26.2 Abrasives and Bonded Abrasives

Abrasives that are used most commonly in abrasive-machining operations are:

Conventional abrasives

- *Aluminum oxide* (Al_2O_3)
- *Silicon carbide* (SiC)

Superabrasives

- *Cubic boron nitride* (cBN)
- *Diamond*

As described in Chapter 8, these abrasives are much harder than conventional cutting-tool materials, as may be seen by comparing Tables 22.1 and 26.1 (see also Fig. 2.15). Cubic boron nitride and diamond are listed as superabrasives because they are the two hardest materials known.

In addition to hardness, an important characteristic of abrasives is **friability**, defined as the ability of abrasive grains to fracture into smaller pieces. This property gives abrasives their *self-sharpening* characteristics, essential in maintaining their sharpness during use. High friability indicates low strength or low fracture resistance of the abrasive. Thus, a highly friable abrasive grain fragments more rapidly under grinding forces than one with low friability. For example, aluminum oxide has lower friability than silicon carbide and, correspondingly, a lower tendency to fragment.

The *shape* and *size* of the abrasive grain also affect its friability. For example, *blocky* grains, which are analogous to a negative rake angle in single-point cutting tools (as shown in Fig. 21.3), are less friable than less

TABLE 26.1

Ranges of Knoop Hardness for Various Materials and Abrasives

Common glass	350–500
Flint, quartz	800–1100
Zirconium oxide	1000
Hardened steels	700–1300
Tungsten carbide	1800–2400
Aluminum oxide	2000–3000
Titanium nitride	2000
Titanium carbide	1800–3200
Silicon carbide	2100–3000
Boron carbide	2800
Cubic boron nitride	4000–5000
Diamond	7000–8000

blocky or platelike grains. Moreover, because the probability of defects decreases as grain size decreases, smaller grains are stronger and less friable than larger ones, a phenomenon known as *size effect*. (See also Section 26.3.)

Abrasive Types. The abrasives commonly found in nature are *emery*, *corundum* (alumina), *quartz*, *garnet*, and *diamond*. Because in their natural state these abrasives generally contain impurities and possess nonuniform properties, their performance as an abrasive is inconsistent and unreliable; consequently, abrasives have been made *synthetically* for many years.

- **Aluminum oxide** was first made in 1893, and is produced by fusing bauxite, iron filings, and coke. Fused aluminum oxides are categorized as *dark* (less friable), *white* (very friable), or *single crystal*.
- **Seeded gel** was first introduced in 1987, and is the purest form of *unfused aluminum oxide*. Also known as *ceramic aluminum oxide*, it has a grain size on the order of 0.2 μm (coarse human hair is about 200 μm), which is much smaller than other types of commonly used abrasive grains. These grains are *sintered* (heating without melting; see Section 17.4) to form larger sizes. Because they are harder than fused alumina and have relatively high friability, seeded gels maintain their sharpness and are especially effective for difficult-to-grind materials.
- **Silicon carbide** was first discovered in 1891, and is made with silica sand and petroleum coke. Silicon carbides are classified as *black* (less friable) or *green* (more friable), and generally have higher friability than aluminum oxide; hence, they have a greater tendency to fracture and thus remain sharp.
- **Cubic boron nitride** was first developed in the 1970s; its properties and characteristics are described in Sections 8.2.3 and 22.7.
- **Diamond**, also known as *synthetic* or *industrial diamond*, was first used as an abrasive in 1955; its properties and characteristics are described in Sections 8.7 and 22.9.

Abrasive Grain Size. As used in manufacturing operations, abrasives generally are very small when compared to the size of cutting tools and inserts, described in Chapters 21 and 22. They have sharp edges, thus allowing the removal of very small quantities of material from the workpiece surface, resulting in very fine surface finish and dimensional accuracy.

The size of an abrasive grain is identified by a **grit number**, which is a function of sieve size, whereby the smaller the grain size, the larger the grit number. For example, grit number 10 is typically regarded as very coarse, 100 as fine, and 500 as very fine. Sandpaper and emery cloth also are identified in this manner, as can readily be observed by noting the grit number printed on the back of an abrasive paper or cloth.

