALAYSIA

2022

SCHOOL OF MATERIALS AND MINERAL RESOURCES ENGINEERING

UNIVERSITI SAINS MALAYSIA

COMPARISON ANALYSIS OF ROCK FRAGMENTATION AFTER BLASTING BETWEEN IMAGEJ ANALIZER AND WIPFRAG SOFTWARE

By

NURHANISAH BINTI ABDUL JALIL

Supervisor: Assoc. Prof. Ir. Ts. Dr. Mohd Hazizan Mohd Hashim

Dissertation submitted in partial fulfillment of the requirements for the degree of

Bachelor of Engineering with Honours

(Mineral Resources Engineering)

Universiti Sains Malaysia

August 2022

DECLARATION

I hereby declare that I have conducted, completed the research work and written the dissertation entitled 'Comparison analysis of rock fragmentation after blasting between ImageJ Analizer and Wipfrag Software'. I also declare that it has not been previously submitted for the award of any degree and diploma or other similar title of this for any other examining body or University.

Name of Student: NURHANISAH BINTI ABDUL JALIL   Signature: Hanisah

Date: 16th August 2022

Witness by

Supervisor: ASSOC. PROF. IR. TS. DR. MOHD HAZIZAN MOHD HASHIM   Signature:

Date: 16th August 2022

ACKNOWLEDGEMENT

First and foremost, thanks to Allah because give me an opportunity to finish my Final Year Project successfully and smoothly. Besides, it is my honour to acknowledging the support and help received in completing this thesis. Throughout this project, I am able to improve my knowledge especially in blasting activity and geological setting in Imerys Mineral Malaysia Sdn. Bhd.

I express my deepest gratitude, Dr. Mohd Hazizan Bin Mohd Hashim , who provided me with encouragement, advice, and support from the beginning to the end of the project, allowing me to gain a clearer understanding of the project. Here, I would like to express my appreciation for his continuous support and valuable assistance in helping me to complete the writing of this thesis as well as challenging research that lies behind this project. This project would not have been completed without encouragement, advice, and support from Dr. Hazizan.

Next, I take this opportunity to express my gratitude to the management of Imersy Mineral Malaysia Sdn. Bhd. Mining manager;Mr. Ali Reza, mining engineer;Mr. Pugalyenthiran ,shotfirer; Mr Fazlan and blasting team. My thanks and appreciations also go to all the workers in Imerys Mineral Malaysia Sdn. Bhd. For giving me such attention, time and willing helped me out with their abilities.

Besides, I would like to thank to all the staff and technicians especially Mr Junaidi and Mr Zulkarnain who had helped me by giving support and assistance throughout my experimental work. I also express my sincere gratitude to all my lovely family and friends for their support and motivation throughout the project period. In addition, I would like to express my appreciation to those whom I fail to mention for help and guidance. Thanks for the help and guidance.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

Mpa	Megapascal
PSD	Particle Size Distribution
IMM	Imerys Mineral Malaysia
UCS	Uniaxial Compressive Strength
PLT	Point Load Test
RMR	Rock Mass Rating
mm	Milimeter
meter	Meter
kg	Kilogram
m3	meter cube
%	Percent

LIST OF APPENDICES

ANALISIS PERBANDINGAN PEMECAHAN BATU SELEPAS LETUPAN ANTARA IMAGE-J ANALYZER DAN WIPFRAG

ABSTRAK

Kajian ini bertujuan untuk mengkaji analisis perbandingan pemecahan batuan selepas peletupan antara Image-J analizer dan perisian Wipfrag. Kajian lapangan telah dijalankan di Imerys Malaysia Sdn. Bhd., Simpang Pulai, Perak, Malaysia. Kajian ini disusun kepada tiga fasa: (1) pemerhatian tapak, (2) analisis data, dan (3) kerja eksperimen. Selepas letupan, imej timbunan batuan pecah telah diambil menggunakan kamera telefon bimbit kemudian dimuat naik ke dalam perisian ImageJ Analizer dan WipFrag untuk analisa pemecahan graf taburan saiz zarah (PSD) yang diperoleh daripada perisian telah dikaitkan dengan reka bentuk letupan. Data penilaian pemecahan daripada beberapa aktivit letupan kemudiannya dibandingkan. Keputusan ujian UCS dan data struktur terhadap sampel lapangan turut dinilai dan dihubungkaitkan. Daripada kesemua empat sesi letupan yang dijalankan, peratusan lulus terkumpul penghancur adalah antara 60 hingga 80 % untuk ImageJ manakala julat dari 70 hingga 90 % untuk Wipfrag yang sepadan dengan pembukaan penghancur rahang, 800 mm. Seterusnya, ujian beban titik nilai (PLT) terendah ialah 2.03 MPa manakala yang tertinggi ialah 3.08 MPa yang secara signifikan dianggap sebagai kekuatan sederhana. Analisis juga mendapati terdapat tiga aktivit peletupan dengan Faktor Bahan Letupan (PF)= 0.30 kg/m^3 manakala sesi 4 iaitu PF=0.54 kg/m^3 yang agak tinggi berbanding yang lain. Masalah pemecahan batu besar turut dipengaruhi lagi oleh ketakselanjaran yang sedia ada di tapak letupan, bergantung pada arah, jarak, saiz bukaan dan keadaannya, serta keadaan geologi lain termasuk kekuatan batu dan ketebalan lapisan.

