8.1 Impact Energy

In Section 6.4, hardness was seen to be the analog of strength measured by the tensile test. **Impact energy**, the energy necessary to fracture a standard test piece under an impact load, is a similar analog of toughness. The most common laboratory measurement of impact energy is the **Charpy*** **test**, illustrated in Figure 8.1. The test principle is straightforward. The energy necessary to fracture the test piece is directly calculated from the difference in initial and final heights of the swinging pendulum. To provide control over the fracture process, a stress-concentrating notch is machined into the side of the sample subjected

Millimeter scale flaws such as the notch illustrated in this impact test can lead to the catastrophic failure of materials.

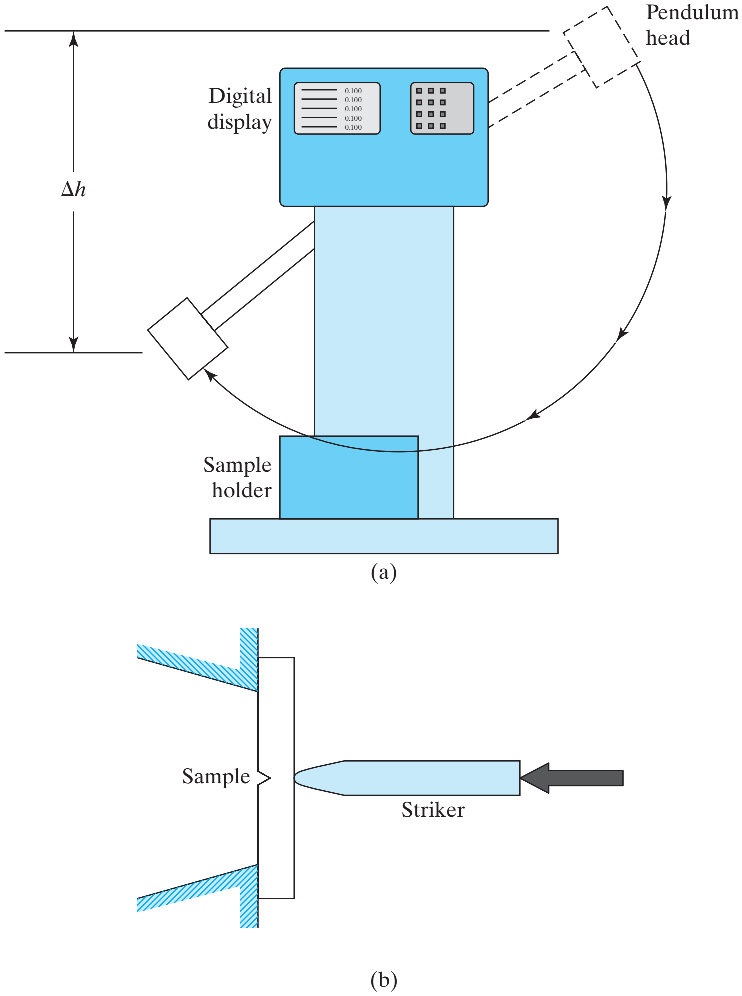

FIGURE 8.1 *(a) Charpy test of impact energy. The drop in height between the initial and final pendulum positions (Δh) corresponds to the impact energy absorbed by the sample upon fracture. (b) The instant of contact between the Charpy striker (inside the pendulum head) and the sample.*

*Augustin Georges Albert Charpy (1865–1945), French metallurgist. Trained as a chemist, Charpy became one of the pioneering metallurgists of France and was highly productive in this field. He developed the first platinum-resistance furnace and the silicon steel routinely used in modern electrical equipment, as well as the impact test that bears his name.

