A STUDY ON THE PRODUCTION OF HIGH QUALITY AGGREGATES FROM METSO BARMAC ROCK ON ROCK VERTICAL SHAFT IMPACT CRUSHER AND CONE CRUSHER

By

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Thesis submitted in fulfillment of the requirements

for the degree of

Master of Science

April 2009

ACKNOWLEDGEMENTS

Bismillaahirrahmanirrahiim,

My greatest gratitude to Allah S.W.T Almighty God, for the grace which enables me to complete my research. I would like to express my deep debt of inadequate acknowledgment to my main-supervisor, Prof. Dr. Khairun Azizi Binti Mohd Azizli for her guidance, supervision, assistance and encouragement throughout this work. Her patience and hard work have always been admired. I am also thankful to my co-supervisor, Dr. Hashim Bin Hussin for his encouragement and invaluable advice.

I am thankful to Universiti Sains Malaysia (USM) and my parents for the financial support, which enables me to pursue my studies. I am also thankful to Institute of Postgraduate Studies (IPS) for giving me the opportunity to conduct and complete my studies here. I would also like to express my indebtedness to Metso Minerals for loaning us the Metso Barmac Rock On Rock Vertical Shaft Impact Crusher.

My greatest gratitude and appreciation is extended to my father, En. Hamir Bin Hassan, mother Puan Sabariah Binti Mohd Rasid and all my family members for their sacrifice, continuous support and motivation. Many thanks also go to En. Kemuridan Bin Mat Desa for providing me his fullest effort, assistance and help. My sincere thanks are also directed towards other technical staff including En. Shahrul Ami, En. Rashid, and En. Halim and En. Ali, from School of Civil Engineering, for their help and guidance on the usage of the laboratory equipment. Thank you to my friends and everyone who has helped me in the completion of the thesis.

Mahathir Bin Amir

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LIST OF ABBREVIATIONS

ACV	Aggregate Crushing Value
AIV	Aggregate Impact Value
c	corners
CSS	Close Side Setting
e	Edge
EI	Elongation Index
f	Face
FI	Flakiness Index
Hz	hertz
tph	tonne per hour

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KAJIAN PENGHASILAN AGREGAT BERKUALITI TINGGI OLEH PENGHANCUR METSO BARMAC HENTAMAN BATU KE BATU ACI MENEGAK DAN PENGHANCUR KON

ABSTRAK

Kajian telah dijalankan untuk menilai prestasi penghancur kon dan penghancur Metso Barmac Aci Menegak ke atas penghasilan agregat berkualiti tinggi. Beberapa analisis telah dilakukan untuk mengkaji ciri-ciri bagi produk penghancuran seperti bentuk (Indeks Pemanjangan (IP); Indeks Kekepingan (IK); dan analisis kandungan lompang), taburan saiz, tekstur permukaan (Imbasan Mikroskop Elektron (IME)) dan kekuatan (Nilai Penghancuran Agregat (NPA) dan Nilai Hentaman Agregat (NHA)). Kajian juga dijalankan untuk mengenal pasti binaan-dalaman batuan yang baik dalam mempengaruhi mekanisma penghancuran. Produk penghancuran dari Suapan B menunjukkan keputusan yang lebih baik berbanding dengan produk penghancuran dari Suapan A. Penghancuran dengan tetapan bahagian tertutup iaitu 12mm dan pada kadar suapan 2.6 t/j dimana penghancuran 'cekik' berlaku, memberi penambahbaikan kepada ciri-ciri produk daripada segi bentuk dan tekstur permukaan dengan nilai IP dan IK masing-masing 31.25% dan 16.29%. Analisis NPA dan NHA menunjukkan nilai masing-masing 19.58% dan 24.42%. Pengendalian penghancur Barmac pada kelajuan pemutar 60 Hz dan nisbah lataan 0% menghasilkan produk dengan nilai IP dan IK yang rendah iaitu masing-masing 19.96% dan 12.02% berbanding dengan penghancur kon. Nilai NPA dan NHA yang rendah turut diperolehi, iaitu masing-masing 15.61% dan 21.06%. Jelas bahawa penghancur Barmac berupaya untuk menghasilkan produk yang berkualiti tinggi daripada segi bentuk dan tekstur permukaan jika dibandingkan dengan penghancur kon.

A STUDY ON THE PRODUCTION OF HIGH QUALITY AGGREGATES FROM METSO BARMAC ROCK ON ROCK VERTICAL SHAFT IMPACT (VSI) CRUSHER AND CONE CRUSHER

ABSTRACT

A study was conducted to evaluate the performance of cone crusher and Metso Barmac VSI crusher in producing high quality aggregates. Various analyses were completed to study the characteristics of crushed products such as shape (Elongation Index (EI); Flakiness Index (FI); and voids content analysis), size distribution, surface texture (Scanning Electron Microscopy (SEM)) and strength (Aggregate Crushing Value (ACV) and Aggregate Impact Value (AIV)). A study was also conducted to evaluate a good rock build-up formation in influencing the crushing mechanism. Crushed products of Feed B displayed better results compared to the crushed products of Feed A. Crushing with CSS of 12mm and increasing the feed rate of the cone crusher to 2.6 t/h which was the choked feeding crushing, gave improvement to the characteristics of crushed products in terms of shape and surface texture with EI and FI values of 31.25% and 16.29% respectively. ACV and AIV analyses showed values of 19.58% and 24.42% respectively. Operating the Barmac crusher at 60 Hz rotor speed and 0% cascade ratio was found to produce crushed products with lower percentage of EI and FI which were 19.96% and 12.02% respectively compared to the cone crusher. Similarly, lower values of ACV and AIV were obtained, which were 15.61% and 21.06% respectively. Overall, Barmac crusher was capable to produce better quality of products in terms of shape and surface texture compared to the cone crusher.