COMPARISON ANALYSIS OF ROCK FRAGMENTATION AFTER BLASTING BETWEEN IMAGE-J ANALIZER AND WIPFRAG SOFTWARE

ABSTRACT

This study was sought to study the comparison analysis of rock fragmentation after blasting between Image-J analizer and Wipfrag software. The field study was carried out at Imerys Malaysia Sdn. Bhd., Simpang Pulai, Perak, Malaysia. This study is organised into three phases: (1) site observation, (2) data analysis, and (3) experimental work. After blasting, images of the muck pile were taken using a handphone camera then were uploaded into ImageJ Analyzer and WipFrag software for fragmentation analysis of the particle size distribution graph (PSD) obtained from the software was correlated with the blast design. Fragmentation assessment data from several blast activities were then compared. UCS test results and structural data on field samples were also evaluated and correlated. From all four blasting sessions conducted, the cumulative pass percentage of the crusher ranged from 60 to 80 % for ImageJ while the range from 70 to 90 % for Wipfrag corresponded to the jaw crusher opening, 800 mm. Next, the lowest value point load test (PLT) was 2.03 MPa while the highest was 3.08 MPa which was significantly considered as medium strength. The analysis also found that there were three blasting activities with Powder Factor (PF) = 0.30 kg/m^3 while session 4 which was PF = 0.54 kg/m^3 was relatively high compared to the others. The boulder problem is also further influenced by the existing discontinuities at the blast site, depending on the direction, spacing, aperture and its condition, as well as other geological conditions including rock strength and layer thickness.

CHAPTER 1

INTRODUCTION

1.1 Background

Our capacity to evaluate and analyse blasting performance has improved significantly during the previous decade. These may now be paired with ongoing computer capacity improvements to provide future blasting practitioners with a more precise description of rock fragmentation. In mining, rock blasting is the most prevalent form of rock breakup. Controlling blast fragmentation after blasting is a topic that the mining sector is continuously concerned about (Shad, 2018). The categorization and size distribution of muck piles are key components of blasting operation management. Fragmentation has an impact on all downstream processes, including loading, hauling, and crushing, and can be employed to reduce these costs. Good fragmentation where the condition where fragmented rock does not require extra treatment after the primary blast, such as secondary breaking, and may be transferred directly to the next processing step with the least amount of unsalable fraction.

The stress wave and the gas pressurisation process very important for rock fragmentation in rock blasting. For the past 50 years, scientists have argued the relevance of shock and gas in fragmentation. Recent research suggests that stress waves generated by the detonation of an explosive charge are affected the development of a damage zone in the rock mass subsequent affect fragment size distribution, and that the explosion gases are important in separating the crack pattern that forms after the stress wave passes through, as well as in throwing the fragments (Kaneko, 2004).When an explosive enclosed within a blasthole detonates, a tremendous number of gases at extremely high temperatures and pressures are created in a relatively short period of time.

By exposing the rock surrounding the blasthole to stresses and strains, this gas serves as the energy to shatter the rock (Bhandari, 1996). Using the energy released when explosives are detonated, rocks are broken and dislodged from the wall face, generating a muckpile of rock bits that are then loaded and hauled to be processed further (Afeni & Osasan, 2009).

Limestone rock fragmentation is influenced by a variety of variables. The size of blasting fragments is determined by two factors which are uncontrolled characteristics (mine site geology) and controllable parameters (design of the blast). The controllable parameters include burden, spacing, bench height, powder factor, sub-drilling, stemming, blast start sequence, and hole diameter.

Mechanical (rock strength) properties and structural properties are the main geological features influencing fragmentation, with mechanical properties influencing the formation of initial cracks and structural properties. This throughout the rock mass influencing the propagation of shock wave and high-pressure explosion gas. Rock samples were subjected to point load tests to ensure that the strength and geological structure in the research region were consistent.

Size distribution measurement methods may be divided into two categories which are direct and indirect methods (Siddiqui, 2009). Sieving (or screening) is a direct and accurate way of evaluating particle and fragment size distribution; but, for production blasting, this process is expensive, time-consuming, and inconvenient (Sudhakar, 2006). As a result, indirect approaches such as observational, empirical, or image analysis have been developed. Image analysis such as ImageJ Analizer and Wipfrag software was employed in this investigation since sieving pieces from the final scale blast operation proved unfeasible.

