MODELLING THE EFFECT OF PARTICLE BREAKAGE IN COMMINUTION MACHINE

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by

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TABLE OF CONTENTS

CHAPTER THREE: METHODOLOGY

CHAPTER FOUR: RESULTS AND DISCUSSIONS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOL

A, b	Ore specific impact breakage parameters
ai,j	Breakage distribution function
Bi,j	The breakage function
bi,j	Weight fraction broken from size j which falls into size i
Ecs	Specific comminution energy (kWh/t)
h	Drop height (m)
$Is_{(50)}$	Point load strength (MPa)
i=1	Coarsest size fraction and
cm	Centimeter
cm/s	Centimeter per second
mm	millimeter
µm	Micrometer
$S_{i(t)}$	Selection function for the *ith* size fraction
$s_{i(t)}$	Mass of material in size fraction i, at time t
t_{10}	Cumulative percent passing one tenth of the initial mean size
x_i	First size fraction
x_2	Second size fraction
wt%	Weight percentage
β	Beta
γ	Gamma
ϕ	Omega

LIST OF ABBREVIATION

AG	Autogenous
BI	Method 1
BII	Method 2
BIII	Method 3
DEM	Discrete Element Method
Gbp	Mill grindability
JKMRC	Julius Kruttschnitt Mineral Research
PBM	Population Balance Model
RTD	Residence time distribution
SAG	SEMI autogenous

PEMODELAN KESAN PEMECAHAN PARTIKEL DI DALAM MESIN KOMUNISI

ABSTRAK

Dalam kajian ini, proses menetukan fungsi pemecahan dan memahami pemecahan yang kompleks berlaku dalam proses komunisi telah dikaji. Kaedah yang digunakan dalam kajian ini melibatkan ujian pemecahan pemberat, saiz partikel tunggal, indeks Bond dan kekuatan. Ciri-ciri pemecahan ditentukan melalui ujian-ujian tersebut terhadap tiga jenis batuan yang berbeza iaitu clinker, batu kapur dan granit. Kajian terhadap ciri-ciri pecahan saiz (maksimum 20 mm dan minimum 6.3 mm) dan bentuk (granul, bulat dan pipih) yang berbeza boleh ditentukan pada pelbagai tahap tenaga, dimana tenaga kominusi (Ecs) dinyatakan dalam jumlah tenaga terhadap satu tan berat (kWh/t). Perkaitan antara tahap tenaga yang dikenakan semasa pemecahan dan indeks pecahan (t_{10}) di tentukan berdasarkan pada saiz pecahan batuan. Saiz batuan yang kasar akan menghasilkan pecahan yang lebih berbanding saiz batuan yang kecil. Selain itu, ketiga-tiga kaedah (BI, BII dan BIII) digunakan untuk menganalisis satu ujian pecahan saiz berkelompok. Kaedah ini merangkumi tiga sampel iaitu clinker, batu kapur dan granit yang di kisar di dalam mesin pengisaran bebola besi di dalam makmal untuk masa yang tertentu. Kaedah BIII telah di ambil kira sebagai kaedah yang memberikan fungsi pemecahan yang paling tepat. Walau bagaimanapun, hanya satu saiz sahaja di gunakan dalam analisis iaitu -3.35mm + 2.36mm. Secara keseluruhan, data yang diperolehi menunjukkan nilai γ lebih dari 1.3 tetapi tidak mencapai 2. Manakala untuk nilai β pula ialah antara julat 1.1 hingga 2.12 dan nilai ϕ kurang daripada 1 untuk ketiga-tiga sampel clinker, batu kapur dan granit.

