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Comminution test method using small drill core samples

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ABSTRACT

Comminution tests aim to measure the comminution properties of ore samples to be used in designing and sizing the grinding circuit and to study the variation within an ore body. In the geometallurgy context this information is essential for creating a proper resource model for production planning and management and process control of the resource's exploitation before and during production.

Standard grindability tests require at least 10 kg of ore sample, which is quite a lot at early project stages. This paper deals with the development of a method for mapping the variability of comminution properties with very small sample amounts. The method uses a lab-scale jaw crusher, standard laboratory sieves and a small laboratory tumbling mill equipped with a gross energy measurement device. The method was evaluated against rock mechanics tests and standard Bond grindability test. Within this approach textural information from drill cores is used as a sample classification criterion.

Experimental results show that a sample of approximate 220 g already provides relevant information about the grindability behavior of iron ores at 19% mill fillings and 91% fraction of the critical mill speed. The gross energy measured is then used to calculate an equivalent grinding energy. This equivalent energy is further used for predicting the variations in throughput for a given deposit and process.

Liberation properties of the ore connected to grindability elaborates energy required for grinding and significances of it when deciding to move to higher grinding energy considering the improvement of liberation of the desired mineral. However, high energy significantly enhanced the degree of liberation of magnetite and is expected to improve the concentrate grade after downstream treatment. The higher the magnetite content the better is the liberability of magnetite and the lower the energy required to liberate the desired mineral. Liberability of magnetite is also affected by texture classes containing low magnetite content. A methodology that combines this information has been developed as a practical framework of geometallurgical modeling and simulation in order to manage technical and economic exploitation of resource at early, project stages and during mining operations.

1. Introduction

Ore testing is an important part of the geometallurgical experimental framework and modeling. Tests are used in characterization of ore processing behavior at different process stages, such as comminution. Several test methods are available for testing comminution behavior but they require comparatively large (>10 kg) samples. In the early stage of resource evaluation only drill core samples are available while for metallurgical testing only half or quarter of the drill core is left. Therefore commonly samples collected for the testing are composite samples representing a broad mineralogical variation within them. This hinders the detailed mapping of ore variability using drill core samples. Some of the methods used in geometallurgy are the JK Tech drop weight test (Napier-Munn et al., 1996; Narayanan, 1986), JK Rotary Breakage Test (JKRBT; Shi et al., 2009) and SMC test (Morrell, 2004). For detailed characterization of metallurgical properties along the mineralogical variability small-scale comminution test methods are needed.

Mineral processing properties within an ore body can vary a lot and bring several challenges for production. For the Collahuasi copper mine Alruiz et al. (2009) and Suazo et al. (2010) showed that the plant throughput and the copper recovery significantly vary between the geometallurgical domains. In geometallurgical programs, like for the Collahuasi mine, it is common that the comminution circuit throughput is determined by fixing the particle size of a comminution product. This is questionable when there is a big variation on micro-texture or liberation size within a deposit, e.g. as shown by Lund (2013) in Malmberget iron ore. However,

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comminution characterization studies that would take into account mineral information are very rare (Kim et al., 2012).

This study aims at establishing a comminution test method for geometallurgy and evaluating it with a case study from Malmberget iron ore, Northern Sweden. Another aim of the study is to demonstrate how and why modal mineralogy, mineral textures and liberation should be considered already in comminution tests.

2. Comminution tests most suitable for geometallurgy

A short review on existing comminution tests is here done to estimate their directly usability and easiness to modify for geometallurgical purposes. A suitable geometallurgical comminution test should fulfill the following requirements:

1. The test should be relatively simple and use instruments available in common analytical and mineral processing laboratories.
2. The test should be repeatable and not dependent on person.
3. The test should be easy to execute so that technicians with basic skills in sample preparation should be able to do it with short training.
4. The test should be fast (max 1 h) and inexpensive.
5. The amount of sample per test should be less than 0.5 kg; preferentially the test could use assay rejects.
6. The test, or rather a combination of tests, should give measured values on both crushability and grindability.
7. It should be possible to use the parameters derived from the test directly in the modeling and simulation of a comminution circuit.
8. It should be easy to extend the test to include mineral liberation information.