CHAPTER 1

INTRODUCTION

1.1 Aggregates

Aggregates are from the natural rocks which are produced through the crushing process. It is used in construction sector such as roads, buildings and other structures. Granite and limestone are the main sources for the aggregate industries in Malaysia. The qualities of aggregates which are used in concrete and asphalt mix depend on mineralogy and petrographic characteristics of the main rocks as well as the crushing machines used to produce these aggregates. Aggregates used in construction materials must adhere to certain standard specifications.

Physical characteristics of aggregates such as rock composition, hardness, size distribution, surface texture and shape are significant properties that influence the properties of concrete and asphalt pavement mixtures. The shape of aggregate for concrete plays an important role with the strength properties. Equidimensional shape of aggregate is the main choice because it is dense and strong. In reality, particles with equidimensional shape are difficult to obtain from the compression type of crushing process. Aggregate in the crushing products can be classified into six essential shapes which are rounded, irregular, flaky, angular, elongated; and flaky elongated. Particles with cubical or equidimensional shape will give additional strength to the construction products. It is more difficult for the particles to break when forces are imposed from various directions. Hudson (1995) stated that cubical or equidimensional shape helped particles to arrange more packly and closely to fill the voids in the concrete mixtures.

The construction industry highly depends on the quarrying sector for its aggregates. In recent time, the construction sector demands better quality aggregate not only for its size grading, but also for the aggregate shape. The continuous growth experienced by the construction sector and aggregate industry through the years are due to the construction works as declared in the Ninth Malaysian Plan. Referring to Figures 1.1 and 1.2, the Malaysian Government plans to spend more than RM 70 billion for development of infrastructures (health and educational), public facilities, expanding of low and medium cost housing areas; city services and road developments. These developments are carried out not only in the urban areas, but will be expanded to rural areas so as to improve information system and the economic growth and upgrading the quality of residents' life (Anon, 2006). These facts proved that the demand for aggregate as the raw material for construction purpose will increase to fulfill the requirement of the development sector.

1.2 Importance of Aggregate Shape in Asphalt Pavement

It is known that usage of aggregates that are equidimensional in shape will give better outcome on the product mixtures performance, because this property of aggregate is

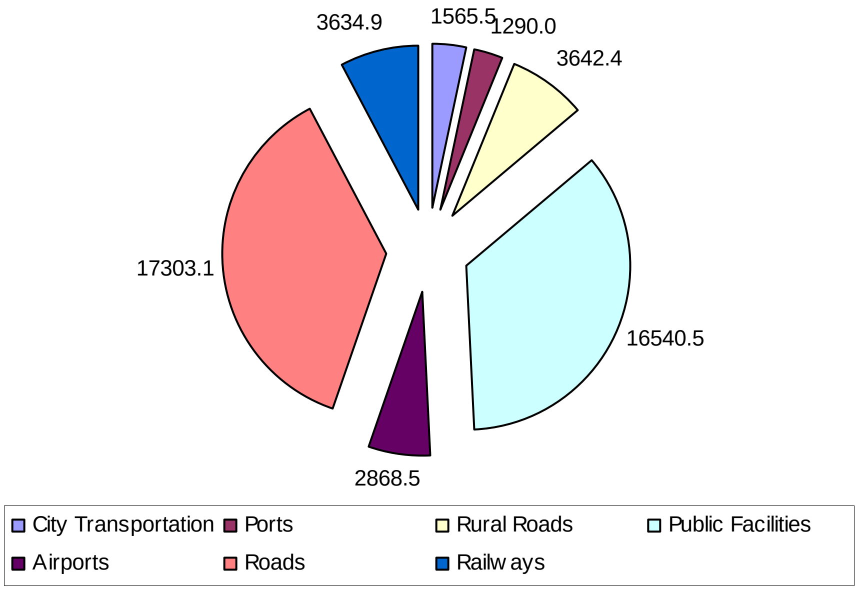

Figure 1.1: Expenditure and allocation for expansion of infrastructure and public facilities (RM millions) (Anon, 2006)

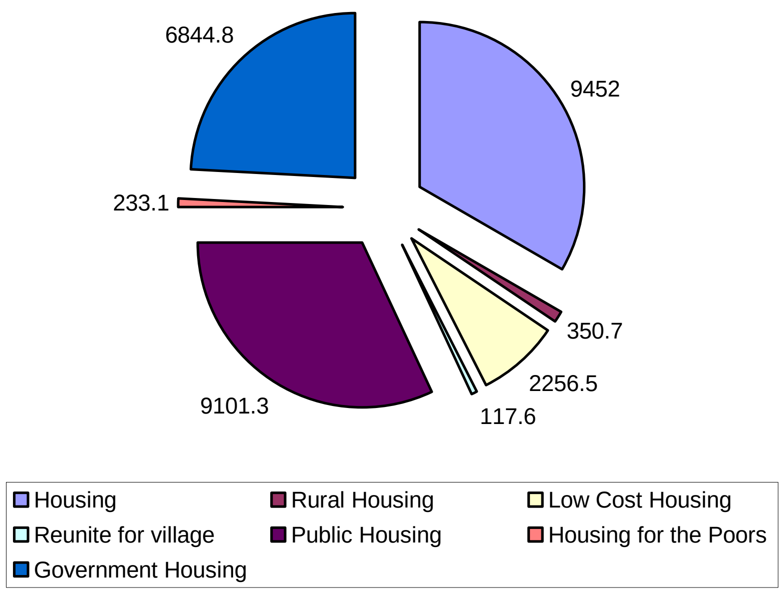

Figure 1.2: Expenditure and allocation for development of housing and urban services (RM millions) (Anon, 2006)

capable to control the performance of mixtures for the final products (Topal *et al.*, 2005 & Atkins, 2003).