MODELLING THE EFFECT OF PARTICLE BREAKAGE IN COMMINUTION MACHINE

ABSTRACT

In this study, determination of breakage distribution and understanding of complex nature particle breakage took in comminution process were investigated. The test work involved the drop weight test, single particle size fraction batch test, standard Bond test and point load test. The tests are conducted to obtain the breakage characteristic of three types of rock which is clinker, limestone and granite. The breakage characteristic of different size fractions (maximum 20 mm and minimum 6.3 mm) and shape (granular, spherical and flaky) were examined at various input energy, Ecs express in kWh/t. The relation between specific comminution energy level and the breakage index (t_{10}) was established on the size fractional base. As expected, the coarser particles tend to generate more fragments than the smaller ones. Furthermore, the three methods (BI, BII and BIII) are used to analyze one size fraction batch test. These test consists of grinding material samples which are clinker, limestone and granite in a batch laboratory scale ball mill, for a selected period of time. The BIII method was considered to give most accurate breakage function and value of three variables β,γ and ϕ were calculated. However, the only one size fraction most reliable to be used for data fitting which is -3.35mm + 2.36mm. Overall after fitting the size range for the three samples clinker, limestone and granite obtained γ more than 1.3 but not reach 2. The value of β within 1.1 to 2.12 and ϕ value less than 1 for all samples. The trend showing similar for all types of rock samples. In conclusion, the different size shows significant effect in determined the breakage function where it involve high impact energy or low impact energy during comminution process.

CHAPTER ONE

INTRODUCTION

1.1 Background of study

One of the common features of a typical mining operation is the comminution plant, which is an integral part of the mineral processing plant. Comminution is one of the most important steps in the size reduction of particles by crushing, grinding or other processes to liberate the valuable minerals for further downstream separation events. Generally the process of rock breakage consumes a certain amount of energy and it is a significant component of international electricity (Ballantyne, 2014). Curry et al. (2014) stated that the crushing, grinding and separation process typically consume between 35% to 50% of the total mine cost. The proportion of energy consumed by comminution has been calculated by many researchers in energy reduction field (Tromans, 2008). The energy consumed through comminution is can be defined in different concept but it is most commonly reported as the specific energy per ton of material processed (kWh/t).

The greatest challenge in comminution is always the optimization of the energy input into the comminution machine such as crusher and grinding mill. It has been observed that only small percentage of the total energy input that really does the crushing and grinding while the rest lost due to inefficiency of the machine and lost to contacts that do not result in breaking the particle. The optimization part enters the picture in trying to specify the conditions to ensure a minimum amount of energy is use for achieving desired size class (Austin et al., 1984).

The modelling in comminution process has historically been dependent on the computational power available to perform the necessary calculations. Before usage of

computers all models related energy input to the degree of size reduction expressed as a percent passing size or to the proportion of final product generated (Napier-Munn et al., 1996). Thus, the powerful of computers have led to development of mathematical model that design and optimization of these processes.

Good models of comminution processes should find a way to present the application energy by a breakage equipment to a material. The current comminution model is able to reduce the complex operation to a few numbers or parameters (Powell, 2007). These parameters can be made independent of ore type and operational factors to some degree, which helps make real world data easier to interpret. One of the most important features of these models is the breakage function. The breakage function was defined as the product size distribution for a given particle size which obtain from comminution process (Kelly, 1990). There are many methods to determine the breakage function of a material such as includes Bond test, batch grinding and single particle impact test (Tavares, 1999; Banini, 2002; Weedon, 2001; Genc and Benzer, 2009).

The existing method used to determine the breakage function is dependent of particle size. Particle size effect should be defined in the breakage models make the grinding models more reliable (Vogel and Puekert, 2003, 2004; Shi and Kojovic, 2007). Somehow, normal comminution machine that feed size distribution may vary at wide range and it is surely difficult to assume size invariance. The current method to determine the breakage distribution function normally considers only one type of breakage mechanism that is body breakage or surface breakage (Banini, 2000). Body breakage is typically a high energy event in which the original particle is broken into smaller particles. However, in surface breakage the input energy is low and the original particle remains largely intact. The situation is further complicated by the various

mechanisms of breakage taking place with different comminution operations. (Barrios et al, 2011). In most crushing breakage is mainly by fracture, which is referred to body breakage while breakage in grinding mills consist of the both breakage mechanism. Thus, it is important to obtain the real value of breakage function that represent breakage in comminution machine which allows the models to be developed to get better prediction. In particular, to obtain the breakage function, the size-energy reduction relationship the main focus of the laboratory test developed to assist in communition equipment specification, circuit design and optimization. Such test includes Bond test, batch grinding and single particle testing.