TABLE 8.1

Impact Test (Charpy) Data for Some of the Alloys of Table 6.1

Alloy	Impact energy [J (ft·lb)]
1. 1040 carbon steel	180 (133)
2. 8630 low-alloy steel	55 (41)
3. b. 410 stainless steel	34 (25)
4. L2 tool steel	26 (19)
5. Ferrous superalloy (410)	34 (25)
6. a. Ductile iron, quench	9 (7)
7. b. 2048, plate aluminum	10.3 (7.6)
8. a. AZ31B magnesium	4.3 (3.2)
b. AM100A casting magnesium	0.8 (0.6)
9. a. Ti–5Al–2.5Sn	23 (17)
10. Aluminum bronze, 9% (copper alloy)	48 (35)
11. Monel 400 (nickel alloy)	298 (220)
13. 50:50 solder (lead alloy)	21.6 (15.9)
14. Nb–1 Zr (refractory metal)	174 (128)

to maximum tensile stress. The net test result is to subject the sample to elastic deformation, plastic deformation, and fracture in rapid succession. Although rapid, the deformation mechanisms involved are the same as those involved in tensile testing the same material. The load impulse must approach the ballistic range before fundamentally different mechanisms come into play.

In effect, a Charpy test takes the tensile test to completion very rapidly. The impact energy from the Charpy test correlates with the area under the total stress–strain curve (i.e., toughness). Table 8.1 gives Charpy impact energy data for the alloys of Table 6.1. In general, we expect alloys with large values of both strength (Y.S. and T.S.) and ductility (percent elongation at fracture) to have large-impact fracture energies. Although this is frequently so, the impact data are sensitive to test conditions. For instance, increasingly sharp notches can give lower impact-energy values due to the stress concentration effect at the notch tip. The nature of stress concentration at notch and crack tips is explored further in the next section.

Impact-energy data for a variety of polymers are given in Table 8.2. For polymers, the impact energy is typically measured with the **Izod* test** rather than the Charpy. These two standardized tests differ primarily in the configuration of the notched test specimen (cantilevered beam for the Izod test as opposed to three-point bending for the Charpy). Impact test temperature can also be a factor. The fcc alloys generally show ductile fracture modes in Charpy testing, and hcp alloys are generally brittle (Figure 8.2). However, bcc alloys show a dramatic variation in fracture mode with temperature. In general, they fail in a brittle mode at relatively low temperatures and in a ductile mode at relatively high temperatures. Figure 8.3 shows this behavior for two series of low-carbon steels. The ductile-to-brittle transition for bcc alloys can be considered a manifestation of

*Edwin Gilbert Izod (1876–1946), English engineer, presented his test concept to a meeting of the learned society, the British Association, in 1903 and subsequently published it in the article: E. G. Izod, "Testing Brittleness of Steels," *Engr. 25* (September 1903).

TABLE 8.2

Impact Test (Izod) Data for Various Polymers

Polymer	Impact energy [J (ft·lb)]
General-use polymers	
Polyethylene	
High-density	1.4–16 (1–12)
Low-density	22 (16)
Polyvinylchloride	1.4 (1)
Polypropylene	1.4–15 (1–11)
Polystyrene	0.4 (0.3)
Polyesters	1.4 (1)
Acrylics (Lucite)	0.7 (0.5)
Polyamides (nylon 66)	1.4 (1)
Cellulosics	3–11 (2–8)
Engineering polymers	
ABS	1.4–14 (1–10)
Polycarbonates	19 (14)
Acetals	3 (2)
Polytetrafluoroethylene (Teflon)	5 (4)
Thermosets	
Phenolics (phenolformaldehyde)	0.4 (0.3)
Urea-melamine	0.4 (0.3)
Polyesters	0.5 (0.4)
Epoxies	1.1 (0.8)

Source: From data collections in R. A. Flinn and P. K. Trojan, *Engineering Materials and Their Applications*, 2nd ed., Houghton Mifflin Company, Boston, 1981, M. F. Ashby and D. R. H. Jones, *Engineering Materials*, Pergamon Press, Inc., Elmsford, NY, 1980, and *Design Handbook for DuPont Engineering Plastics*.