Stronger aggregates with improvement in particle shape and textural characteristics tend to produce stronger asphalt pavement as the weak planes and structures are being reduced. Masad Eyad *et al.* (2003) stated that, if good performance of hot mix asphalt is required, the coarse aggregate which is used in the hot mix asphalt mixtures must have at least 85 percent of cubical or equidimensional particles. Cubical or equidimensional aggregates can increase the resistance strength of the hardened asphalt mixtures because they give much greater particle-to-particle mechanical bond and results in a larger adhesive force as they bind more securely between the particles and the asphalt cement mix. When forces are imposed on the hardened asphalt mix, frictional properties between aggregates themselves and asphalt cement mix as well can help to neutralize the absorption of the forces with the existence of good resistance to sliding of one particle over another (Atkins, 2003; Topal *et al.*, 2005; Kaplan, 1959 & Masad Eyad *et al.*, 2003). Asphaltic mixture properties that are affected by the shape and surface texture of aggregate includes, dynamic stiffness, stability, durability, permeability, resistance to moisture damage, air voids in the mixture, permanent deformation, fatigue resistance and the skid resistance of pavements (Topal *et al.*, 2005).

1.3 Problem Statement

There are few factors that influence the production of cubical or equidimensional shape particles. Not only crusher and crushing techniques contribute to the production of good quality aggregates, but the rock and mineralogy were also affecting to the quality or characteristics of the product/aggregate. Based on the previous studies, it was proved that rock-on-rock crushing method was capable to reduce the production of flaky and elongated particles (Kojovic, 1995). Other researchers (Hosking, 1992; Jamkar *et al.*, 2004 & Topal *et al.*, 2005) found that product produced by impact crusher will give better shape compared to compression type of crusher.

In Malaysia, construction industries are completely dependent on the aggregate obtained from local quarries. Presently, most of the quarries are using conventional crushing method which is compression type of crushing machine to produce the aggregates. The usage of compression type of crusher influences the characteristics of aggregates produced by generating high percentage of poor quality aggregates. According to Fernlund (2005), the production of aggregate with enhanced characteristics is highly emphasized because it gives a better outcome, life expectancy and safety to several engineering materials for housing, buildings, roads, bridges, dams and others. Aggregates which are good in quality have improvements in their characteristics with more cubical or equidimensional shape and better graded or size distribution (Hammer, 1991). They are also free from weak planes which are easily fractured or damaged as forces are imposed on them. Products which are produced from the compression breakage method contained a lot of irregular, flaky and elongated particles. These types of shape will reduce the capability of the aggregate to arrange densely when used in concrete and asphalt pavement mixtures.

Cone crusher is a compression type of crushing machine. It is widely used in aggregate industry to produce the final saleable product (Moshgbar *et al.*, 1995). It uses the principle of grinding rock between an eccentrically rotating mantle and a stationary concave liner. The material entering will be crushed between the two surfaces by compressive forces due to the eccentric motion (Napier-Munn *et al.*, 1996 & Wills, 1995). The high speed will cause the aggregate particles to shatter resulting from the great constraint forces (Bengtsson *et al.*, 2006). In this research, focus shall be put on the operating variables (feed rate and close side setting, CSS) of a cone crusher, which those operating variables are capable to influence the provision of an effective breakage situation in producing aggregates with better physical characteristics. Besides, there is a situation where the operating variable of feed rate can be manipulated to create a condition known as "choke feeding". There are numerous reasons as to why this is employed by manufacturers. Besides reducing wares and damage on the mantel and concave parts of the crusher, choke feeding could improve the breakage imposed in the crushing chamber thus improving the cubicity of the product. Moreover it gives a more consistent product sizing (Bearman *et al.*, 1998). Choke feeding provides the rock-to-rock crushing mechanism which is a unique breakage mechanism that influences the shape of the crushed aggregates. Interparticle collisions provide the breakage and fracture such as crushing, shatter, shear, and compressive. The crushed aggregates are free from weak planes such as microfractures, mineral boundaries and jointing (Anon, 1994).

Impact crusher can give an alternative to the conventional methods that have been used widely. Metso Barmac Rock on Rock Vertical Shaft Impact (ROR) crusher is a type of impact crusher that uses a spinner or rock lined rotor that continuously accelerates and discharges the incoming aggregates outward onto a solid pack of rock lining in the crushing chamber, so that nearly all crushing energy is used in rock-to-rock impact crushing and attrition. The combination of high velocity impact crushing with high pressure attrition grinding is capable to produce high volumes of cubical and equidimensional products (Anon, 1994 & Briggs *et al.*, 1996). The crushing action in the Metso Barmac Rock on Rock Vertical Shaft Impact (ROR) crusher concentrates on several aspects of aggregate particles such as areas of softer material, areas of planes of weakness, mineral boundaries and flat or thin edges of a particle. The process of autogeneous crushing occurring within the crushing chamber of the Metso Barmac Rock on Rock Vertical Shaft Impact (ROR) crusher varies from other type of crushers. The effectiveness of crushing works using impact crusher depends on the best condition of the three different operating variables which are crushing chamber build-up characteristics, rotor speed (hertz) and cascade ratio (%). Crushing under the optimum conditions is capable to provide a breakage that will destroy any weaknesses in the material, breaking elongated and flaky feed which are naturally produced through normal compression type of crushing operations; thus producing stronger aggregates.

The production of quality aggregate by both crushing machine shall be studied in this research. Cone crusher and Metso Barmac Rock on Rock Vertical Shaft Impact (ROR) are chosen for this research as the representative of widely used crushing machine in aggregate producing industry of our country. Result analysis which displayed by both crushing machine can give picture clear regarding factors which give effect to production quality aggregate according to type of crusher used. The factors should be given high attention where this condition is able to provide safe and long lasting construction products, resulting from better aggregate quality.

