equilibrium balance moves from left to right in Equations 12.1 and 12.2 and adhesion/cohesion increases. This also means that more tightly packed powders require a higher driving force to produce powder flow than more loosely packed particles of the same powder.

Characterization of packing geometry by porosity and bulk density

A set of monosized spherical particles can be arranged in many different geometric configurations. At one extreme, when the spheres form a cubic arrangement, the particles are most loosely packed and have a porosity of 48% (Fig. 12.2a). At the other extreme, when the spheres form a rhombohedral arrangement, they are most densely packed and have a porosity of only 26% (Fig. 12.2b). The porosity used to characterize packing geometry is linked to the bulk density of the powder. Bulk density, ρ_B, is a characteristic of a powder rather than individual particles and is given by the mass, M, of powder occupying a known volume, V, according to the relationship:

$$\rho_B = \frac{M}{V}\,\mathrm{kg\,m^{-3}} \qquad (12.3)$$

The bulk density of a powder is always less than the true density of its component particles because the powder contains intraparticular pores or interparticulate air-filled voids. Thus whereas a powder can only possess a single true density, it can have many different bulk densities, depending on the way in which the particles are packed and the bed porosity. However, a high bulk density value does not necessarily imply a close-packed low-porosity bed, as bulk density is directly proportional to true density.

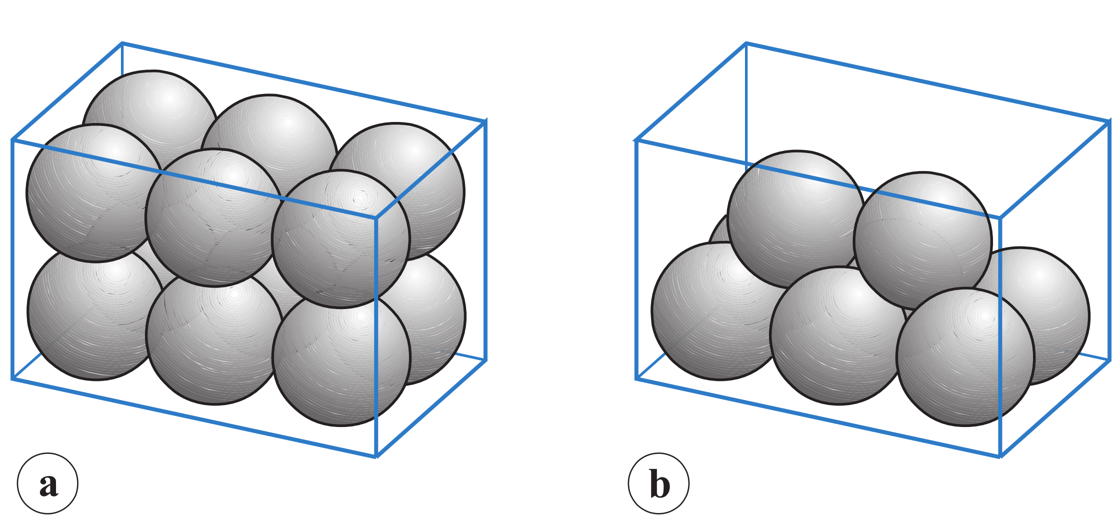

Fig. 12.2 • Different geometric packings of spherical particles, **(a)** Cubic packing. **(b)** Rhombohedral packing.

bulk density α true density

i.e. bulk density = k true density

$$(12.4)$$

or:

$$k = \frac{\text{bulk density}}{\text{true density}} \qquad (12.5)$$

The constant of proportionality, k, is known as the *packing fraction* or *fractional solids content*. For example, the packing fraction for dense, randomly packed spheres is approximately 0.65, whereas the packing fraction for a set of dense, randomly packed discs is 0.83. Also:

$$1 - k = e \qquad (12.6)$$

where e is the *fractional voidage* of the powder bed, which is usually expressed as a percentage and termed the bed porosity. Another way of expressing fractional voidage is to use the ratio of particle volume V_p to bulk powder volume V_B, i.e.:

$$e = \frac{1 - V_p}{V_B} \qquad (12.7)$$

A simple ratio of void volume V_v to particle volume V_p represents the voids ratio:

$$\frac{V_v}{V_p} = \frac{e}{(1-e)} \qquad (12.8)$$

which provides information about the stability of the powder mass.

For powders having comparable true densities, an increase in bulk density causes a decrease in porosity. This increases the number of interparticulate contacts and contact areas and causes an increase in adhesion/cohesion. For very coarse particles, this may still be insufficient to overcome the gravitational influence on particles. Conversely, a decrease in bulk density may be associated with a reduction in particle size and produce a loose-packed powder bed which, although porous, is unlikely to flow because of the inherent adhesiveness/cohesiveness of the fine particles.