1.2 Problem Statement

Fragmentation of rocks is poorly understood, and further study into predicting and managing fragmentation is needed (Kaneko, 2004). The understanding of the fragmentation mechanisms in explosively loaded rock is crucial for creating viable ways for rapidly extracting rock for a variety of uses, and it has progressed significantly in the previous two decades. Factor that can affect the fragmentation is the burden, spacing, stemming, amount explosive used, etc. The effect of blast pattern on fragmentation in bench blast was investigated in this study.

Nonetheless, rock mass characteristics are provided and used in part of the research. Furthermore, the traditional approach of measuring blast-induced fragmentation using image and sieve studies is vulnerable to biassed sampling and human-induced mistakes. Due to the impossibility of sieving fragments from the final scale blast operation, ImageJ Analizer and Wipfrag applications were employed in this investigation.

As a result, this research will assist the blasting sector in improving its performance. They can enhance the efficiency of their succeeding operations, such as hauling, comminution, and separation, by enhancing their blasting performance. This will help them optimise their mining operation.

1.3 Objective

In investigating the suitable parameters that can be used in the experiment, the objective specifically targeting as below:

1. To analyse rock fragmentation after blasting using ImageJ Analizer and Wipfrag software

2. To examine the PSD graph of both softwares and study the results obtained.
3. To examine the rock strength on the post-blast fragmentation.

1.4 Scope of Study

This study is organised into three phases: (1) site observation, (2) data analysis, and (3) experimental work. In this research, the rock fragmentation analysis is produced by blasting in a limestone quarry at Imerys Malaysia Sdn. Bhd. at Simpang Pulai, Perak, Malaysia, since the condition of the in-situ rock mass is one of the key variables impacting fragmentation degree. Imerys quarry site, which owns the Zain Liew and Hornaik quarry operations. Both quarries are located on Gunung Terundum, which is on the Kinta Valley's eastern side. Hornaik quarry, in particular, is located on the west side of Gunung Terundum.

This field work was completed in two weeks, and preparatory analysis was conducted to obtain the best results possible during the study. The data gathered for this study comprises blast design parameters and geological features. Some research has been done in finding the rock mass parameters and blast design that have an effect on blasting performance in order to produce desired or good fragmentation following blasting actions.

A photo of the muck pile after each blast is taken with a scale as a size reference for comparing fragmentation (in this study, a metre ruler is used). The photo will next be processed to determine the size of fragment rocks using ImageJ and Wipfrag software. The Particle Size Distribution (PSD) of the resulting fragmentation size for 800 mm feed of jaw crusher is plotted into a graph for comparison.

Experimental work was carried out at Mineral Processing Laboratory in School of Materials and Mineral Resources Engineering. Laboratory work such as Point Load Test carried out to determine the strength of the rock, which will be related to rock fragmentation after blasting.

1.5 Thesis Outline

This study consists of five chapters, including references and appendices. First, the literature review, methodology, results, discussion and conclusions and recommendations are included. Chapters are arranged in numerical order, Chapter 1, Chapter 2, Chapter 3, Chapter 4, and Chapter 5.

Chapter 1 provides an overview of research work. This chapter elaborates on the significance of this research work, the problem statement, objective, the scope of the study, and the flow of the dissertation.

Chapter 2 discusses a review of the literature related to this study. Articles and journals related to this task will be briefly described in previous studies. The focuses of Chapter 3 are methodologies. This section details the steps taken for the methods selected for sample preparation, studying the characterization studies performed on the raw materials, and analysing the experimental working sequences and the data obtained.

After Chapter 3 there are Chapter 4 that includes discussion of the methods used to collect information and data for the purpose of this study preparation, comparison fragmentation analysis and point load test further analysed and results. Based on past research and engineering knowledge, the results of this study were properly tabulated and interpreted.

Finally, Chapter 5 concludes the study. This chapter contains recommendations for further research in this area to improve and conclusions also results of each objective.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter presents literature review focusing to the research topic. Firstly, will discusses on explosives then about controllable parameters. Next, further discusses on uncontrollable parameters and continue discusses about fragmentation analysis digital of ImageJ Analizer and Wipfrag software.

2.2 Explosives

For decades, explosives have been employed in mining and quarrying businesses, particularly those operating in hard rock areas, as a means of breaking the rock masses and removing the needed resources because it is the most cost-effective method. All large-scale mining, quarrying, and civil construction excavations involve the use of explosives to fragment rock. The appropriate design of blasts and control, as well as the forecast of blast effects, has grown increasingly important as the scope of these activities has increased (Zhua, 2007). The use of significant amounts of explosives while charging, on the other hand, can lead to unfavourable outcomes.

Explosive is described as a solid or fluid substance or a mixture of components that, in the event of a suitable jolt, transforms into other more stable substances, to a large extent or completely vaporous with the advancement of heat and high pressure in a short period of time. When a commercial explosive is properly ignited, it rapidly converts to a gas at high temperature and pressure.

When a litre of explosive is detonated unconfined, it expands to roughly 1000 litres of gas in milliseconds and expanding explosion gases cause extraordinarily high strain within the rock when confined by rock. The energy generated upon detonation operates equally in all directions but, as one would assume, tends to escape along the path(s) of least resistance. As a result, charged and stemmed blast holes are required to ensure that the gases are confined for an adequate period of time to offer optimal breaking, displacement, and looseness of the blasted rock (Orica, 2008). Batch production of explosives is used.