1.4 Objective

The main objective of this research is to study the performance of two different types of crushers in producing high quality aggregates in terms of shape, surface texture and size grading to fulfill the requirements of asphalt pavement mixes.

Measurable objectives:

- To study the breakage mechanisms in the cone crusher and impact crusher and evaluating the effects by changing the operating variables like feed rate (ton/hour), close side setting (mm), rotor speed (Hz) and cascade ratio (%) in controlling the production of products with good quality.
- To investigate the influence of feed characteristics such as mineralogy, chemical and physical properties on the final products.

The results of this study are expected to provide more information and knowledge for better prediction and control of the quality aggregate for use in the production of better asphalt pavement.

CHAPTER 2

LITERATURE SURVEY

2.1 Introduction

Malaysia is among the countries that is experiencing rapid infrastructures growth. Effective management of the material resources for construction purpose is highly demanded to ensure optimum production and usage of these construction material resources. One of the best solutions is to produce aggregates with high quality by upgrading the rock physical characteristics. Using high quality aggregates can produce better construction materials with improved quality and the advantage of avoiding carelessly and unappreciative usage of raw materials (Rajeswari, 2004).

Hot mix asphalt (HMA) is the most common pavement surfaces in use today. It is used on all types of roadway. Aggregates constitute the major part of the pavement structure. Aggregates have been reported as having considerable influence on strength and as well as the asphalt pavement performance. Moreover, it is relatively inexpensive and does not enter into complex chemical reactions with water and thus considered as inert mineral filler. Due to these characteristics, aggregates are considered as the most favorable filler ingredient in HMA, which determines many important properties of HMA.

Aggregates are obtained through crushing process on certain type of rocks. Crushing is the mechanical stage widely used in the aggregate-producing industry for the construction and development sector. The main objective is to reduce the particle size and dimension of rock materials (Wills, 1995; Tang *et al.,* 2001 & Topal & Sengoz, 2005). It reduces the size of the rock particles to make them suitable for use in mixtures of concrete and hot mix asphalt. There are two main methods utilized in crushing for size reduction that are compression and impact.

There are a number of factors that can influence the shape of particles such as breakage energy, the rock type, and crusher type in terms of machine design. Impactors are capable to produce cubical particles compared to the compressive breakers. This kind of breakage method can influence the production of high quality aggregates in terms of improved shape and graded size. It takes place at a much shorter time scale, implying a dynamic crack propagation that leads to a much faster failure of the particles. Furthermore, the impact generates compressive and tensile shock waves traveling throughout the particle. Consequently, the larger particles break more easily compared to the smaller particles because they contain larger micro-cracks. Compared to compressive breakers, the crushing trend of the jaw and cone crusher is causing a slow disintegration of the compression breakage. However, for the cone crusher (compressive breakers), the crushing technique of choked feeding crushing should be employed because it can reduce the production of particles with poor shapes (Kojovic, 1995). The choked feeding crushing occurs when the volume of material arriving at a particular cross-section is greater than that leaving. There are numerous reasons as to why choked feeding crushing is recommended by manufacturers, the most common points include:

i. develops a uniform wear profile;

ii. gives a more consistent product sizing;

iii. maximises throughput;

iv. extends the liner life;

v. Improves the cubicity of the product (Bearman and Briggs 1998).

2.2 Cone Crusher

Cone crushers operate on the principle of compressive breakage. They are usually used in the mining and quarry sectors (for production of road stones or aggregates) which are widely used for secondary and tertiary crushing of rock (Moshgbar, *et al.,* 1995 & Yaxley & Knight 1999). They operate with dry feeds and their purpose is to reduce the ore to the size suitable for grinding.

The cone crusher (Figure 2.1) consists essentially of a spindle, a crushing head (a hard steel conical grinding element), spider and shell. During the crushing process, the material in the crushing chamber is subjected to a series of hammer-like blows and gradually nipping and compressing by both mantle and concave (Tang *et al.,* 2001). Both mantle and concave which represent the jaws are moving relative to each other. The gradually actions allow particles to flow freely through the crushing chamber. Sometimes, the smaller sizes go through the crusher without change, whereas larger particles are broken down to the desired size (Harold, 2003).

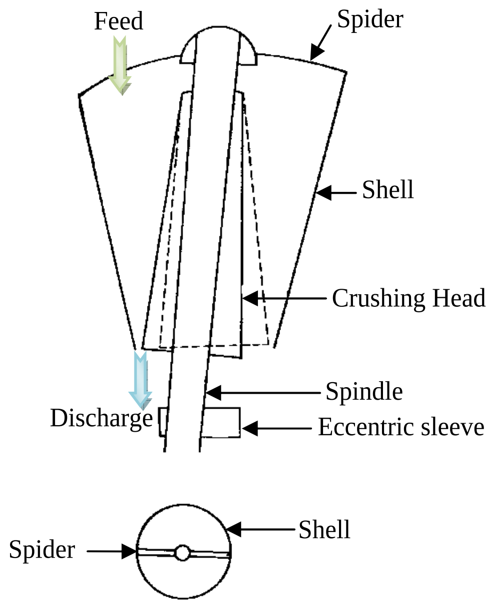

Figure 2.1: Important parts in the cone crushers (Wills, 1995).

Crushing process in the cone crusher occurs in the crushing chamber which is located between mantle and concave. Inside this chamber, aggregates will be shattered by the great compressive energy and will cause them to break undesirably to the smaller sizes. The particles in the size range near to the crusher setting are mainly influenced by the crushing mechanism. For the fine particles, it is more difficult for the crusher surfaces to give the large impact of the compressive load, but only the coarse particles will receive larger percentage of the impact. There are two types of breakage actions which are imposed on the aggregates. They are the blows of the crushing head itself and the forces from the collisions between the aggregates. Nevertheless, these breakage impacts are influenced by the equilibrium between the free spaces and the amount of aggregates in the crushing chamber.

