9.2 Principles of fine grinding

9.2.1 Breakage mechanisms

Fine grinding is accomplished by breaking particles into smaller fragments. Contact forces (compressive or shear) deform particles and generate internal stresses which, when strong enough, bring about fractures. The number and direction of these fractures determine the size distribution, shape and surface characteristics of the fragments. For failure to occur, the strain energy released must exceed the surface energy generated. The magnitude, rate of application and frequency of application of contact forces determines the efficacy of the size reduction process.

How a particle responds to contact forces depends on its material characteristics. Most materials can be classified as either brittle or non-brittle. Brittle materials deform elastically in response to an applied stress, before failing suddenly at stress levels above some critical value. Brittle materials can be broken by simple stress application (usually compressive), and failure occurs as a catastrophic event resulting in a suite of fragments ranging in size from about 30–40% of that of the original down to submicron sizes (Figure 9.1). Internal stress concentrates at imperfections or microscopic flaws in the material such as cracks, air bubbles or foreign inclusions, increasing the probability of failure at these points. As the size is reduced, a grindability limit may be reached as smaller particles contain fewer imperfections and the critical stress increases.

Breakage of brittle materials can occur at lower levels of stress application if the stresses are localised, for example at the edges or corners of irregular particles.

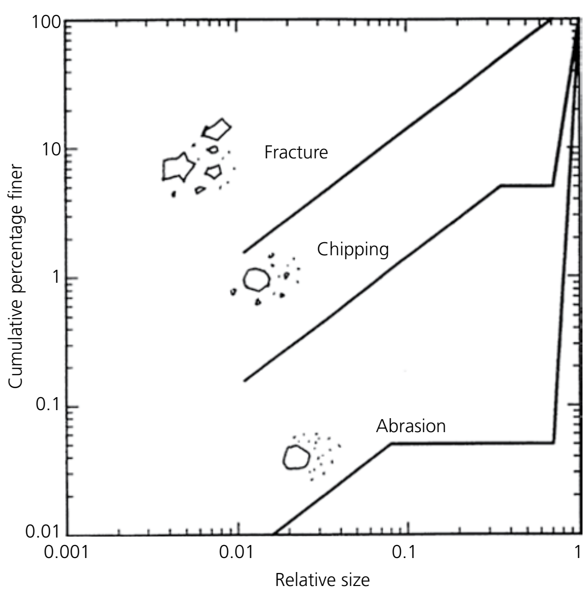

Figure 9.1 Fragment size distributions resulting from different breakage mechanisms (schematic).

This kind of chipping action leads to gradual breakdown of the particle leaving a residual core only slightly smaller than the original and a suite of fragments of much finer size (Figure 9.1). Abrasion of particles, through surfaces rubbing together, should probably be considered as a limiting case of the chipping mechanism (Tangsripongkul, 1993). Brittle materials may exhibit plastic behaviour as the size of the particles becomes small.

Non-brittle materials, classified as either ductile or tough, are more difficult to grind than brittle materials. Ductile materials undergo substantial plastic deformation before simple failure occurs, and tough materials relieve stresses through internal rearrangement. Tough materials, for example cocoa shell and germ, often possess a fibrous structure. Failure occurs as a gradual loss of integrity resulting from accumulated damage due to repeated deformation. The breakage of non-brittle materials often requires the application of shear, although some tough materials exhibit work hardening and can be broken down by repeated application of compressive stress. Cutting actions generally result in the production of relatively few (e.g. two) fragments from each breakage event. The relative size of these fragments may differ widely, so that a set of breakage events on many similar particles can lead to a fairly broad particle size distribution.

Temperature can affect a material's response to stress – tough materials may become brittle at low temperatures and amorphous materials are generally brittle below their glass transition temperature (Blanshard, 1995) – hence the application of cryogenic grinding. A sugar glass may deform plastically above the glass transition temperature. However, brittle fracture may still occur if the critical stress is applied faster than the material can relax. Increasing moisture content generally reduces brittleness and may make some materials more difficult to grind. Temperature control is important for heat-sensitive materials.

9.2.2 Grinding processes

The basic operation of any grinding device involves two aspects: placement or setting up of the particles to receive stress and the stress application itself. Particle placement can be direct (particles are brought to the stressing site) or random (particles arrive at stressing sites by chance). Single-pass devices such as a two-roll refiner involve direct placement where the particles are provided with a single breakage opportunity before exiting. On the other hand, retention devices, such as media mills, mostly rely on random placement and a particle may be subjected to repeated stress application. Direct placement systems make the most efficient use of input energy. Many nominally single-pass devices do include some degree of retention.

The effectiveness of a machine can be characterised, for the single-pass mills by a *breakage probability* that describes the fraction of particles actually broken during passage, or for retention mills by a *breakage rate* that describes the fraction broken during a given time period. For any mill, these quantities are determined by a combination of the effectiveness of the device in placing the particles to