Compatibility of Abrasive versus Workpiece Material. As in selecting cutting-tool materials for machining, the *affinity* of an abrasive grain to the workpiece material is an important consideration. The less the reactivity of the two materials, the less wear and dulling of the grains during grinding, thus making the operation more efficient and causing less damage to the workpiece surface (see Section 26.3.1 for details). As an example, because of its chemical affinity, diamond (which is a form of carbon, Section 8.7) cannot be used for grinding steels, since diamond dissolves in iron at the high temperatures that are encountered in grinding. Generally, the following recommendations are made with regard to selecting abrasives:

- **Aluminum oxide:** Carbon steels, ferrous alloys, and alloy steels
- **Silicon carbide:** Nonferrous metals, cast irons, carbides, ceramics, glass, and marble
- **Cubic boron nitride:** Steels and cast irons above 50 HRC hardness and high-temperature alloys
- **Diamond:** Ceramics, carbides, and some hardened steels where the hardness of diamond is more significant than its reactivity with the carbon in steel

26.2.1 Grinding Wheels

Each abrasive grain typically removes only a very small amount of material at a time; consequently, high material-removal rates can only be achieved if a very large number of these grains act together. This is done by using **bonded abrasives**, typically in the form of a grinding wheel, in which the abrasive grains are distributed and oriented randomly.

As shown schematically in Fig. 26.4, the abrasive grains in a grinding wheel are held together by a **bonding material** (Section 26.2.2), which acts as supporting posts or braces between the grains. In bonded abrasives, *porosity* is essential in order to provide clearance for the chips being produced, as otherwise there would be no space for the chips being produced, and thus would severely interfere with the grinding operation. Porosity can be observed by looking at the surface of a grinding wheel with a magnifying glass.

A very wide variety of types and sizes of abrasive wheels is available today. Some of the more commonly used types of grinding wheels for conventional abrasives are shown in Fig. 26.5; superabrasive wheels are shown in Fig. 26.6. Note that, due to their high cost, only a small volume of superabrasive material is used on the periphery of these wheels.

Bonded abrasives are marked with a standardized system of letters and numbers, indicating the type of abrasive, grain size, grade, structure, and bond type. Figure 26.7 shows the marking system for aluminum-oxide and silicon-carbide bonded abrasives; the marking system for diamond and cubic boron nitride bonded abrasives is shown in Fig. 26.8.

The cost of grinding wheels depends on the type and size of the wheel. Small wheels (up to about 25 mm in diameter) cost approximately \$2 to \$15 for

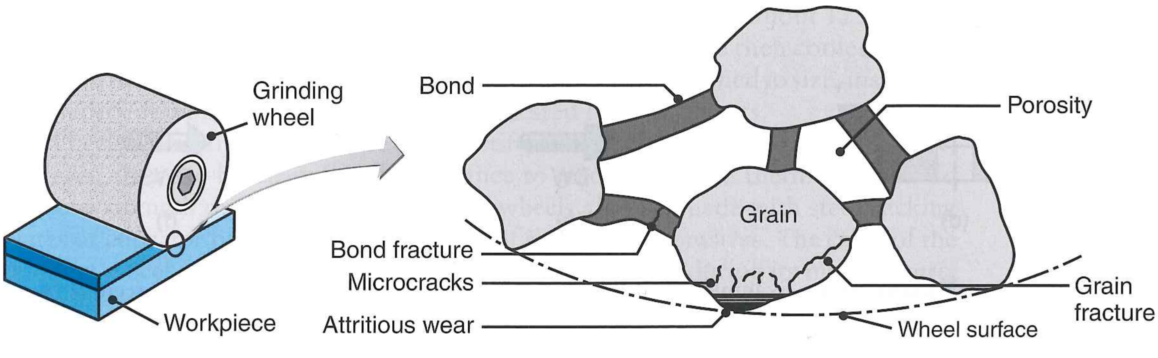

FIGURE 26.4 Schematic illustration of a physical model of a grinding wheel, showing its structure and its wear and fracture patterns.