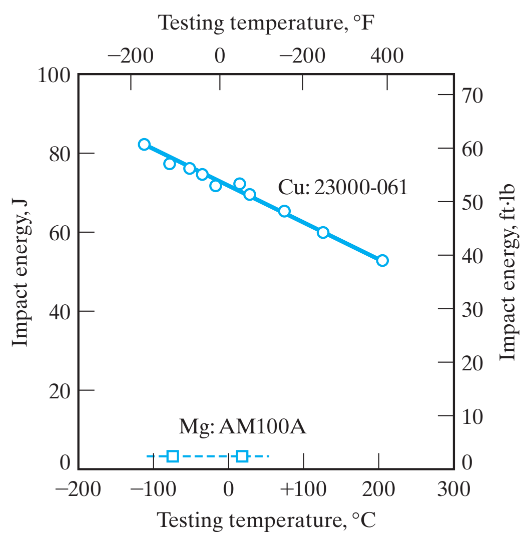

FIGURE 8.2 *Impact energy for a ductile fcc alloy (copper C23000–061, "red brass") is generally high over a wide temperature range. Conversely, the impact energy for a brittle hcp alloy (magnesium AM100A) is generally low over the same range. (From* Metals Handbook, *9th ed., Vol. 2, American Society for Metals, Metals Park, OH, 1979.)*