1.2 Problem statement

Comminution has always occupied the center stage in mineral processing operations. It will continue to do so for a long time to come because comminution is a problematical unit operation. It is impossible to extract the minerals without through the comminution stage. The equipments of the comminution operations are direct by comparison with other process engineering operations, and as a result comminution operations deliver products that are never optimal for their subsequent use. In addition to the problems caused by technical difficulties and operations, comminution consume more energy. The cost of energy for comminution is often a determining factor in the economic viability of a mineral producing activity. Although there are important in focusing the factor, but the application of these studies for improving the efficiency in comminution processes is still limited. Since the energy consumption by industrial processes is becoming major issue, it is now very clear that further progress in the understanding of how comminution energy is used can only come from a detailed and fundamental understanding of relationship energy size reduction and material size from a given feed size.

Thus, the development of the model such population balance techniques for the description of the size distribution in the charge in a comminution machine and its product has provided an important framework which allows the comparison of different processes. In recent years this application of the model very useful in order to determine the breakage parameter. The breakage function is the breakage parameter was used in this study which is the progeny size distribution of particles following breakage. This distribution can be either obtained by single particle breakage technique or batch grinding. Therefore, it was very important to find a suitable model and its application to comminution process.

There are many factors that governed this breakage function. The characteristic depend mainly on physical properties of the rock such as size and shape. The shape properties are increasingly being recognized as an important parameter influencing the performance particles in mineral processing operations. Therefore, these parameters were determined in order to find the correlation with fundamental rock properties such grain size distribution.

In most standard communition test, particles are broken in high energy single impact process. However, many of the breakage mechanism inside the industrial mills are due to low energy collisions then it is led to accumulate the damage in body or surface breakage of the particles. The low energy impact process is defined as impact loading of particle where the specific energy of the impact is either of not sufficient to produce any breakage or not sufficient to produce significant size reduction of the original particle. It was found in surface breakage or bulk fracture, where the primary fragment produced is of similar size to the parent particle (Benjamin, 2016). It is happened in batch grinding test which is consist of two main breakage mechanism, impact and attrition. Both mechanism are comparatively low energy events.

Determination of relationship between breakage parameter from the surface breakage with particle size or input energy become important. But somehow, it is need to understand the basis of the appropriate parameter extracted from the breakage event in order to obtain the significant of the correlation between such variables. Applying the existing model to extract the breakage parameters form batch grinding process more efficient in understanding the complex of surface breakage mechanism.

Consequently, the ability to understand the extraction breakage function from both breakage method (drop weight test and one size fraction) were lead to combined the breakage function and tested by validating using suitable model. These breakage event consists high energy and low energy breakage. However, it is may vary each of the model depending on the breakage parameter obtained but the fundamental mathematical modelling was used.

1.3 Research Objectives

The objectives of this research are:

i. To determine the relationship between input energy and product size distribution for low energy breakage.
ii. To establish the effect of particle size and shape on the apparent strength of particles during impact breakage.
iii. To establish correlations between breakage parameters with fundamental rock properties.

1.4 Research Approach

The rock samples used in this research which are clinker (artificial rock), limestone and granite were obtained from a local quarry and cement plant which located in Perak and Penang. The early stages of this research include visual observation and sampling process to segregate the size range and shape (granular, spherical and flaky). Representative homogenous rock samples were prepared for the drop weight test, batch grinding (one size fraction method), bond work index and point load test. All the testing methods used for determination of breakage properties and finally to obtain the important parameter in mathematical model is breakage function. The breakage function is a given particle size which results from a comminution process. The feed size distribution for all methods were selected in range between 50 mm down to 600 μm. It is doubtful whether the accuracy of this assumption of size invariance can be justified. The situation is further complicated by the various mechanisms of breakage associated with different comminution operations. Meanwhile, crushing breakage is mainly by fracture and breakage in ball mills consists of high and low impact breakage which resulting from chipping and abrasion. It is expected that the two mechanisms of breakage, (high energy and low energy breakage) will exhibit some level of size or shape effect. Due to this, that is the propensity for a rock to break in either of these models will vary with particle size. At the end of this research, there are three question to be answered can therefore be summarized as follows;

i. To what extent does particle size and shape influence both breakage mechanisms and what is the limit of the effect?