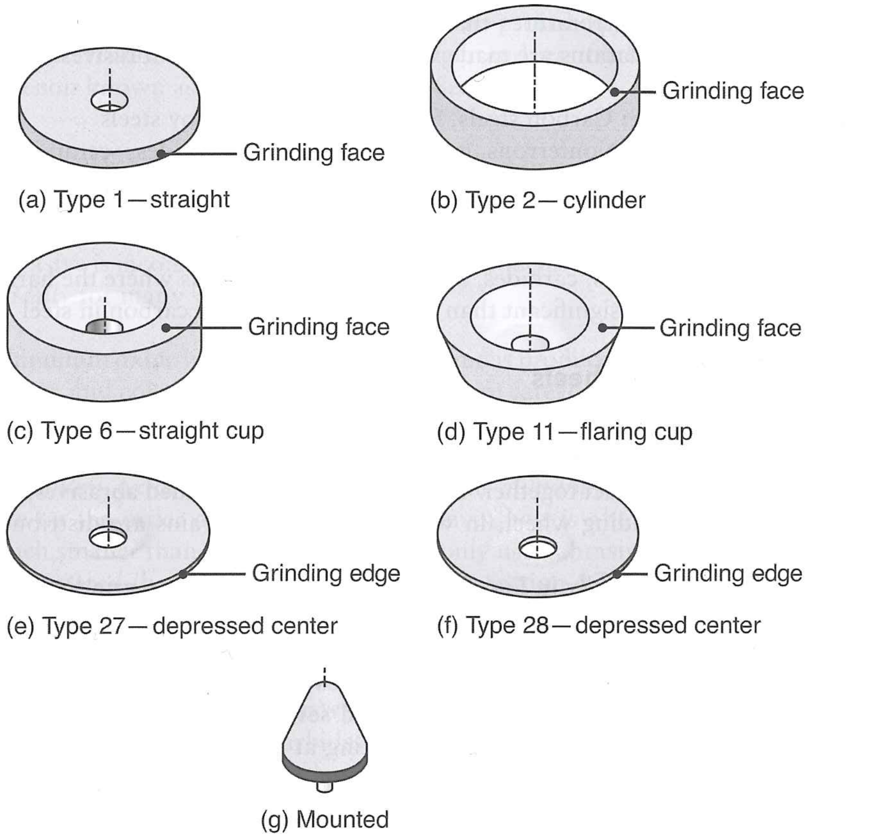

FIGURE 26.5 Common types of grinding wheels made with conventional abrasives; note that each wheel has a specific grinding face; grinding on other surfaces is improper and unsafe.

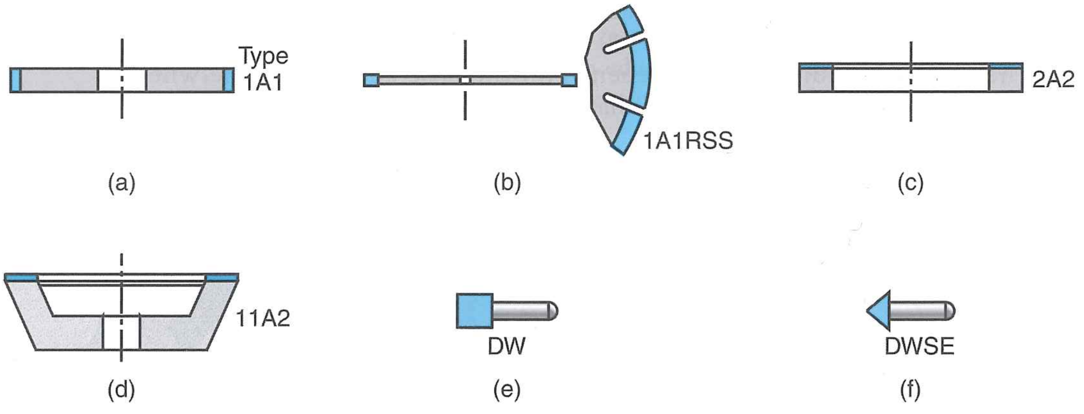

FIGURE 26.6 Examples of superabrasive wheel configurations; the annular regions (rims) are superabrasive grinding surfaces, and the wheel itself (core) generally is made of metal or composites. The bonding materials for the superabrasives are (a), (d), and (e) resinoid, metal, or vitrified; (b) metal; (c) vitrified; and (f) resinoid.

