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SCIENCE DIRECT®
Minerals Engineering 18 (2005) 969–976
MINERALS ENGINEERING
This article is also available online at: www.elsevier.com/locate/mineng

Influence of dry grinding on talc and kaolinite morphology: inhibition of nano-bubble formation and improved dispersion

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Received 1 December 2004; accepted 4 January 2005
Available online 23 February 2005

Abstract

The effects of dry grinding in a porcelain ball mill and a chrome steel ring mill on the structure and morphology of talc and kaolinite minerals and mixtures have been studied. It is well known that ground talc is easier to make down as a suspension than unground talc and that it displays better rheological behaviour in the slurry. Morphological and structural studies (SEM, TEM, AFM, XRD) of both ground and unground talc and kaolinite samples have revealed new factors accounting for this behaviour during make down as a mineral suspension in water. Short-term (<1 min) grinding in the ring mill not only breaks the platelets, which lowers the aspect ratio, but also disaggregates most of the particles. In both talc and kaolinite, this action destroys voids in aggregates. In talc, it also destroys the splayed ends of the sheets at the particle edges. Both actions reduce trapped nano-bubbles and their tendency to reduce wetting and promote flotation. Platelets of talc, during grinding, also become more stepped and damaged on basal surfaces as a result of abrasion. Abrasion on basal surfaces exposes additional edge area, which increases the proportion of reactive sites and assists dispersion of talc in aqueous solution. Prolonged grinding (60 min) of mixtures (10% talc) produces rounded aggregates that are composed of nm-sized colloidal particles. These colloids and aggregates are strongly hydrophilic. Structural observations (XRD and electron diffraction patterns) indicated that crystalline structure destruction occurs during prolonged grinding in the ring mill making both minerals totally amorphous. This does not occur after mixing (15 min) in the porcelain ball mill.

Keywords: Tailings disposal; Dewatering; Fine particle processing

1. Introduction

Grinding of kaolinite and talc as brightness additives is an important process in the paper, adhesives, paint and plastics industries. Because of this, they have been studied with great interest by many scientists. The effects of grinding on clay minerals have been studied, for instance, by Takahashi (1959), Miller and Oulton (1970), Yariv (1975), Garcia et al. (1991) and Aglietti et al. (1986) for kaolinite; and for talc by Aglietti (1994) Sanchez-Soto et al. (1997) and Zajac and Malandrini (1997). Several of these studies came to the conclusion that intense mechano-chemical effects occur during grinding leading to the destruction of kaolinite structure and formation of an amorphous substance. The laminar structure of kaolinite makes this mineral very sensitive to amorphization.

Aglietti (1994) revealed that intense mechano-chemical effects occur as well in the talc surface. Sanchez-Soto et al. (1997) found that reduction in size of talc particles by grinding continued up to about 30 min. After 30 min,

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doi:10.1016/j.mineng.2005.01.005

the mechanical reduction of the original particles appears to have a limit and particles start a reaggregation process in which adhesion forces act. Garcia et al. (1991) reported similar effects in kaolinite where aggregates appeared to form by tightly bound, extremely small particles, produced during prolonged grinding. Two factors seem to be responsible for such structural changes in the process of dry grinding of kaolinite and talc. One is the production of a non-crystalline substance attended by the disordering of the crystalline part, and the other is a reaggregation process. Despite an extended effort to investigate mechano-chemical effects, and their consequences for dispersion, caused by grinding, some aspects of the alteration remain obscure.

Zbik and Smart (2002) used micronized and ground talc samples to prepare dense talc/water suspension. During these experiments they reported that ground talc was easier to make down as a suspension than the unprocessed sample; ground talc also displayed Newtonian rheological behavior in contrast to the micronized sample. During careful morphological studies of both ground and unground talc samples, Zbik and Smart (2002) found two major reasons for such behaviour during make down as a mineral suspension in water.