The breakage condition of the crushing occupying a small number of aggregates is different than the breakage with lots of aggregates. The management of aggregate quantity involved in the crushing chamber is assisted by a distributing plate on the top of the cone which helps to centralize the feed, distributing it at a uniform rate to the entire crushing chamber where the controlled feed can give different crushing situations (Wills, 1995).

The quantity of aggregates will influence the breakage equilibrium in crushing chamber. This situation has a linkage with the amounts of the feed rate. Hosking (1992); Jamkar & Rao (2004) and Topal & Sengoz (2005) state in their papers that poorer shape was generated by the crushers which were operated with slow feed rates (except impact breakers). Crushing with low feed rates will have a lot of voids among the aggregates, thus they are crushed freely and mostly manipulated by the breakage force of crusher’s head. However, the crushing mechanism will completely change as the feed rate increased to a higher value. Increasing the feed rate shall give a good improvement to the shape of the particles. While the chamber is full with particles, a large amount of the particles are compressed among themselves at the higher parts of crushing chamber. Feed particles start to fill the crushing chamber until it is fully packed. As the crushing chamber is crowded with aggregate particles, the rock-on-rock breakage mechanism shall occur. Antiparticle impacts between particles with same characteristics shall influence the particle breakage on weak planes such as mineral boundaries, jointing and microfractures (Anon, 1994). The breakage energy will be spread completely to all of the aggregates, resulting in ideal breakage mechanism. The energy impressed on the particles by the crusher head is also reduced since the travel of mantle and concave is restricted by the aggregates which filled the crushing chamber. The decreasing breakage energy is shifted on the particles and it is utilized to smash among them. This crushing could produce better shape product compared to crushing by crusher head towards the aggregates itself in the crushing cavity. It causes extra amount of feed materials. Throughout this situation, there shall be various forms of breakage mechanism that occur on every aggregate such as shown in Figure 2.2.

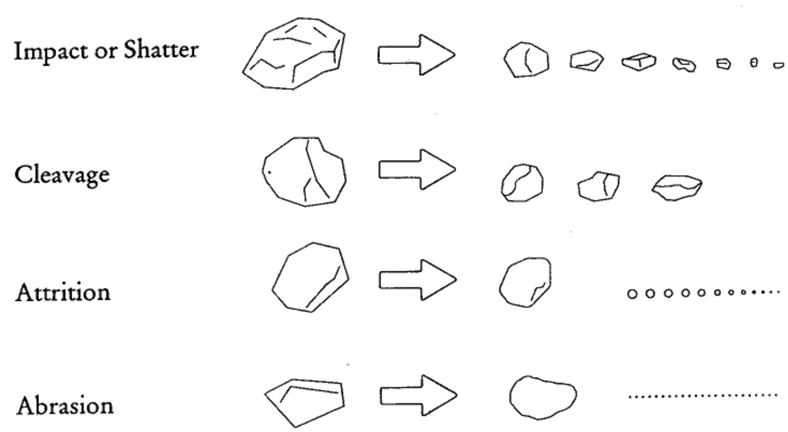

Figure 2.2: Types of fracture mechanisms which are assumed to occur throughout the choked crushing of cone crusher (Anon, 1994).

The features of a cone crusher are important for providing a suitable situation of the crushing chamber. Normally, the crushing chamber's capacity of a cone crusher is up to 1100 ton per hour (t/h^{-1}) (Wills, 1995). A large capacity showing that the cone crusher has extra advantage of bigger crushing chamber for allowing it in receiving a high total feed. A stability of breakage energy occurred between the compressions and shattering of the hard-solid metal and among the aggregate themselves. There are a few studies that have been done and have shown that the existence of rock-on-rock breakage mechanism improves the physical conditions of the crushed aggregates. Without the presence of other aggregates, the huge breakage energy will be imposed directly on the aggregates in the crushing chamber. Consequently, poor characteristics of products with a lot of fines will be produced as shown in Figure 2.3. Once the crushing chamber is full with aggregates, then the impacts and frictions which take place between them are the important sources of strength that permit the aggregates to be processed and crushed without including high breakage energy of the crusher head. On the other hand, the effects gave by both attritions and abrasions are not too big as those in the crushing chamber of the impact crushers.

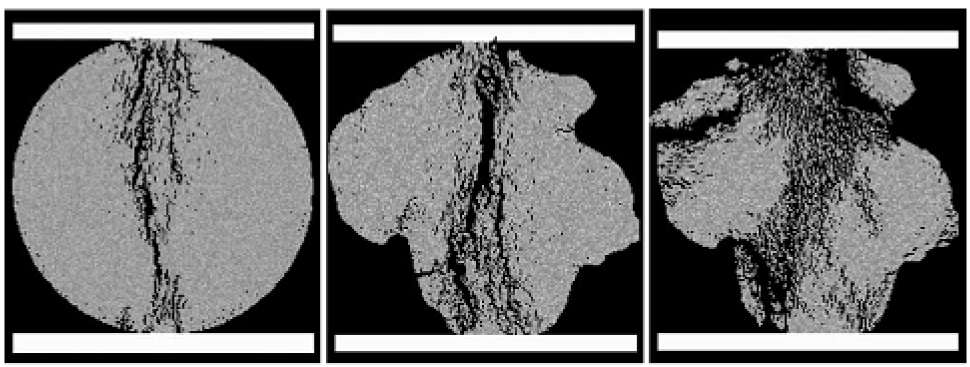

Figure 2.3: Images showing the situation which will be happened whilst an aggregate has been crushed by constraint force of a crushing mechanism (Tang *et al.*, 2001).