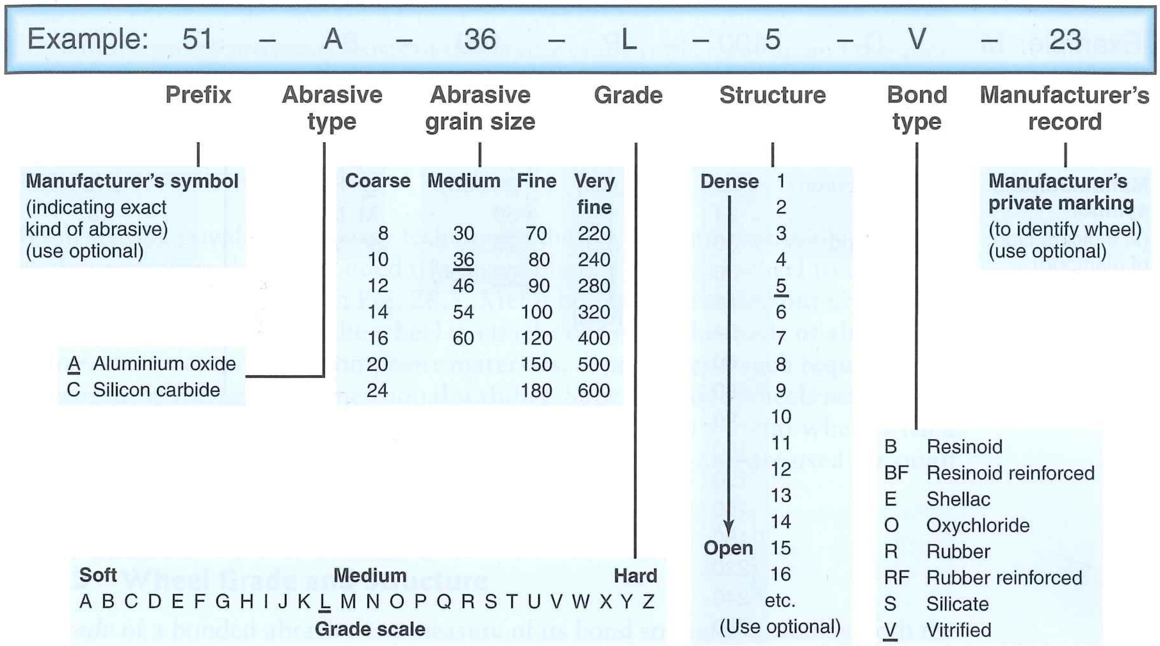

FIGURE 26.7 Standard marking system for aluminum-oxide and silicon-carbide bonded abrasives.

conventional abrasives, \$30 to \$100 for diamond, and \$50 to \$300 for cubic boron nitride wheels. For a large wheel of about 500 mm in diameter and 250 mm in width, the wheel costs are \$500 for conventional abrasives, \$5,000 to \$8,000 for diamond, and \$20,000 for cubic boron nitride.

26.2.2 Bond Types

The common types of bonds used in bonded abrasives are:

Vitrified. Also called *ceramic bonds, vitrified bonds* (from the Latin *vitrum* for glass; Section 8.4) are the most common and widely used material. The raw materials consist of feldspar (a crystalline mineral) and clays. They are mixed with the abrasives, moistened, and molded under pressure into the shape of grinding wheels. These "green" wheels, which are similar to powder metallurgy parts (Chapter 17), are then fired slowly up to a temperature of about 1250°C, to fuse the glass and develop structural strength. The wheels are then cooled slowly (to avoid thermal cracking, due to temperature gradients), finished to size, inspected for quality and dimensional accuracy, and tested for any defects.

Wheels with vitrified bonds are strong, stiff, and resistant to oils, acids, and water; however, they are brittle and lack resistance to mechanical and thermal shock. To improve strength during their use, vitrified wheels also are made with steel backing plates or cups, for better structural support of the bonded abrasives. The color of the grinding wheel can be modified by adding various elements during its manufacture, so that wheels can be color coded for use with specific workpiece materials, such as ferrous, nonferrous, and ceramic.

Resinoid. Resinoid bonding materials are *thermosetting resins*, and are available in a wide range of compositions and properties (Sections 7.4 and 7.7). Because the bond

