26.3 The Grinding Process

Grinding is a chip-removal process that uses an individual abrasive grain as the cutting tool (Fig. 26.9a). The major differences between the action of an abrasive grain and that of a single-point cutting tool can be summarized as:

- The individual abrasive grains have *irregular shapes* (Fig. 26.1), and are spaced randomly along the periphery of the wheel (Fig. 26.10).
- The average rake angle of the grains is highly negative, typically -60° or even less; consequently, grinding chips undergo much larger plastic deformation than they do in other machining processes. (See Section 21.2.)
- The radial positions of the grains (over the peripheral surface of a wheel) vary, thus not all grains are active during grinding.
- Surface speeds of grinding wheels (equivalent to cutting speeds) are very high, typically 20–30 m/s, and can be as high as 150 m/s in high-speed grinding, using specially designed and manufactured wheels.

The grinding process and its parameters can best be observed in the *surface-grinding* operation, shown schematically in Fig. 26.11. A straight grinding wheel

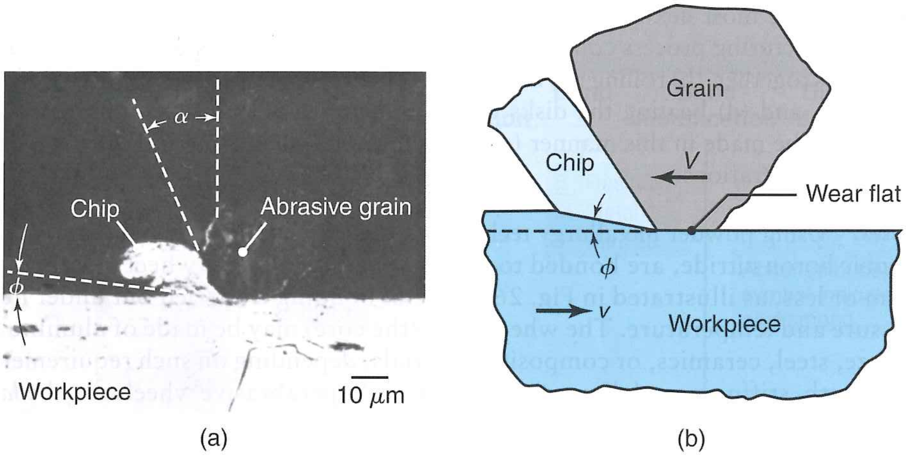

FIGURE 26.9 (a) Grinding chip being produced by a single abrasive grain; note the large negative rake angle of the grain. (b) Schematic illustration of chip formation by an abrasive grain with a wear flat; note the negative rake angle of the grain and the small shear angle. *Source:* (a) After M.E. Merchant.

(Fig. 26.5a), with a diameter of D, removes a layer of metal at a depth d (called **wheel depth of cut**). An individual grain on the periphery of the wheel moves at a tangential velocity of V, while the workpiece moves at a velocity of v. Each abrasive grain produces a small chip, which has an *undeformed thickness* (**grain depth of cut**), t, and an *undeformed length*, l.

Typical chips from grinding operations are shown in Fig. 26.12. Note that the chips, just as in machining, are thin and long.

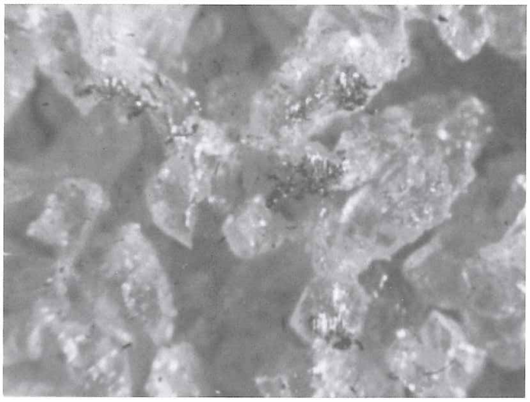

FIGURE 26.10 The surface of a grinding wheel (A46-J8V), showing abrasive grains, wheel porosity, wear flats on grains, and metal chips from the workpiece adhering to the grains; note the random distribution and shape of the abrasive grains. Magnification: 50×.

Grinding Forces. A knowledge of grinding forces is essential for

- Estimating power requirements
- Designing grinding machines and work-holding devices and fixtures
- Determining the deflections that the workpiece, as well as the grinding machine and its components, may undergo; deflections adversely affect dimensional accuracy, and are especially critical in precision and ultraprecision grinding

It can be shown that, because of the small dimensions involved, forces in grinding are typically much smaller than those in the machining operations described in Chapters 23 and 24. The forces in grinding should be kept low, in order to avoid distortion and to maintain high dimensional accuracy of the workpiece.