There are a few blasting issues, such as faulty explosives and improper explosive rotation (i.e. storing for an inordinate amount of time) that are offered by the manufacturer. Most issues are caused by the date of production being painted on the cases and packages in order to ensure effective stock rotation in the magazine. The maximum timeframe for explosives is as follows:

1. Delay electric detonators 2½ years
2. Detonating cord 4 years
3. Emulsion explosives 12 months

2.2.1 Classification of Explosives

Industrial explosives are divided into two classes based on their detonation requirements: low explosives and high explosives. Low explosives are explosive materials that do not require the use of a detonator to ignite. Black powder and gun powder are examples of low explosives. Low explosives are typically set off by a flame that gives heat or a spark, which is provided by the spit of a safety fuse, a wick, or an electronic fuse head. The elements in the mechanical mixture do not react chemically to generate a new compound, and they are not explosives on their own. "It is a mixture of charcoal, sulphur and potassium nitrate. Black powder burn rapidly producing large quantity of gas. They deflagrate from few cm/s to 400 m/s. A simplified reaction is as follows in Equation 1:

$$2KNO3 + S + 3C = K2S + N2 + 3KCO2 \qquad \text{(Equation 1)}$$

Another type is high explosives, which are divided into two classes: primary and secondary. In detonators, primary high explosives are employed as the beginning explosive. Primary high explosives include lead azide, mercury fulminate, and lead styphnate. High explosives produce large volume of gas, exothermic reaction and temperatures of detonation are extremely high.

Furthermore, secondary high explosives are impervious to shock, friction, and heat. They can be ignited in small unconfined quantities when exposed to heat or flame, although detonation is possible. When put to detonators to improve power, their power is utilised. Dynamites, emulsion, watergels, as well as cast boosters like pentolite, are examples of secondary boosters. Depending on the composition, densities, degree of confinement, and diameter, the velocity of detonation (VOD) ranges between 4000 and 7500 m/s.

High explosives require a shock wave to initiate the detonator. When confined in a drill hole, the explosive on detonation produces extremely high-pressure gases which impart energy in the form of shock and heave into the surrounding rock.

2.2.2 Explosives Ingredient

The following ingredients are required for explosives to work:

1. Oxidizer: An oxidiser is a substance that allows the reaction to take place by supplying oxygen Ammonium nitrate is the most commonly used oxidizer.
2. Fuel: Reacts with oxygen to heat the mixture sufficiently. The fuel then combines with oxygen to produce heat. The fuel then combines with the oxygen in the air to produce heat. The most frequent fuels used to provide heat are fuel oil and aluminium powder.

3. Sensitizer: A sensitizer creates voids that act as 'hot spots,' where reactions begin to occur during explosion. Sensitizers are often air or gas in the form of very small bubbles, which are occasionally encased in glass micro-balloons (GMBs).

2.2.3 Types of Explosives

In the rock loosening process from benches, the mining industry uses many types of explosives, including ammonium nitrate and fuel oil (ANFO), gelignite, watergels, and emulsions.

1. Gelignite: A nitroglycerin (NG)-based chemical compound that is produced in a gelatinous or semi-gelatinous state. The use of gelignite in the mining industry is declining, owing to its expensive cost and increasing safety standards. Water-resistant "gel" is made by dissolving nitro-cotton on nitro-glycerine in the base of gelatine dynamites. The nitro-cotton gel is water insoluble and ready to bind other chemicals, rendering them water resistant and forming a solid, plastic-like structure with a constrained explosion velocity of 13000 ft/s (4000 m/s). These explosives have the following advantages:

    i. high bulk strength
    ii. excellent water resistance
    iii. propagate exceedingly between cartridges and failures are highly unlikely even under difficult conditions; and
    iv. a wide variety of cartridge sizes.

    Semi-gelatine are the explosives have a semi-gelatinous consistency that falls in between gelatine and powder. These explosives have qualities that are similar to gelatines and powders. The density is sufficient to prevent floating in wet boreholes and to provide some water resistance. The advantage of these explosives is that they may be tailored to match specific requirements; however, semi-gelatines are still occasionally used, although only in small diameter cartridges.

