to help keep the cast-iron engine assembly intact. Transformation-toughened zirconia (TTZ) has higher toughness, because of dispersed tough phases in the ceramic matrix.

CASE STUDY 8.1 Ceramic Knives

Generally made of zirconium oxide, ceramic knives are produced by a process described in Section 18.2. It starts with a ceramic powder mixed with various binders, and compacted (molded) into blanks under high pressure. The blanks are then fired (sintered) at temperatures above 1000°C (1830°F) for several days. An optional hot isostatic pressing operation (Section 17.3.2) can be used to densify and toughen the ceramic. Next, the blanks are ground and polished on a diamond wheel to form a sharp edge, and the handle is attached. The Mohs hardness (Section 2.6) of the zirconium oxide ceramic is 8.2, as compared to 6 for hardened steel and a maximum of 10 for diamond.

Among the advantages of ceramic knives over steel knives are: (a) Because of their very high hardness and wear resistance, ceramic knives can last months and even years before resharpening. (b) They are chemically inert; consequently, they do not stain and food does not stick to them, hence they are easy to clean, and leave no metallic taste or smell. (c) Because they are lightweight, they are easier to use.

The knives should, however, be stored in wooden knife blocks and handled carefully. Sharp impact against other objects (such as dishes or dropping it on its edge on a hard surface) should be avoided, as the sharp edges of the knife can chip. Also, they should be used only for cutting (not for prying); in cutting meat, contact with bones is not advisable. Furthermore, the knives have to be sharpened at the factory to a precise edge, using diamond grinding wheels. Ceramic knives are comparable in cost to high-quality steel knives, typically ranging from $20–80 for a 3-in. paring knife to $50–200 for a 6-in. serrated knife.

Source: Courtesy of Kyocera Corporation.

8.2.3 Other Ceramics

Carbides. *Carbides* are typically used as cutting tools and die materials, and as an abrasive, especially in grinding wheels. Common examples of carbides are:

- Tungsten carbide (WC) consists of tungsten-carbide particles with cobalt as a binder. The amount of binder has a major influence on the material's properties; toughness increases with cobalt content, whereas hardness, strength, and wear resistance decrease.
- Titanium carbide (TiC) has nickel and molybdenum as the binder, and is not as tough as tungsten carbide.
- Silicon carbide (SiC) has good resistance to wear (thus suitable for use as an abrasive), thermal shock, and corrosion. It has a low friction coefficient and retains strength at elevated temperatures, and thus it is suitable for high-temperature components in heat engines. First produced in 1891, synthetic silicon carbide is made from silica sand, coke, and small amounts of sodium chloride and sawdust; the process is similar to that for making synthetic aluminum oxide (Section 8.2.2).

Nitrides. Examples of *nitrides* are:

- Cubic boron nitride (cBN) is the second-hardest known substance (after diamond), and has special applications, such as in cutting tools and as abrasives in grinding wheels. It does not exist in nature, and was first made synthetically in