Choked crushing is extremely suggested in the crushing process because it has some advantages on the aggregates. A high feed rate crushing controls the crushing mechanism in the crusher's cavity. The choked crushing occurs when the volume of material arriving at a particular cross-section is greater than that leaving. The difference between these two crushing types is; in arrested crushing, crushing is the rock to steel only, whereas in choked crushing, particles break each other (Wills, 1995). During the usual crushing action of a cone crusher, particle breakage in the cone crusher is influenced by constraint force of crusher's surfaces. Poor shape of particles is produced from the collision between the particles and the crusher's surfaces as the great energy of the crusher's surfaces enforced the particles to shatter incompletely and undesirably. Besides, this interparticle comminution (choked crushing) can lead to excessive production of fines. Negatively, if choked crushing is severe, it can damage the crusher (Wills, 1995 & Tang *et al.,* 2001).

2.3 Impact Crusher

Comminution in impact crusher is by impact rather than compression, by sharp blows applied at high speed to free-falling rock. Wills (1995) stated that the important difference between the states of material crushed by pressure, which can cause cracking later. However, impact causes immediate fracture with no residual stresses. The condition of stress-free for material crushed by impact force is particularly valuable in stones used for brick making, building, and road making, in which a binding agent, such as bitumen, is subsequently added to the surface. Thus, impact crushers have a wider use in the quarrying industry compared to that in the metal mining industry.

2.3.1 Metso Barmac Rock on Rock Vertical Shaft Impact (ROR) crusher

Metso Barmac Rock on Rock Vertical Shaft Impact (ROR) crusher was invented by Jim Macdonald when he was deputy city engineer, Wellington. Metso Barmac Rock on

Rock Vertical Shaft Impact (ROR) crusher is the only thoroughly field, proven, successful rock-on-rock vertical shaft impactors (Anon, 1994). Metso Barmac Rock on Rock Vertical Shaft Impact (ROR) crusher is ideal for third and fourth stage crushing machines (Anon, 1994). Figure 2.4 shows the Metso Barmac Rock on Rock Vertical Shaft Impact (ROR) crusher.

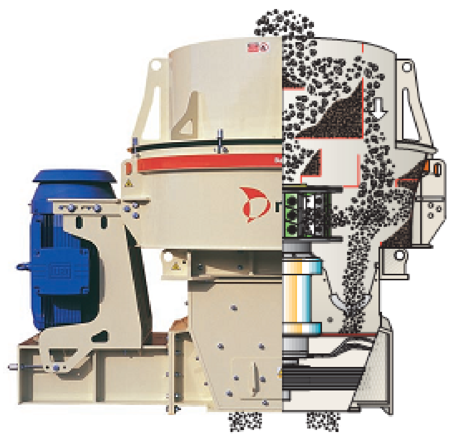

Figure 2.4: Metso Barmac Rock on Rock Vertical Shaft Impact (ROR) crusher (Anon, 2006)

2.3.1.1 The unique principle of breakage

Metso Barmac Rock on Rock Vertical Shaft Impact (ROR) crusher is a machine for crushing the complete range of ores, rocks and minerals. Metso Barmac Rock on Rock Vertical Shaft Impact (ROR) crushers are unique amongst all other vertical shaft impactors because they incorporate pure rock-on-rock crushing principle technology, not using impeller shoes or impact anvils to achieve reduction in the size. Accordingly, the invention of the Metso Barmac Rock-On-Rock Vertical Shaft Impact Crusher rock-on-rock crushing principle has revolutionised material reduction of the aggregates and minerals industries worldwide in the last two decades (Anon, 1994; Anon, 2006).

Rotor is one of the most important components in Metso Barmac Rock-On-Rock Vertical Shaft Impact Crusher. It is in the crushing chamber and surrounded by rock lining. Rotor works as a tool which acts as a high velocity dry stone pump to project incoming aggregate outward onto a solid pack rock lining of the same aggregate as a continuous rock stream as shown in Figure 2.5, so that nearly all crushing energy is used in rock-to-rock impact crushing and attrition (Anon, 2006 & Anon, 1994). They combine high velocity impact crushing with high pressure attrition grinding that tends to produce high volumes of cubical products and quality sand (Anon, 1994 & Briggs & Bearman, 1996). Rotor is run by the specialized motor via a drive belt placed outside of the crusher. The speed of the rotor can be increased from the lowest to the maximum value, where the speeds are controlled by the central controlling machine. The selection of rotor speed is based on the 3 stages of speed which are the minimum speed, 20 hertz, the central speed, 40 hertz, and the maximum speed, 60 hertz.

2.3.1.2 Breakage Mechanism

Figure 2.6 shows the interior parts of the crusher and the aggregate flow into the crusher as the feed material. The material entering into the crusher will go through the feed hopper first at the upper part of the crusher. The feed hopper will centralize the flow of the feed material into the crushing chamber (Anon, 1994).