2. ANFO: An inert chemical mixture that, when combined in the proper proportions, produces an explosive compound. The best ratio for the mix is 94.3 percent AN: 5.7 percent FO, which produces a blasting agent that is effective. A detonator alone will not detonate ANFO; it requires a primer for detonation. A simplified reaction of ANFO is as follows in Equation 2:

   $$3NH_2NO_3 + CH_2 \rightarrow 3N_2 + 7H_2O + CO_2 \ (3900 \text{ kJ/kg}) \qquad \text{(Equation 2)}$$

3. Watergels: Watergels were created to compensate for the shortcomings of ANFO in damp situations. They have a gelatinizing ingredient, often known as a thickening, that changes the consistency of the product. Watergels are less hazardous and easier to make, transport, and store.
4. Emulsions: Ammonium, sodium, or calcium nitrate droplets are finely dispersed in the continuous phase of fuel oil. An emulsifying ingredient stabilises this emulsion against liquid separation. Emulsions have a high level of water resistance. This water-in-oil emulsion is then stabilized against liquid separation by an emulsifying agent such as sodium oleate or sodium monooleate. Dispersed gas can be put into the emulsion matrix for density control within a range of 0.70 to 1.35 g/cm3. This is achieved with microballoons or by chemical gassing of the composition.

2.2.4 Properties of Explosives

Meaningful predictions in blast design can be formed by understanding which properties are crucial to performance. Detonation velocity, density, detonation pressure, water resistance, and fume class are the attributes. These properties vary depending on the maker of an explosive.

2.2.4(a) Velocities Of Detonation (VOD)

The VOD is the pace at which a detonation wave travels through an explosive column. With this velocity, the shock energy produced by detonation rises rapidly. Most mine-related high explosives have a VOD of 2500-5500 m/s. For satisfactory rock fragmentation, a higher VOD explosive is necessary. The rate at which the explosion wave moves through the explosive charge is referred to as VOD. This is a crucial detonation parameter.

Explosives VODs speeds range from 2500 to 5500 m/s. The Dautriche test can be used to evaluate an explosive's VOD indirectly. For satisfactory fragmentation, higher VOD is required. Two explosives with the same strength but different VODs may function very differently in a blast. The higher the VOD, the larger the shock energy and the lower the heave energy are in general. In any event, it's critical not to mix together shock and fragmentation energy. Most explosives' VOD increases as charge diameter and confinement increase. Because of their high degree of refinement and effectiveness, emulsion explosives frequently maintain a very high VOD even in poor confinement and small diameters.

2.2.4(b) Density

When selecting an explosive, density is a vital factor to consider. A dense explosive is frequently required for tough blasting conditions or when fine fragmentation is desired. The specific gravity of an explosive can be used to determine its density. The specific gravity of an explosive is the ratio of its density to the density of water under typical conditions. Commercial explosives have a specific gravity ranging from 0.6 to 1.7 g/cc. The density of free-running explosives is sometimes expressed in pounds of explosives per foot of charge length in a certain borehole diameter.

Denser explosives, with a few exceptions, produce higher detonation velocities and pressures. A low-density explosive will frequently be sufficient in easily shattered rock or where fine fragmentation is not required. Low-density explosives are especially useful for making riprap and other coarse materials. When working in damp settings, the density of an explosive is especially significant. Water will not sink an explosive with a specific gravity of less than 1.0. High density means high energy concentration for NG-based explosives.

2.2.4(c) Sensitivity

The ease with which it will detonate is referred to as explosive sensitivity. Explosives must be sensitive enough to be easily detonated upon initiation when required, but insensitive enough to be manufactured, handled, and placed in blast holes for safety reasons. The explosive reaction to shock, impact, friction, electrostatic discharge, and heat is referred to as sensitivity. Describes how easily it will explode; this is vital when making allowances for safety when handling and using explosives. It must be shocked and heat insensitive; as safe to make, handle, and set in position as feasible, yet sensitive enough to explode when required. In commercial explosives, the trend is towards lower initiation sensitivity without sacrificing detonation efficiency.

If the explosives' sensitivity is great, especially in the presence of grit, they can be set off by mechanical impact or friction. In practise, commercial explosions are started by shock from the primer, detonator, or detonator cord. To produce proper explosion, the explosive density and blast hole diameter must be taken into account. In general, the substitution of Gelignite and other nitro-glycerine-based compositions with ANFO and emulsion explosives has been followed by a decrease in explosive sensitivity to impact and friction. This reduction in sensitivity has lowered the risk of unintended detonation and led to more secure explosives manufacturing, transit, storage, and use (Orica, 2008).

2.2.4(d) Fume Characteristics

The fume class is a measurement of the amount of harmful gases created by an explosion, primarily carbon monoxide (CO) and nitric oxide (NOx). Slurry explosives and explosives based on AN are preferred for blasting. During detonation, factors such as insufficient charge diameter, insufficient priming, incorrect delay timing, and water deterioration can alter the chemistry of an explosive. A commercial explosive should, in theory, create water vapour, carbon dioxide, and nitrogen when detonated.

Furthermore, toxic gases like as carbon monoxide and nitrogen oxides are commonly produced. These gases are referred to as fumes, and an explosive's fume class specifies the type and quantity of unwanted gases produced upon detonation. Explosives that produce fewer fumes receive higher ratings. In open work, fumes are normally unimportant; but, in confined places, the explosive's fume rating is critical. In any case, the blaster must guarantee that no one is exposed to the gases produced during a shot. Carbon monoxide slowly kills the brain and central nervous system, while nitrogen oxides generate nitric acid in the lungs almost immediately.