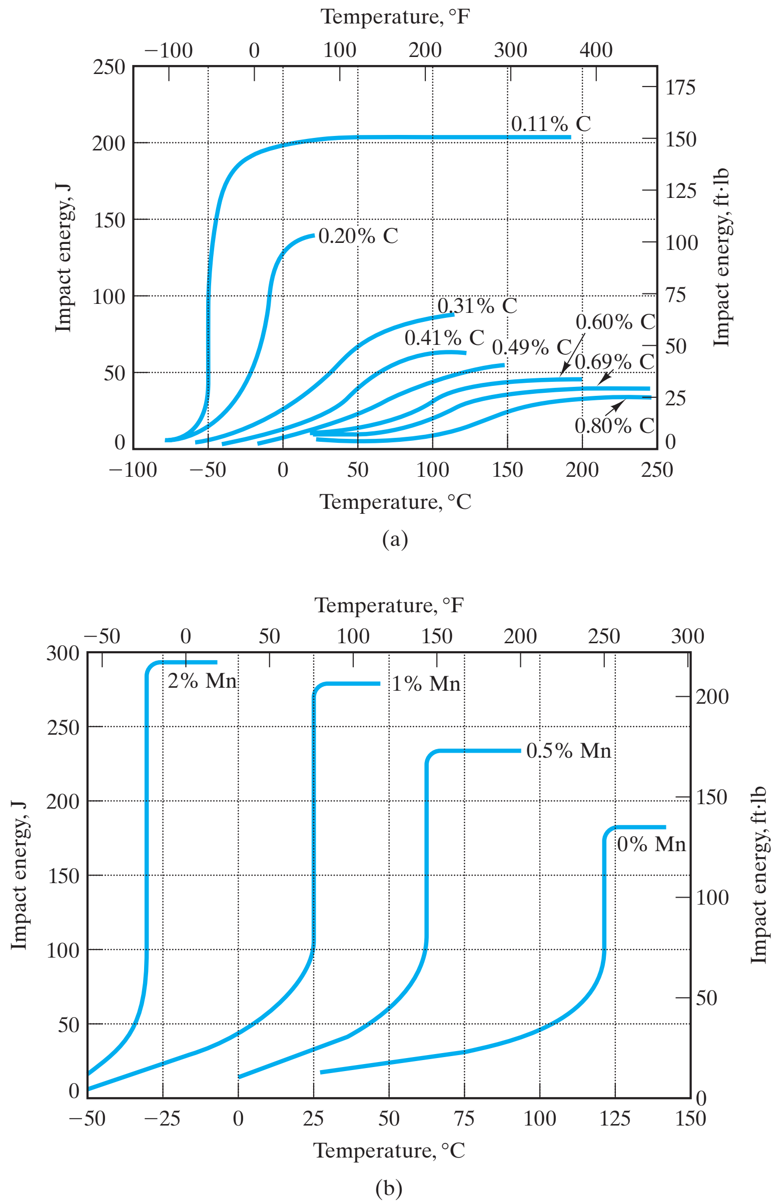

FIGURE 8.3 *Variation in ductile-to-brittle transition temperature with alloy composition. (a) Charpy V-notch impact energy with temperature for plain-carbon steels with various carbon levels (in weight percent). (b) Charpy V-notch impact energy with temperature for* Fe–Mn–0.05C *alloys with various manganese levels (in weight percent). (From* Metals Handbook, *9th ed., Vol. 1, American Society for Metals, Metals Park, OH, 1978.)*

the slower dislocation mechanics for these alloys compared with that for fcc and hcp alloys. (In bcc metals, slip occurs on non-close-packed planes.) Increasing yield strength combined with decreasing dislocation velocities at decreasing temperatures eventually leads to brittle fracture. The microscopic fracture surface of the high-temperature ductile failure has a dimpled texture with many cuplike projections of deformed metal, and brittle fracture is characterized by cleavage

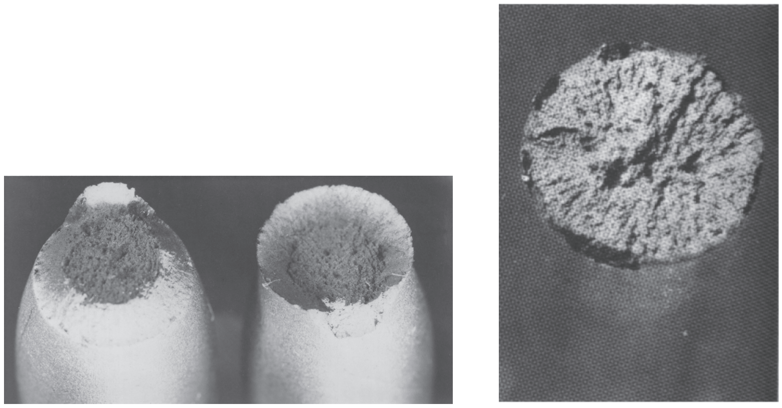

FIGURE 8.4 *(a) Typical "cup and cone" ductile fracture surface. Fracture originates near the center and spreads outward with a dimpled texture. Near the surface, the stress state changes from tension to shear, with fracture continuing at approximately* 45°. *(From* Metals Handbook, *9th ed., Vol. 12, ASM International, Metals Park, OH, 1987.) (b) Typical cleavage texture of a brittle fracture surface. (From* Metals Handbook, *8th ed., Vol. 9, American Society for Metals, Metals Park, OH, 1974.)*

surfaces (Figure 8.4). Near the transition temperature between brittle and ductile behavior, the fracture surface exhibits a mixed texture. The **ductile-to-brittle transition temperature** is of great practical importance. The alloy that exhibits a ductile-to-brittle transition loses toughness and is susceptible to catastrophic failure below this transition temperature. Because a large fraction of the structural steels are included in the bcc alloy group, the ductile-to-brittle transition is a design criterion of great importance. The transition temperature can fall between roughly −100 and +100°C, depending on alloy composition and test conditions. Several disastrous failures of Liberty ships occurred during World War II because of this phenomenon. Some literally split in half. Low-carbon steels that were ductile in room-temperature tensile tests became brittle when exposed to lower-temperature ocean environments. Figure 8.3 shows how alloy composition can dramatically shift the transition temperature. Such data are an important guide in material selection.

D **EXAMPLE 8.1**

You are required to use a furnace-cooled Fe–Mn–0.05C alloy in a structural design that may see service temperatures as low as 0°C. Suggest an appropriate Mn content for the alloy.

SOLUTION

Figure 8.3 provides the specific guidance we need. A 1% Mn alloy is relatively brittle at 0°C, whereas a 2% Mn alloy is highly ductile. Therefore, a secure choice (based on notch-toughness considerations only) would be

$$\text{Mn content} = 2\%.$$