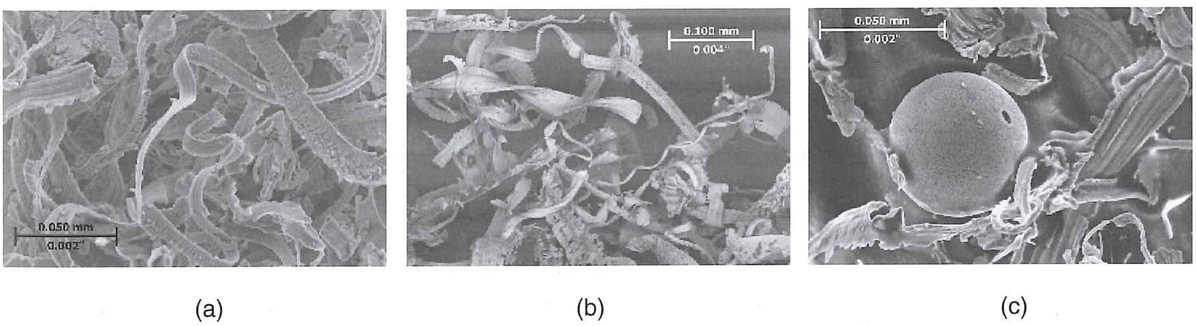

FIGURE 26.12 Typical chips, or *swarf*, from grinding operations. (a) Swarf from grinding a conventional HSS drill bit; (b) swarf from a tungsten-carbide workpiece using a diamond wheel; (c) swarf of cast iron, showing a melted globule among the chips. *Source:* Courtesy of J. Badger.

Temperature. The temperature rise in grinding is an important consideration because

- It can adversely affect the surface properties of the workpiece, including metallurgical changes
- The temperature rise can cause residual stresses on the workpiece
- Temperature gradients in the workpiece cause distortions due to thermal expansion and contraction of the workpiece surface, thus making it difficult to control dimensional accuracy

The *surface-temperature rise* (ΔT) in grinding is related to process variables by the following expression:

$$\Delta T \propto D^{1/4} d^{3/4} \left(\frac{V}{v}\right)^{1/2}. \tag{26.4}$$

Thus, temperature increases with increasing depth of cut, d, wheel diameter, D, and wheel speed, V, and decreases with increasing workpiece speed, v. Note from this equation that the depth of cut has the largest exponent; hence, it has the greatest influence on temperature.

Although *peak temperatures* during grinding can reach 1600°C, the time involved in producing a chip is on the order of microseconds, hence the chip produced may or may not melt. Because the chips carry away much of the heat generated, as do chips formed in high-speed machining processes (see Section 25.5), only a small fraction of the heat generated in grinding is conducted to the workpiece. If this was not the case, it would be very difficult to grind workpieces with sufficient dimensional accuracy and without causing any possible metallurgical changes in the workpiece.

Sparks. The sparks produced when grinding metals are actually chips that glow, due to the *exothermic* (heat producing) reaction of the hot chips with oxygen in the atmosphere. Sparks do not occur during grinding in an oxygen-free environment or when the workpiece material does not readily oxidize at elevated temperatures. The color, intensity, and shape of the sparks depend on the composition of the metal being ground. Charts are available that help identify the type of metal being ground, from the appearance of its sparks. If the heat generated due to exothermic reaction is sufficiently high, chips can melt, acquire a spherical shape (because of surface tension), and solidify as metal particles.

Tempering. An excessive temperature rise in grinding can cause *tempering* and *softening* of the workpiece surface. Process variables must therefore be selected carefully in order to avoid excessive temperature rise. The use of grinding fluids (Section 26.4) is an effective means of controlling temperature.

Residual Stresses. Temperature gradients within the workpiece during grinding are primarily responsible for the development of *residual stresses*. Grinding fluids and their method of application, as well as process parameters such as depth of cut and speeds, significantly influence the magnitude and type of residual stresses. Because of the adverse effect of tensile residual stresses on fatigue strength, process variables should be selected carefully. Residual stresses usually can be reduced by lowering wheel speed and increasing workpiece speed, a process called **low-stress grinding** or *gentle grinding*. Softer grade wheels, known as **free-cutting** grinding wheels, also may be used to reduce residual stresses.