International Journal of Mineral Processing 133 (2014) 83–90

Contents lists available at ScienceDirect

International Journal of Mineral Processing

journal homepage: www.elsevier.com/locate/ijminpro

Dynamic image analysis of calcite particles created by different mills

Ugur Ulusoy *, M. Yekeler

Department of Mining Engineering, Cumhuriyet University, TR 58140 Sivas, Turkey

ARTICLE INFO

Article history:
Received 20 January 2014
Received in revised form 28 August 2014
Accepted 1 October 2014
Available online 24 October 2014

Keywords:
Calcite
Mill
Dynamic image analysis
Circularity
Aspect ratio

ABSTRACT

In this study, particle shapes of calcite mineral ground by different mills namely ball, rod and autogenous mills were measured using a new 3D analysis with random orientation technique (by Micromeritics® Particle Insight Dynamic Image Analyzer). The results were expressed by the shape parameters such as circularity, ellipse aspect ratio (EAR), bounding rectangle aspect ratio (BRAR) and feret aspect ratio (FAR). More than 6400 particles were measured for each mill product with a 99% statistical accuracy. The results showed that, the highest aspect ratio (EAR, BRAR and FAR) and the lowest circularity were obtained by autogenous mill. However, the highest circularity and the lowest aspect ratio were obtained by rod milling. These differences in shape were attributed to the different grinding mechanisms acted in the mills employed. The results of the 3D dynamic image analysis were also compared with previous study for the same mineral based on 2D SEM technique. Although different techniques were used for shape analysis, the results were in good agreement with each other. This approach will find various applications for calcite characterization, preparation and utilization processes as well as for other minerals.

1. Introduction

Particulate materials play an increasingly important role in modern society. Most industrial processes involve particulates in some stage of the operation, perhaps as raw materials, products, unwanted by-products of wear, or simply as atmospheric dust (Hogg, 1988).

The shape of ingredient particles has a substantial impact on the performance or processing of particulate materials as well as particle size. Therefore, shape measurements of particles are also used by many industries in addition to particle size for understanding their products and processes (Malvern Instruments, 2012).

Flotation is a well-known primary concentration process based on the interfacial chemistry of ground mineral particles in the size range of $-0.300 + 0.038$ mm. Numerous factors influence flotation which is determined by collision, adhesion and detachment (Trahar and Warren, 1976). Although particle hydrophobicity and size have drawn much attention in research, particle shape is also important, but it has received less attention (Ahmed, 2010). Spherical and prismatic particles behave differently in the attachment of particles with bubble for flotation. In other words, prismatic particles are advantaged in the attachment with air bubbles in flotation system (Wotruba et al., 1991).

Microscopes, which employ (2D) static image analysis, have been widely used as an instrument for shape characterization of particles. Since they are slow, tedious, time-consuming and labor intensive, it becomes impractical to analyze a large number of particles and achieving statistical significance is a problem. SEM, which is the most widely used technique, directly measures the particle size by using the microscope's contrast mechanisms to differentiate the particle from the background. All particle dimensions and shape factors are calculated in 2D for each particle recognized (http://www.particletesting.com). Microscopy orients particles so that the largest area of the particle faces the viewing point.

However, the advent of 3D dynamic image analysis is becoming more and more popular. Automated particle shape and size measurement by image analysis were implemented by using different models of manufacturers in many industries such as; mineral industry (Tysmans et al., 2006; Ulusoy and Igathinathane, 2014), aggregate industry (Lee et al., 2005; Fernlund, 2005; Persson, 1998; Mora and Kwan, 2000), pharmaceutical industry (Nalluri et al., 2010; Yu and Hancock, 2008), wastewater treatment (Rabinski and Thomas, 2014) and root zone sands (Miller and Henderson, 2010).

3D dynamic image analysis entails using techniques for dispersing particles in liquid or gas and analyzing images of these particles while in motion using a several shape parameters (http://www.particulatesystems.com). They allow statistically significant sampling of large number of particles in one measurement. Automated imaging is a high resolution direct technique for rapid characterizing particles from a few microns up to a few millimeters in size. It has been developed to provide users with a more accurate measurement of their particles. Each image is captured from dispersed samples and analyzed to determine its size, shape and other physical properties. Statistically representative distributions can be built by measuring thousands of particles per measurement (Malvern Instruments, 2012).

Large tonnages of mineral particles are produced each year by comminution in the world. Calcite has a crucial importance in modern

* Corresponding author. Fax: +90 346 219 11 73.
E-mail address: uulusoy@cumhuriyet.edu.tr (U. Ulusoy).

http://dx.doi.org/10.1016/j.minpro.2014.10.006
0301-7516/

Nomenclature

ECAD	Equivalent circular area diameter
D_{BC}	Bounding circle diameter
A	Area
EEAL	Equivalent elliptical area length
EEAW	Equivalent elliptical area width
BEL	Bounding ellipse length
BEW	Bounding ellipse width
EAR	Ellipse aspect ratio
BRL	Bounding rectangle length
BRW	Bounding rectangle width
BRAR	Bounding rectangle aspect ratio
FAR	Feret aspect ratio

industries such as paint, powder coating, ceramic, rubber, PVC pipe and glass industries due to its versatility, availability, and traceability (http://www.calcite.in/calcite-powder.asp). Since, particle size and shape play primary role in calcite flotation where attachment of mineral particles to the air bubbles is required (Ahmed, 2010; Verelli et al., 2012; Ulusoy, 2003). Therefore, the aim of this work is to determine the image analysis of calcite particles generated by different mills, and also to compare the results with previously reported study by 2D SEM technique (Ulusoy et al., 2004) for the same calcite samples.

