18.2.4 Drying and Firing

The next step in ceramic processing is to dry and fire the part to give it the proper strength and hardness. *Drying* is a critical stage, because of the tendency for the part to warp or crack from variations in its moisture content and thickness. Control of atmospheric humidity and ambient temperature is important in order to reduce warping and cracking.

Loss of moisture during drying causes shrinkage of the part, by as much as 20% from the original, moist size (Fig. 18.6). In a humid environment, the evaporation rate is low, and thus the moisture gradient across the thickness of the part is lower than that in a dry environment. The low moisture gradient prevents a large, uneven gradient in shrinkage from the surface to the interior, reducing the tendency for excessive warping or cracking.

A ceramic part that has been shaped by any of the methods described thus far is in the green state. It can be machined in order to bring it closer to a near-net shape. Although the green part should be handled carefully, machining it is not particularly difficult, because of the relative softness of the materials.

Firing, also called **sintering**, involves heating the part to an elevated temperature in a controlled environment. Although some shrinkage occurs during firing, the ceramic part becomes stronger and harder. This improvement in mechanical properties is due to (a) the development of strong bonds among the complex oxide particles in the ceramic body and (b) reduced porosity. A more recent technology is **microwave sintering** of ceramics, conducted in furnaces with generators producing microwaves with frequencies in excess of 2 GHz. Microwave sintering can be significantly faster and less expensive than conventional sintering, and requires less energy per part.

Nanophase ceramics, described in Section 8.2.5, can be sintered at lower temperatures than those used for conventional ceramics. They are easier to fabricate, because they can be (a) compacted at room temperature to high densities, (b) hot pressed to theoretical density, and (c) formed into net-shaped parts without using binders or sintering aids.

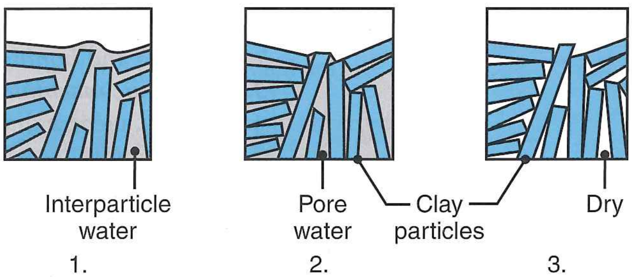

FIGURE 18.6 Shrinkage of wet clay caused by the removal of water during drying; shrinkage may be as much as 20% by volume. *Source:* After F.H. Norton.

EXAMPLE 18.1 Dimensional Changes during the Shaping of Ceramic Components

Given: A solid, cylindrical ceramic part is to be made, with a final length, L, of 20 mm. For this material, it has been established that linear shrinkages during drying and firing are 7 and 6%, respectively, based on the dried dimension, L_d.

Find: Calculate (a) the initial length, L_o, of the part and (b) the dried porosity, P_d, if the porosity of the fired part, P_f, is 3%.

Solution:

a. On the basis of the information given and noting that firing is preceded by drying, we can write

$$\frac{(L_d - L)}{L_d} = 0.06,$$

or

$$L = (1 - 0.06)\, L_d.$$

Hence,

$$L_d = \frac{20}{0.94} = 21.28 \text{ mm}$$

and

$$L_o(1 + 0.07)L_d = (1.07)(21.28) = 22.77 \text{ mm}.$$

b. Since the final porosity is 3%, the actual volume, V_a, of the solid material in the part is

$$V_a = (1 - 0.03)\, V_f = 0.97 V_f,$$

where V_f is the volume of the part after firing. Because the linear shrinkage during firing is 6%, we can determine the dried volume, V_d, of the part as

$$V_d = \frac{V_f}{(1 - 0.06)^3} = 1.2 V_f.$$

Hence,

$$\frac{V_a}{V_d} = \frac{0.97}{1.2}, \text{ or } 81\%.$$

Therefore, the porosity, P_d, of the dried part is 19%.