2.2.4(e) Water Resistance

Water resistance refers to an explosive's capacity to withstand exposure to water without losing potency or becoming insensitive. An explosive's capacity to withstand water and retain its explosive capabilities in the presence of water can be classified as excellent, good, fair, or poor. The chemicals in an explosive and how they are mixed throughout the production process determine its water resistance. Emulsions have great water resistance under normal conditions, and boosters are essentially waterproof, while ANFO does not.

As a result, many Malaysian mines and quarries opt to utilise emulsion rather than ANFO. Because ANFO has minimal water resistance, the energy released when poured into holes under damp conditions would be much lower. In damp settings, a gelatinous or slurry explosive is far more reliable. Bulk explosive decay accelerates with the intensity and duration of water exposure. Bulk emulsions, for example, can typically endure prolonged immersion in still water.

They can, however, degrade and fall apart swiftly in flowing or dynamic water, resulting in the product failing to detonate. Packaged explosives can also degrade if the cartridge is torn or pierced in these conditions. To reduce the time spent exposed to blast hole water, all explosives should be fired promptly after charge (Orica, 2008). Water resistance is irrelevant when working dry.

When there is water in the borehole and the interval between loading and firing is brief, a “excellent” water-resistance explosive will suffice. “Very good” to “excellent” water resistance is required if the exposure is extended or if the water is percolating through the borehole. Gelatins and emulsions have the best water resistance in general. Water resistance varies from good to outstanding in higher-density explosives, but low-density explosives and blasting agents have little or none.

2.3 Controllable Parameters

The amount of material fractured by blasting is linked to blast design parameters. Controllable parameters include the following: burden, spacing, bench height, drill hole depth, sub-drill, number of holes, explosive per hole, stemming length, delay sequence, blast pattern, detonation velocity, number of delays, and delay time between decked charge and powder factor.

Figure 2.1 shows the blast design parameters used in a bench blast. According to (Rajpot, 2009) for the purposes of blast design, the controllable parameters are classified in the following groups:

A- Geometric: Diameter, charge length, burden, spacing etc.

B- Physicochemical or pertaining to explosives: Types of explosives, strength, energy, priming systems, etc.

C- Time: Delay timing and initiation sequence.

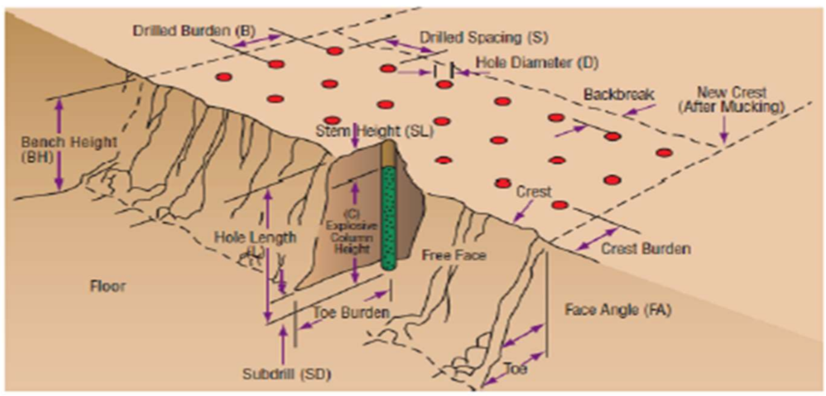

Figure 2-1: Blast design parameters (after (Sharma, 2012))

A variety of criteria, including as geometric, physicochemical, and explosive-related aspects, must be considered while constructing the ideal blasting strategy.

2.3.1 Burden

The burden is the shortest distance between a blasthole's axis and the free face. The drilling diameter, bench height, and desired degree of fragmentation and displacement are all factors that influence these values. It is critical to ensure that the burden size is appropriate. Marking and collaring errors, inclination and directional deflection during drilling, and flaws in the face of the slope could all cause burden size errors.

The location of the blast hole's front line should be given special attention. If the front row charges are overburdened, second row charges will not be broken by the time detonate. The limiting of motion at the start of the blast prevents optimal blasting results throughout the blast. When blasting using ANFO, the formula used is ash shown in Equation 3:

$$\text{Burden} = (25 \text{ to } 45) \times \text{Borehole diameter} \qquad \text{(Equation 3)}$$

The burden unit is metres, although the diameter is millimetres. Whereas 30 is utilised for hard massive rock while 45 is used for soft rock. In other hand, when blasting using bulk emulsion, the burden should increase in 20%.

Field testing and experience can be used to determine the optimal burden. The ratio of lower burden to charge diameter should be utilised as a first approximation. When using ANFO (0.85 g/cu. cm), the assumption of 25 times the diameter is a fair starting point for burden in rock with a density of 2.7 g/cu. cm (granite). When a denser bulk emulsion (1.2 g/cm3) is utilised in blasting, the weight can be increased by 30 to 35 diameters.