2. Particle characterization models

3D dynamic image analysis which refers to analysis while particles in motion, uses several particle characterization models. Brief descriptions of these models are given as follows:

2.1. Circle model

2.1.1. Equivalent circular area diameter (ECAD)

ECAD characterizes the size of a non-spherical shape with a single number. With typical particle shapes that are not fibrous, ECAD represents the diameter of a sphere that would have a volume close to the actual volume of the particle. Since the software has access only to a flat shadow or silhouette of the particle, ECAD is defined in terms of the silhouette area. It is defined as the diameter of a circle that has the same area as the silhouette.

2.1.2. Circularity

It is computed from area (A) and bounding circle diameter (D_{BC}) as $4A/\pi D^2_{BC}$. It is a fractional measure, and is not affected by small irregularities in the perimeter. While it is equal to 1 for a spherical particle it is lower than 1 for irregular particles such as elongated particles. It can be thought of as the fraction of the bounding circle's area covered by the actual shape (Fig. 1(a)).

2.2. Ellipse model

2.2.1. Equivalent elliptical area length (EEAL) and width (EEAW)

Of all equivalent area ellipses, the one chosen is that which has the same aspect ratio as that of the bounding rectangle for the EEAL and EEAW measurement.

2.2.2. Bounding ellipse length (BEL) and width (BEW)

The bounding ellipse is the ellipse of least area that bounds the shape.

2.2.3. Ellipse aspect ratio (EAR)

It is computed as the ratio of EEAL to EEAW (Fig. 1(b)).

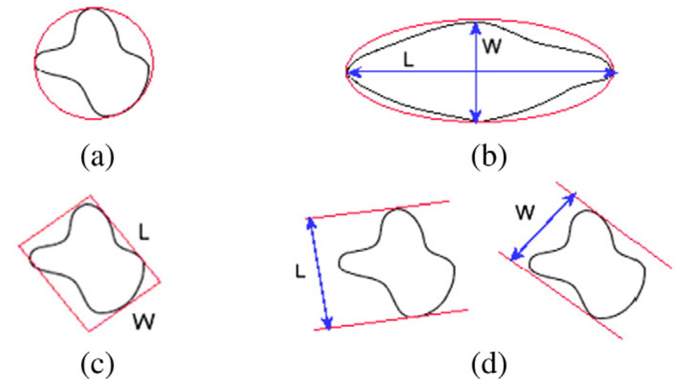

Fig. 1. Particle Characterization Models employed in Micromeritics® Particle Insight Dynamic Image Analyzer. (a) Circle model; (b) ellipse model; (c) rectangle model; (d) irregular model.

2.3. Rectangle model

2.3.1. Bounding rectangle

It is intended for non-fiber shaped objects, usually particles that are not perfectly round but still have low aspect ratio. It is defined as the rectangle of smallest area that encloses but does not intersect the object.

2.3.2. Bounding rectangle width (BRW)

It is the smaller side of the bounding rectangle

2.3.3. Bounding rectangle length (BRL)

It is the larger side of the bounding rectangle.

2.3.4. Bounding rectangle aspect ratio (BRAR)

It is the ratio of length (BRL) to width (BRW) (Fig. 1(c)). The value of BRAR is always greater than or equal to 1. The BR model assumes a thickness in the third dimension equal to the average of the other two distances, for purposes of calculating estimated surface area and volume.

2.4. Irregular model

2.4.1. Feret width and length

They are measures of the smallest possible and largest possible spacing between two parallel lines that contact but do not intersect the particle. These measures can be thought of as "caliper dimensions". The feret measures are sometimes close in value to bounding rectangle length and width, but not always, since they are not always orthogonal (at right angles to each other).

2.4.2. Feret aspect ratio (FAR)

It is the ratio of feret length to feret width as shown in Fig. 1(d). The value of FAR is always greater than or equal to 1 (ParticleInsight Manual, 2013).

Fig. 2 illustrates the changes of circularity, BRAR and FAR values by various particle shapes. It can be noted that the values of circularity, BRAR and FAR come close to 1 for spherical particles but are less than 1 for irregular particles such as elongated or fiber particles. On the other hand, the values of BRAR and FAR are greater than 1 for irregular particles. For example, a rod-like particle has a low circularity value of 0.199 (Fig. 2a) and high BRAR and FAR values of 4.15 (Fig. 2b) and 6.66 (Fig. 2c), respectively.