Firstly, the short grinding time in the ring mill has a significant effect on the talc platelet diameters, breaking platelets apart, which lowers the aspect ratio. Secondly, voids in aggregates and splayed or puckered sheets at particle edges are destroyed during ring mill grinding which may reduce trapped nano-bubbles and stop particles floating on the water surface.

SEM observations by Zbik and Horn (2003) of low solid content cryo-vitrified kaolinite clay suspensions reveal that clay platelets build porous three-dimensional networks with platelets contacting each other mostly by their edges. To explain this behaviour, which must require long range edge-to-edge attractive forces, a hydrophobic-like interaction has been proposed. This interaction may be induced by the presence of nanobubbles existing on the edges of clay crystallites which may cause clay particles to flocculate. Nanobubble coalescence has recently been presented as a partial explanation (e.g. Meagher and Pashley, 1995; Considine et al., 1999; Ishida et al., 2000) for strong, long-range attractive forces that have measured between hydrophobic surfaces. (Israelachvili and Pashley, 1982; Christenson, 1992). The following indirect evidence for such hydrophobic behaviour was presented. First, a clay platelet is shown attached to an oil drop by its edge; second, clay flocs were attracted by a vertically placed hydrophobic Teflon strip but not to the hydrophilic mica basal surface; third, a much thicker porous sediment occurred in CO_2-saturated water solution compared to vacuum-degassed water.

The work reported here has revealed new factors which have been observed when grinding and focuses on the both the morphological and structural changes (using SEM, TEM, XRD and AFM) which occur as a result of prolonged dry grinding.

2. Experimental

North Queensland kaolinite and Commercial Minerals Ltd., Talc (CM) were used in this study as single minerals and as the kaolinite/talc mixture. The North Queensland kaolinite was supplied by Comalco Research Centre (Thomastown, Victoria, Australia). It is the final processed product from their previous North Queensland operation. Its characteristics, particularly the layered structure of the particle surfaces, wide steps and ragged edges revealed in SEM and AFM studies, have been described by Zbik and Smart (1998). Commercial Minerals Limited (CM) talc T20A used in this study is a commercial talc described as premium grade with excellent whiteness, micronized (dry, without additives) below 20 μm. The micronising process involves colliding air/talc streams at 120 atm pressure in an air cyclone with classification to extract the −20 μm fraction. It is typically used in adhesives, paints and plastics. It is produced in Adelaide, predominantly from the Mt. Fitton (South Australia) deposit.

Samples (50 g) were dry ground during 15, 30, 60 and 120 min in the porcelain ball mill (balls ~26 g) and 1 and 60 min in the high power Rocklabs ring mill with chrome steel (AISI, D3) heads. The mineral mixture was kaolinite with 10 wt.% talc mixed for 5 min in a mechanical shaker.

The SEM studies were carried out using a Camscan CS44FE microscope with a field emission gun operating at 20 kV acceleration voltage. The kaolinite and talc particles were coated by gold/palladium films to a thickness of 2–3nm using a Dentron Magnetron Sputter Coater system. A Nanoscope III AFM (Digital Instruments) was used with scan heads E ($14 \times 14\ \mu m^2$) and scan rate between 5 and 20 Hz in height and deflection modes. The AFM was calibrated on a gold grid with 5 μm pits separated by 5 μm. The standard pyramidal silicon nitride tip with a solid angle of 70° and a radius of curvature at the end of ~50 nm was mounted on a cantilever of nominal spring constant 0.06–0.58 Nm^{-1}. The standard lateral and vertical deviation of the AFM measurements is ±0.15 nm due, at least in part, to the uneven nature of the kaolinite and talc particle surfaces and the relatively low aspect ratio of the AFM tip.

For the AFM studies, kaolinite and talc particles were immobilized from a dilute aqueous suspension on to a freshly cleaved atomically flat mica surface. A small amount of suspension, i.e. one or two drops was collected from a depth of 10 cm below the water surface and placed on the freshly cleaved mica surface. The par-