The burden from the blast hole to the nearby perpendicular free face is the load. The true burden can vary depending on the delay method used for the blast. In this manner, the delay configuration should be resolved before the drill pattern is drawn out. The diameter of the explosives, the depth of the hole, and the qualities of the explosives and rock all play a role in determining the burden.

There are two types of burdens: drilled burdens and shot burdens. Drilled load is the distance perpendicular to the row of holes between a row of holes and the nearest free face. It also represents the distance between two rows of holes. Shot burden differs somewhat from drilled burden because it represents the distance between a detonating hole and the next free face that has formed in the explosion (Bender, 1999).

Excessive burden inhibits flexural rapture by increasing bench stiffness. Furthermore, it produces an early relaxation of the stemming column, resulting in a fast drop in blast hole pressure, which negatively affects fragmentation. On the other hand, it encourages the quick release of gases into the atmosphere, which results in air explosions and poor fragmentation. According to (Rajpot, 2009) excessive burden, prevents explosive gases from properly fracturing and displacing rock. This results in total confinement and vibration levels up to five times higher than bench blasting. Small burdens, on the other hand, allow gases to escape and grow rapidly towards the open face, driving the shattered rock and projecting it wildly.

Air overpressure, noise, and fly rock all rise as a result of this phenomena. Excessive crushing between charges leads to superficial crater breaking, massive blocks in front of blast craters, and toe issues. Meanwhile, inadequate burden allows high pressure gases find an easy path to escape and expand rapidly towards the free face, pushing fragmented rock and projecting it unrestrained, resulting in a rise in air overpressure, noise, flyrock and vibration. This is energy that could have been used to accomplish useful work on the rock mass (Orica, 2008).

The correct burden whereas the distances to free faces (which may include the top of the bench) must be sufficient to contain the explosive gases and force them to do valuable work fragmenting the rock, while also being short enough to prevent shock-induced cracking and spalling from affecting most of the blast block. The correct blast hole placement is dictated by the way the rock mass moves. Even within the same quarry region, rock properties might alter and affect the optimal blast geometry requirements (Orica, 2008).

2.3.2 Spacing

Spacing is the distance between adjacent blast holes in a row, measured perpendicular to burden, is defined as spacing. It is estimated depending on the diameter of the drill hole, the bench height of the face, and the degree of fragmentation necessary.

Usually, the relation between the drilled burden and spacing is S= 1 to 1.8B or S= 1.15B (for staggered pattern on an equilateral triangular grid). The assumption of 1.6B to 2.0B is good starting point for determining the spacing of a blast to be initiated simultaneously in holes in the same row.

In Malaysia, the normal practice is an equilateral pattern is obtained by spacing with 1.2 times the burden. Excessive spacing between blastholes leads to insufficient fracturing between charges, as well as toe issues and an uneven face. Before the next blast, the rock pile should be totally excavated or hauled away, and the cost effectiveness of digging should be assessed (Orica, 2008). Crushing and clattering between holes, rocks, and toe difficulties may result from close spacing.

2.3.3 Subdrill

Subdrilling is the extra depth drilled below the grade level to avoid toe problems. The subgrade should be drilled to a maximum one third of the burden. The Equation $ for subdrilling is shown as below:

Subdrill= B/3, whereas B is Burden (Equation 4)

The fragmentation and displacement at the bench floor level must exceed specific key levels for efficient excavation or digging and loading activities. Subdrilling that is effective will have a significant impact on toe condition. Drilling an extra distance allows for unavoidable fallback (of drill cuttings and/or sludge) that tends to accumulate at the bottom of the blasthole. If the subdrilling is small, the rock will not be sheared off entirely at floor level, resulting in a toe look and a significant increase in loading costs. However, extensive subdrilling will result in the following:

i. An increase in the cost of drilling and blasting.
ii. A rise in the level of vibration.
iii. Impacting slope stability in the open pit's end zones.

iv. Increased risk of cutoffs

v. Overbreak as the vertical component of rock displacement is exaggerated

2.3.4 Stemming

Stemming is a method of filling inert material the void between explosive charge and the collar of the blasthole to confine the explosion gases. Usually, rock chipping is used since it could confine explosive energy better than drill cutting.

Stemming length suggested is not shorter than the burden. The goal is to keep the explosives' energy contained within the hole. Cost cutting, fragment production, and material availability dictated sacrifices in terms of explosive gas confinement. This process is influenced by the following:

i. The material type and stemming length. The amount and type of stemming material employed will have a significant impact on the degree of confinement and blast efficiency. The stemming stopper should never blow out and allow the gases to escape prematurely in order to extract the maximum energy from the expanding gases. A stemming length shorter than 20D, where D is hole diameter usually causes flyrock, cut offs and over break problems.

ii. The stemming column's length. The optimum stemming lengths grow as the quality and competence of the rock decrease, ranging from 20D to 60D, where D is the borehole diameter. To minimise difficulties like airblast, flyrock, cutoffs, and overbreak, a stemming length of more than 25D should be maintained whenever possible. Stemming colum usually ranging from 0.5B- 1.3B. A good first approximation for stemming height is about 1B, whereas B is burden.