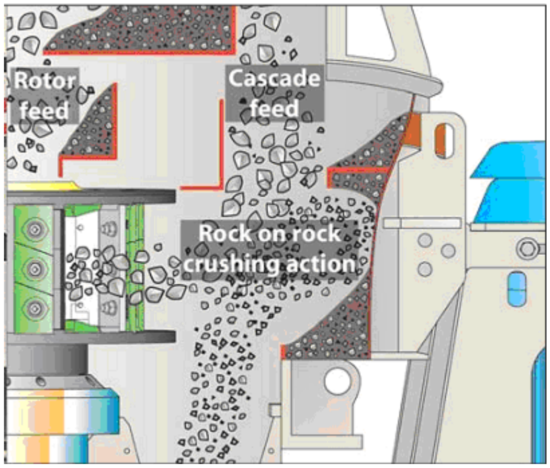

Figure 2.5: Rock on rock crushing action in Metso Barmac Rock on Rock Vertical Shaft Impact (ROR) crusher (Anon, 2006)

Then, the feed material passes the control plate. Control plate is an important part that controls the cascade of the feed that flows into the crushing chamber. Control plate works to separate the feed to two types of flow which are rotor flow and cascading flow. The amount of particles in each flow depends on the control plate settings. The closing of the control plate can be set using the cascade control. Control plate with a big opening allows a huge part of feed to go into the rotor's chamber, while control plate with small opening causes the feed retained to fall into the rotor's chamber, thus falling directly into the crushing chamber as cascading material. Increasing the cascade flow decreases the reduction ratio achieved whilst increasing the capacity of the crusher (Anon, 1994). The position of the choke on the control plate controls flow of the material into the rotor (Anon, 1994). Metso Barmac Rock on Rock Vertical Shaft Impact (ROR) crusher uses the patented cascade feed system to introduce a second stream of material, in a controlled quantity, into the crushing chamber turbulence, causing a supercharging of particle population within the chamber.

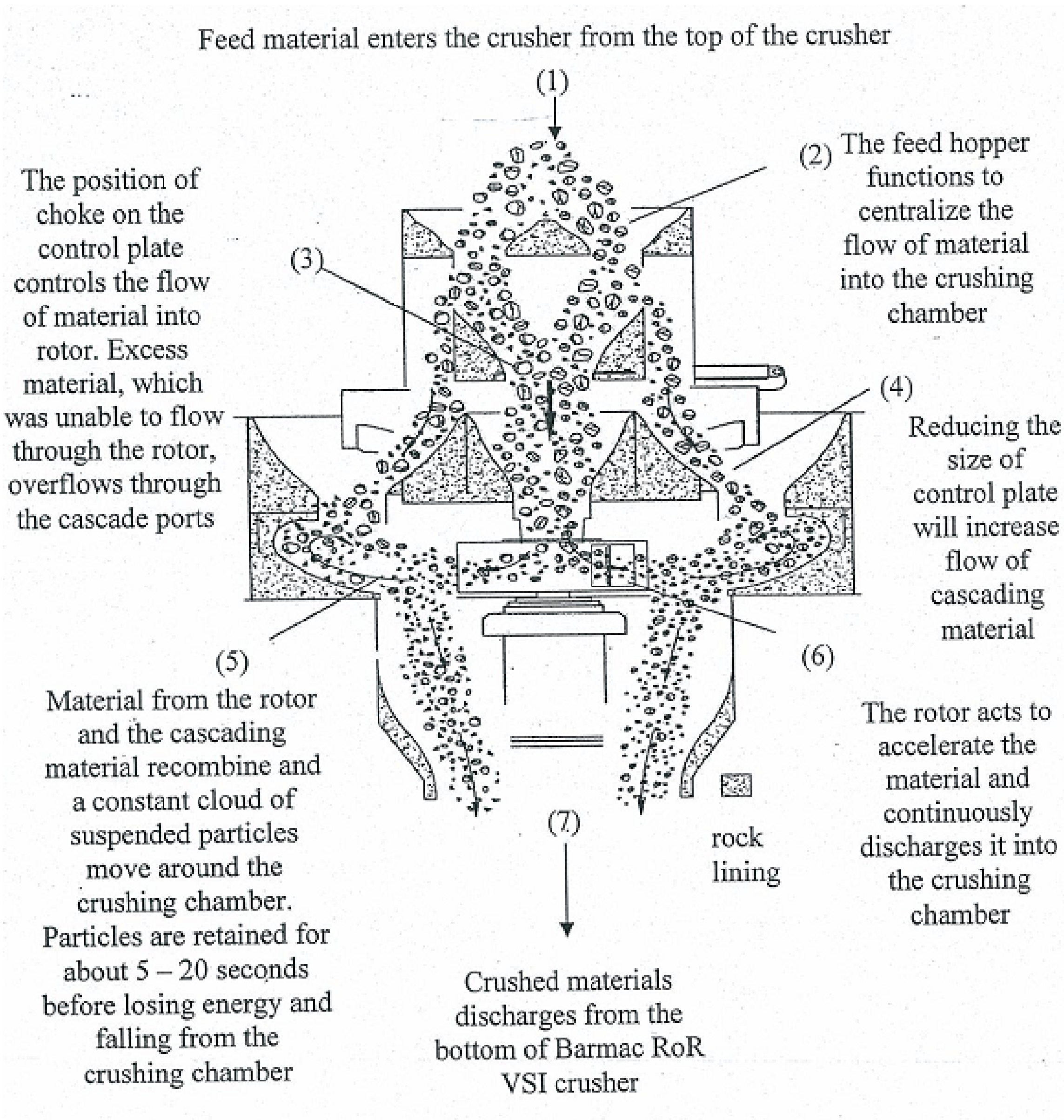

Figure 2.6: The flow of particle aggregates within Metso Barmac Rock on Rock Vertical Shaft Impact (ROR) crusher (Anon, 1994)

This improves the energy transfer between the particles (Anon, 2006). Control plate divides the flow to two different types of flows which are a flow into the rotor and a flow directly into the crushing chamber. Reducing the size of the control plate opening will increase flow of the cascading materials (Anon, 1994).

The rotor accelerates the materials and continuously discharges them into the crushing chamber. As shown in Figure 2.7, particles exit the rotor with velocities range from 50-85 m/s (165-275 ft/s) and accelerated into the crushing chamber with increasing kinetic energy of the particles. Reduction process of abrasion and attrition begins as particles are forced across the rock lining of the rotor. In the crushing chamber, material from the rotor and the cascading material meet and crash together. Besides, they hit the cascading material and patented rock lined rotor as well. Material from the rotor is continuously discharged into the crushing chamber and this process replenishes the rock lining, while at the same time maintains a rock-on-rock chain reaction of crushing and grinding (Anon, 1994).

