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Influence of slurry rheology on stirred media milling of quartzite

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Abstract

The role of slurry rheology in stirred media milling of quartzite has been investigated by varying important grinding parameters such as media bead density and size, addition of chemicals, solids concentration, stirrer rotational speed as well as the combined effect of these factors. Media bead density has an evident but complex effect on stirred milling performance, depending on stirrer rotational speed and solids concentration. The effect of media bead size on the ultra-fine grinding of quartzite is relevant to the feed size. Optimal ratio of media bead size to the median size of a feed is between 150 and 200. The combined effect of grinding bead size and stirrer speed or solids concentration is insignificant. The addition of Dispersant S40 or a lower solids concentration results in better grinding performance (i.e., a higher energy efficiency and a smaller median size) due to the maintenance of lower viscosities at shear rates investigated during grinding. Stirrer rotational speed interacts with solids concentration. For a given solids concentration, an optimal stirrer speed exists. The observed phenomena can be explained by the interaction of slurry rheology and the stress intensity of individual grinding bead.

In addition, an empirical particle size-energy model provides a good fit ($R^2 > 0.904$) to the grinding results under the experimental conditions investigated. Furthermore, the wear of grinding media beads is involved. ZrO_2 beads have a lowest wear rate whereas the wear of SiO_2 beads is most serious. The wear rate of Al_2O_3 beads is related to bead size.
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Keywords: Wet ultra-fine grinding; Stirred media mill; Slurry rheology; Quartzite; Chemicals; Ultra-fine particle

1. Introduction

Due to some advanced properties of ultra-fine powders, such as surface chemistry, packing characteristics, strength, optical properties and reaction kinetics, and an increasing demand for ultra-fine powders for industries, wet ultra-fine grinding has found increased use in many fields such as minerals, ceramic materials, pigments, chemical products, microorganisms, pharmaceutics, papermaking. Most of the mills used in wet ultra-fine grinding are stirred media mills due to their high unit throughput and energy efficiency (Bernhardt et al., 1999; Zheng et al., 1997; Kapur et al., 1996; Blecher et al., 1996). The stirred media mills are equipped with a stationary grinding chamber and a high-speed stirrer (disks or pins) fixed on a drive shaft. The grinding chamber is filled with small grinding media (normally spherical annealed glass, steel, or ceramic beads) at a high bead load. By stirring a slurry-bead mixture at a high stirring speed, a characteristic flow pattern and a grinding action are generated in the

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chamber. The respective kind of flow determines the spatial distribution of zones with high grinding intensity and the predominant types of grinding mechanisms as well as their composition (Blecher et al., 1996; Kwade et al., 1996). Thus, the predominant grinding mechanisms in stirred media mills are dependent on compressional, shear and torsional stresses, which are invoked by stirring the slurry-bead mixture at a very high velocity (Blecher et al., 1996; Kwade et al., 1996; Theuerkauf and Schwedes, 1999; Gao and Forssberg, 1995). The effective grinding motions of the mixture are correlated to its flow behaviour in the grinding chamber.

From a diagnostic point of view, the rheological behaviour of a mineral slurry is indicative of the level of interparticle interaction or aggregation in the slurry. Therefore, it is a useful variable to be controlled in industrial processes such as transportation of slurries, dewatering and wet grinding (Muster and Prestidge, 1995). Physical and chemical properties of a slurry, such as solids concentration, use of dispersants, particle size and distribution, particle shape, pH value, shear rate, and slurry temperature, have a significant influence on the slurry rheology due to the change or modification in surface property (He et al., 2004).

Since the product fineness significantly increases with grinding time in wet ultra-fine grinding operation characterized by a very fine product size and a high solids concentration, the surface properties tend to predominate in the system (Bernhardt et al., 1999; Zheng et al., 1997; Klimpel, 1999). Inter-particle forces, such as van der Waals forces (Greenwood et al., 2002; Reinisch et al., 2001) and electrostatic forces (Bernhardt et al., 1999; Muster and Prestidge, 1995), lead to the formation of agglomeration and aggregation. This results in changes in rheological property in wet ultra-fine grinding operations. The effect of slurry flowability in wet ultra-fine grinding becomes particularly important. The optimization of the rheological behaviour of a ground slurry can enhance the energy efficiency and throughput in wet ultra-fine grinding operations. For instance, the addition of an optimum dispersant to a given feed slurry can result in a drastic reduction or even elimination of yield stress and permits a higher solids concentration of a ground slurry (He et al., 2006b; Klimpel, 1999; Greenwood et al., 2002; Reinisch et al., 2001). In the absence of any dispersant, the typical maximum percentage solids in a slurry is approximately 27.4% by volume for the feed of ultra-fine grinding in stirred media mills, whereas an upper limitation of solids concentration is up to 60.15 vol.% in the presence of an optimal dispersant (Greenwood et al., 2002). Therefore, the improvement of rheological behaviours of a feed slurry with the addition of a suitable dispersant can enhance the productivity and throughput for wet ultra-fine grinding.

However there is still little understanding of slurry rheology relevant to wet ultra-fine grinding characterized by the presence of excessive fineness and a high slurry concentration due to the complex slurry rheological behaviours in stirred media mills (Gao and Forssberg, 1993a; Blecher and Schwedes, 1996). The objective of this work is to study the role of slurry rheology in stirred media milling of quartzite by varying important grinding parameters such as media bead density and size, addition of chemicals, solids concentration, stirrer rotational speed as well as the combined effect of some factors. The grinding results were evaluated by energy efficiency and the median size of a ground product with respect to specific energy consumption.

2. Materials and experimental procedures

2.1. Materials

A quartzite material (94.52% SiO_2) with a real density of 2710 kg/m^3 (Density meter called Multivolume Pycnometer 1305, Micromeritics Instrument Corporation, USA) was provided by LKAB, Sweden and was used for grinding experiments in this study. The chemical analysis and particle size distribution of the quartzite material are presented in Table 1 and Fig. 1, respectively. Dispersant S40 (Sodium polyacrylate) from CDM AB, Sweden and Genamin CC 100 (C8–C18 amine, alias: Flotigam P) from Clariant GmbH, Germany were selected as dispersants.

2.2. Experimental procedures

2.2.1. Mix-up

A quartzite-water slurry was prepared at a predetermined solids concentration by the addition of 40 to 50 kg of quartzite powder into a certain amount of water to

Table 1
Chemical analysis of quartzite composition

Main chemical composition	SiO_2	Al_2O_3	TiO_2	MnO	MgO	CaO	Na_2O	K_2O	V_2O_5	P_2O_5	Fe_xO_y
Percent (%)	94.52	0.65	0.04	0.01	0.53	0.24	<0.001	0.132	0.01	0.041	3.71

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