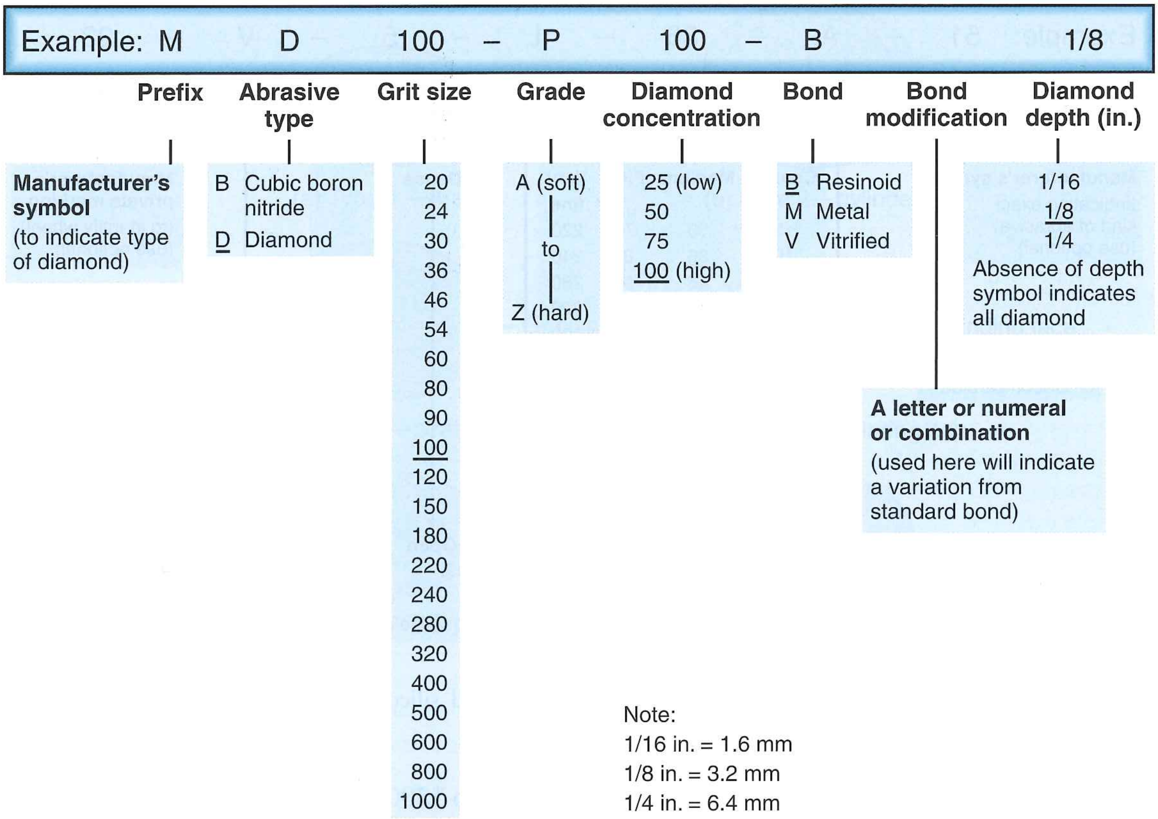

FIGURE 26.8 Standard marking system for cubic boron nitride and diamond bonded abrasives.

is an organic compound, wheels with *resinoid bonds* also are called **organic wheels.** The manufacturing technique for producing them consists basically of (a) mixing the abrasive with liquid or powdered phenolic resins and additives, (b) pressing the mixture into the shape of a grinding wheel, and (c) curing it at temperatures of about 175°C to set the bond. In addition to pressing, *injection molding* also is used to manufacture grinding wheels (see Sections 17.3 and 19.3).

Because the elastic modulus of thermosetting resins is lower than that of glasses (see Table 2.2), resinoid wheels are more flexible than vitrified wheels. As a bonding material, *polyimide* (Section 7.7) also is used as a substitute for the phenolic resin; it is tougher and more resistant to higher temperatures.

Reinforced Wheels. These wheels typically consist of one or more layers of *fiberglass mats* (Section 8.4.2) of various mesh sizes. The fiberglass in this laminate structure provides reinforcement by way of retarding the disintegration of the wheel, rather than improving its strength, should the wheel fracture or break for some reason during use. Large-diameter resinoid wheels can be further supported using one or more internal rings, made of round steel bars inserted during molding of the wheel.

Thermoplastic. In addition to thermosetting resins, thermoplastic bonds (Section 7.3) also are used in grinding wheels. Wheels are available with sol-gel abrasives bonded with thermoplastics.

Rubber. The most flexible matrix used in abrasive wheels is rubber (Section 7.9). The manufacturing process consists of (a) mixing crude rubber, sulfur, and the abrasive grains together, (b) rolling the mixture into sheets, (c) cutting out disks of various diameters, and (d) heating the disks under pressure to vulcanize the rubber. Thin wheels can be made in this manner (called *cutoff blades*) and are used like saws for cutting-off operations.

Metal. Using powder metallurgy techniques, the abrasive grains, usually diamond or cubic boron nitride, are bonded to the periphery of a metal wheel to depths of 6 mm or less, as illustrated in Fig. 26.5. Metal bonding is carried out under high pressure and temperature. The wheel itself (the core) may be made of aluminum, bronze, steel, ceramics, or composite materials, depending on such requirements as strength, stiffness, and dimensional stability. Superabrasive wheels may be *layered*, so that a single abrasive layer is plated or brazed to a metal wheel with a particular desired shape. Layered wheels are lower in cost, and are used for small production quantities.

26.2.3 Wheel Grade and Structure

The *grade* of a bonded abrasive is a measure of its bond strength, including both the type and the amount of bonding material in the wheel. Because strength and hardness are directly related (see Section 2.6.2), the grade is also referred to as the **hardness** of a bonded abrasive. Thus, for example, a hard wheel has a stronger bond and/or a larger amount of bonding material between the grains than a soft wheel.

The *structure* of a bonded abrasive is a measure of its *porosity* (the spacing between the grains, as shown in Fig. 26.4). The structure ranges from *dense* to *open*, as shown in Fig. 26.7. Recall that some porosity is essential to provide clearance for the grinding chips, as otherwise they would interfere with the grinding operation.