The particle cloud appears in the crushing chamber which is driven by the material ejected from the rotor. It swirls around the crushing chamber in a highly turbulent manner. As particles bump, rub and grind together, much reduction by impact, attrition and abrasion occurs before losing sufficient velocity. The particles are retained for 5-20 seconds before losing energy and falling out of the crushing chamber as products. Accordingly, they drop out of the particle cloud and leave the crushing chamber.

Typical residence times for particles in the crushing chamber are between 5 and 20 seconds. Since the size reduction process relies on random interparticle collisions, it follows that crushing efficiency will be improved by increasing the particle cloud density in the crushing chamber thereby increasing the likelihood and frequency of collisions (Anon, 1994).

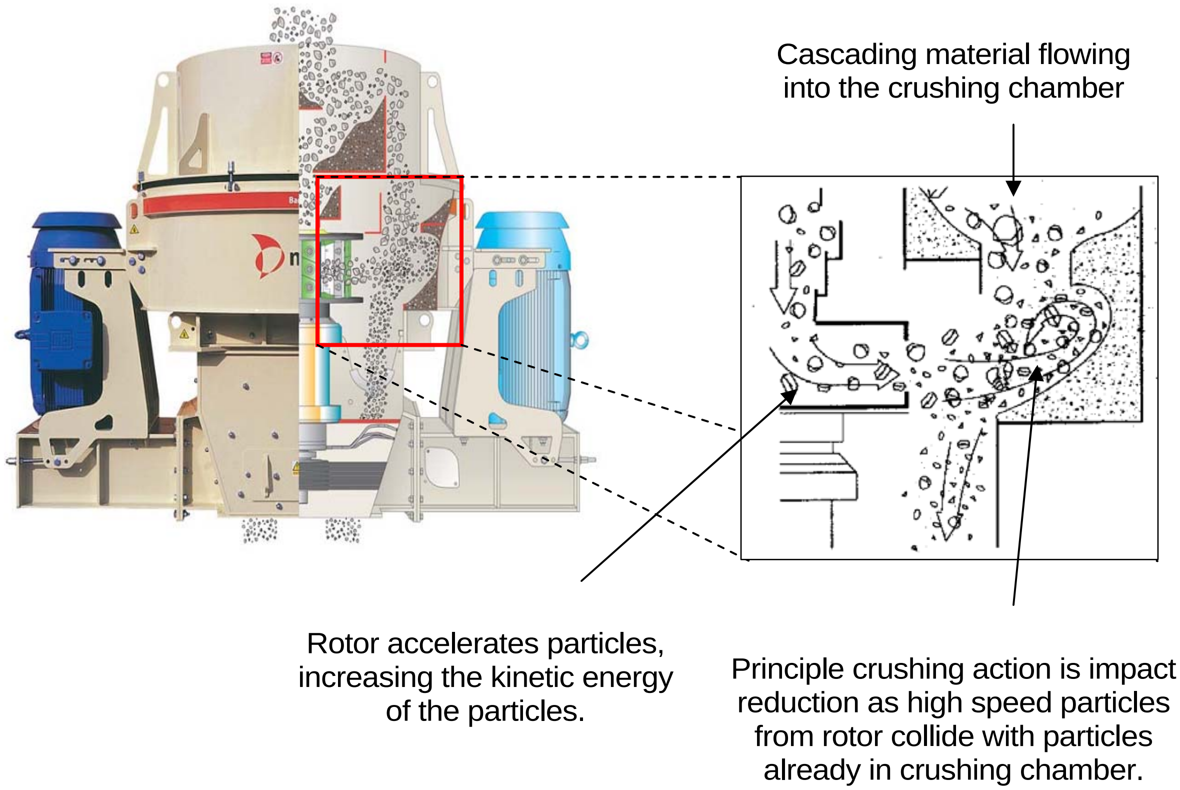

Figure 2.7: Particles inside rotor are accelerated into the crushing chamber and the rock-on-rock impact crushing appears (Anon, 2006; Anon, 1994)

There are four types of fracture mechanisms occurring in the Metso Barmac Rock on Rock Vertical Shaft Impact (ROR) crusher which are:-

- Impact/shatter
- Cleavage
- Attrition
- Abrasion

These fracture mechanisms are due to the high intensity interparticle and particle-to-rock lining collisions occurring within the rotor and crushing chamber. Particle breakage is chiefly along planes of weakness, such as mineral boundaries, jointing and micro fractures. The crushed product is usually free of weak planes, cubically shaped and often has the valuable mineral exposed or liberated (Anon, 1994).

The type of fracture mechanism that prevails depends entirely on the nature of the collision and the speed at which it takes place. Energy for the reduction process is imposed on each particle as kinetic energy as it is accelerated through the rotor and expelled into the particle cloud in the crushing chamber. The velocity of each particle leaving the rotor is dependent on the rotational velocity of the rotor. The size and mass of individual particles leaving the rotor varies according to the size distribution of the feed material, therefore the energy level of individual particles will vary from a maximum for the largest, dense particles to almost zero for very fine particles. As these energised particles enter the particle cloud in the crushing chamber, a chain reaction of particle collisions and energy transfer occurs. Large, dense, high energy particles when colliding with smaller or weaker particles will deliver a severe impact causing shattering and rapid reduction. The lower energy medium sized particles and daughter particles from earlier impacts deliver a less severe impact, chipping and wearing down other particles they come into contact with. The smallest particles, the fines and" dust, although having little kinetic energy are traveling at high velocities and effectively sand blast anything they come into contact with.