2.3.5 Hole Diameter

The diameter of the drilled hole is the diameter of the blast hole. The relation between blasthole diameter and face height can be expressed in Equation 5:

Hole Diameter = 0.001 to 0.02 H, whereas H is face height (Equation 5)

Drillhole diameter affects how explosives are distributed in a blast. It appears to have a significant effect on fragmentation. The diameter of the drillhole is determined by the machine available and the elements that influence blasting.

When large rock has smaller blast holes, it has better explosive dispersal. When The diameter of the blast hole is increased while the explosion energy factor remains constant, the larger blast hole pattern produces predominantly coarser fragmentation. (Rajpot, 2009) found that the distribution of explosives in a blast is dependent on drillhole diameter in his study on the influence of fragmentation specification on blasting cost in 2009.

Blast fragmentation is possible with a small blast hole diameter. This is due to a better energy distribution in blasting since the powder factor is reduced. Drilling, priming, and initiation, on the other hand, are quite costly. Charging and stemming drillholes also takes a long time. Large blasthole diameters result in higher drilling and blasting expenses. It also allows for a lot of weight and distance, which can lead to coaser fragmentation. Drillhole diameter is theoretically depending on:

1. The properties of the blasted rock mass.
2. Required degree of fragmentation
3. Charge arrangement and bench height
4. Drilling and blasting costs

2.3.6 Powder Factor

The powder factor is used in development blasting to express the ratio between the mass of explosives required to break a given quality of rock and is normally expressed or kg/t^3 and calculated as shown in Equation 6. Powder factor is affected by rock structure, blast design, and explosive parameters. Table 2-1 shows the powder factor for different types of explosives in different types of rock.

$$\text{Powder Factor (PF)} = \frac{Weight\ of\ explosive}{Burden\ x\ Spacing\ x\ Bench\ Height} \qquad \text{(Equation 6)}$$

Table 2-1: Typical powder factors used in mass blasts

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

Higher powder factor, on the other hand, reduces the total unit cost of operations like loading, transportation, and boulder crushing. Finer blasted fragments can improve hauling efficiency while reducing cycle time in hauling operations. Aside from that, when the powder component is strong, fewer boulders accumulate in the muck pile. As a result, the hydraulic breaker's fuel consumption can be reduced, lowering boulder crushing costs to an absolute minimum.

When compared to low explosives energy, high explosives energy contains a lot of aluminium powder, which has a larger density charge and can break more rock per unit weight. Soft, low-density rock takes more explosive than hard, solid rock. A rock with multiple, closely spaced joints or fractures, on the other hand, requires a smaller powder factor than a huge rock with few existing planes of weakness. Furthermore, the powder factor is strongly linked to free faces. The rock is fractured by a blast with many free faces with a low powder factor.

Recognize rock structure and apply a precise powder factor to geographical structures. If the area is more shattered with fractured rock, the powder factor chosen should be lower; while, if the area is enormous rock, the powder factor chosen should be greater (Ragunathan, 2017).

2.3.7 Blasthole Pattern

There are a few blasthole pattern, including square, staggered, and rectangle are the most prevalent. They determined that the distribution of energy throughout the blast varies depending on the blast pattern. It is critical to choose the optimal design for this variable so that large boulders are avoided by dealing with geological traits and conditions, as well as energy distribution produced. Due to the ease with which the collaring points may be drawn out in bench blasting, the most common blast hole pattern is square or rectangular.

2.3.7(a) Square Pattern

The drilled spacings are equivalent to the drilled burdens in a square blast pattern. The square layout is intended to generate a high chance of unbreakable rock in an uncovered explosive effect dispersion.

2.3.7(b) Rectangle Pattern

The drilled spacings in a rectangular blast pattern are bigger than the drilled burden.

2.3.7(c) Staggered Pattern

Staggered patterns produce more fragmentation and productivity than square or rectangular patterns, according to operational experience and blast modelling results. The best staggered patterns in solid huge rocks are based on equilateral triangular frameworks, are the most effective because they provide the best distribution of explosive energy in the rock and enable more freedom when arranging the initiation sequence and break direction. However, it should be remembered that the start sequence used might considerably alter the performance of these patterns.

The spacings in a staggered pattern are larger than the burden. Each row's spacings are offset so that the holes in one row are in the center of the spacings of the holes in the row before them. When using equilateral triangular patterns, the drilled blasthole spacing (S) should be equal to the actual burden distance (B) multiplied by a factor of 1.15 (S = 1.15B). This blast pattern is typically employed for row firing, when the holes in one row are fired first, followed by the holes in the row behind them.

2.4 Uncontrollable Parameters

The qualities of the rock mass and the geological structure are uncontrollable aspects in blast design. These must be factored into the blast design. The qualities of the rock, rather than the explosives employed to break it, may determine the outcome of any blast.

The following are the most essential rock qualities that affect blasting results:

i. Rock Density