Comminution tests are here classified into three groups, compare Table 1: (1) Geological and rock mechanics tests, (2) single particle breakage tests and (3) grindability and bed breakage tests. Another dimension in the classification is the particle size range. As shown by Hukki (1961) comminution energy vs. size reduction equation changes by particle size. In the coarse range the energy required for size reduction is smaller than for finer particle sizes. Three different particle size areas following the different comminution laws can be identified: (A) coarse range (crushing, >1 cm, Kick, 1885), (B) middle range (grinding, 0.1–1 cm, Bond, 1952) and (C) fine range (fine grinding, <100 μm, Rittinger, 1867).

Rock mechanics test are used to measure the mechanics strength of the rock in the coarse particle size range (A). They are commonly used in geotechnical studies. The most potential ones for geometallurgical tests are point load test and unconfined compressive tests. They are used for testing small scale drill core samples. It has been shown that the mechanical strength of rock measured from point load can be correlated with comminution parameters (Akram and Bakar, 2007; Flores et al., 2005). These kinds of tests are simple and can quickly generate information about the hardness of an ore and therefore are relevant for geometallurgical mapping. However, they require reasonable large sample amounts and the measured parameters cannot be directly used in comminution or throughput models (Flores et al., 2005).

Single particle breakage tests such as JK Drop Weight tests, SAG Mill Comminution test (SMC) by Morrell (2004), pendulum and ultra fast load describe the crushability (fracture behavior) of the materials in coarse-middle particle sizes (A–B) using empirical parameters which are further used in specifically developed process models (Napier-Munn et al., 1996). As these tests are used especially in designing and optimizing autogenous or semi-autogenous grinding circuits they use large samples, typically >10 kg, which makes it difficult to be practically used in geometallurgical programs (Bailey et al., 2009). The JK Rotary Breakage Test has been developed to rapidly assess the hardness of the materials (Shi et al., 2009 (Hunt et al., 2008). Despite the JKRBT capability to measure hardness of the materials and general suitability for geometallurgical programs (Table 1) it is still very new for that purpose.

Grindability tests are done for multiple particles to characterize the material properties in milling in a middle particle size range (B). The most widely used is the Bond grindability test (Man, 2002). The test has been further improved for wet grinding and different type of circuits (Armstrong, 1985; Wills and Bruce, 1966; Smith and Lee, 1968; refer Wills and Napier-Munn, 2006). However, the test is not very suitable for geometallurgy, because it requires large sample (>10 kg), and the test takes several hours to complete.

A literature survey and simple evaluation showed that no single fracture test method fulfills all eight criteria (Table 1). Putting an emphasize on criteria for modeling and simulation (criterion 6 in Table 1) and liberation (criterion 7), three tests were identified having the best potential for further development towards a comminution test for geometallurgy using small drill core samples: Bond ball mill test, instrumented drop weight test and Rotary Breakage Test (RBT). Here, the Bond test was selected as a base as it has been used for almost a century. It is an accepted industrial standard resulting in large databases of test results (Bond work index, BWI). The test is easy to conduct without requiring special equipment. It also seems to be easy to extent the test to the liberation level.

Table 1
Common fracture test methods having potential for geometallurgical tests. Requirements (see text) – (1) simplicity, (2) repeatability, (3) sample preparation, (4) time exposure and cost, (5) sample amount, (6) parameters can be used in modeling and simulation, (7) can be extended to mineral liberation.

Fracture test method	Reference	Suitability criteria for geometallurgical test (– = adverse, O = acceptable, + = advantage)						
		1	2	3	4	5	6	7
Unconfined compressive strength test	[1]	+	O	–	O	+	–	–
Point load test	[2]	+	O	O	O	+	–	–
Brazilian test	[3]	+	O	–	O	+	–	–
Drop weight test	[4]	O	O	–	–	–	+	O
Ultra-fast load cell test	[5]	–	O	O	O	–	+	O
Twin Pendulum test (Bond CWI)	[6]	–	–	O	O	O	+	O
Split Hopkinson bar test	[7]	–	O	–	–	–	O	O
Rotary breakage test	[8]	–	+	O	O	O	+	O
Bond ball mill test (Bond BWI)	[9]	O	+	O	–	–	+	+
Bond rod mill test (Bond RWI)	[10]	O	+	O	–	–	+	+
Single pass test, e.g. Mergan mill	[11]	+	+	O	O	–	+	+

[1] Rusnak and Mark, 2000; [2] Farah, 2011; [3] Claessona and Bohlolib, 2002; [4] Narayanan, 1985; [8] Shi et al., 2009; [5] Weichert and Herbst, 1986; Abel et al., 2009; [7] Fandrich et al., 1998; [6] Narayanan, 1985; [9] Bond, 1961; Man, 2002); [11] Niitti, 1970.