8.3 Fatigue

Up to this point, we have characterized the mechanical behavior of metals under a single load application either slowly (e.g., the tensile test) or rapidly (e.g., the impact test). Many structural applications involve cyclic rather than static loading, and a special problem arises. **Fatigue** is the general phenomenon of material failure after several cycles of loading to a stress level below the ultimate tensile stress (Figure 8.8). Figure 8.9 illustrates a common laboratory test used to cycle

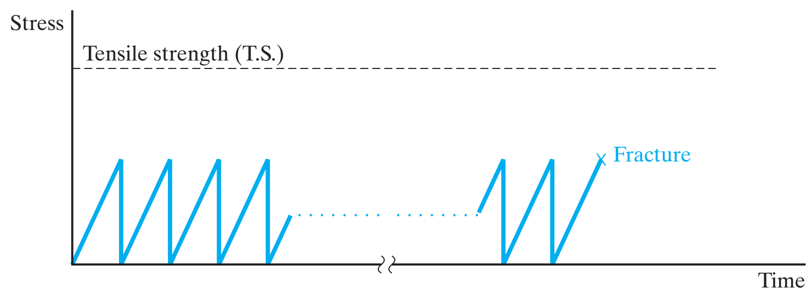

FIGURE 8.8 *Fatigue corresponds to the brittle fracture of an alloy after a total of N cycles to a stress below the tensile strength.*

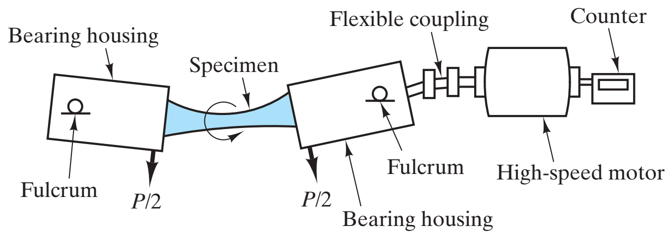

FIGURE 8.9 *Fatigue test. (From C. A. Keyser,* Materials Science in Engineering, *4th ed., Charles E. Merrill Publishing Company, Columbus, OH, 1986.)*

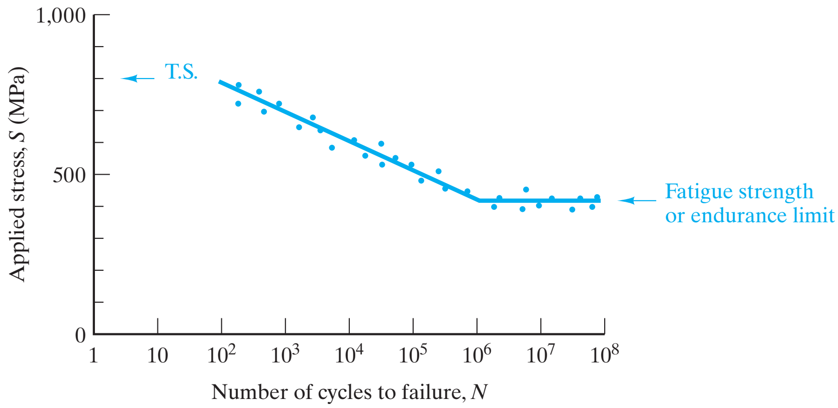

FIGURE 8.10 *Typical fatigue curve. (Note that a log scale is required for the horizontal axis.)*

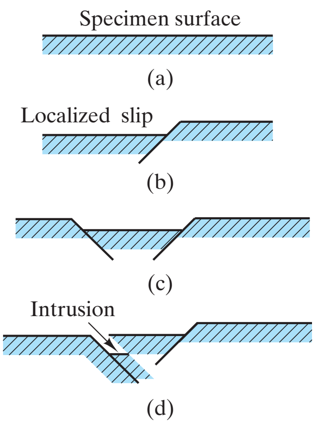

FIGURE 8.11 *An illustration of how repeated stress applications can generate localized plastic deformation at the alloy surface leading eventually to sharp discontinuities.*

a test piece rapidly to a predetermined stress level. A typical **fatigue curve** is shown in Figure 8.10. This plot of stress (S) versus number of cycles (N), on a logarithmic scale, at a given stress is also called the *S–N curve.* The data indicate that while the material can withstand a stress of 800 MPa (T.S.) in a single loading ($N = 1$), it fractures after 10,000 applications ($N = 10^4$) of a stress less than 600 MPa. The reason for this decay in strength is a subtle one. Figure 8.11 shows how repeated stress applications can create localized plastic deformation at the metal surface, eventually manifesting as sharp discontinuities (extrusions and intrusions). These intrusions, once formed, continue to grow into cracks, reducing the load-carrying ability of the material and serving as stress concentrators (see the preceding section).

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Figure 8.10 showed that the decay in strength with increasing numbers of cycles reaches a limit. This **fatigue strength**, or *endurance limit,* is characteristic of ferrous alloys. Nonferrous alloys tend not to have such a distinct limit, although the rate of decay decreases with N (Figure 8.15). As a practical matter, the fatigue strength of a nonferrous alloy is defined as the strength value after an arbitrarily large number of cycles (usually $N = 10^8$, as illustrated in Figure 8.15). Fatigue strength usually falls between one-fourth and one-half of the tensile strength, as illustrated by Table 8.4 and Figure 8.16 for the alloys of Table 6.1. For a given

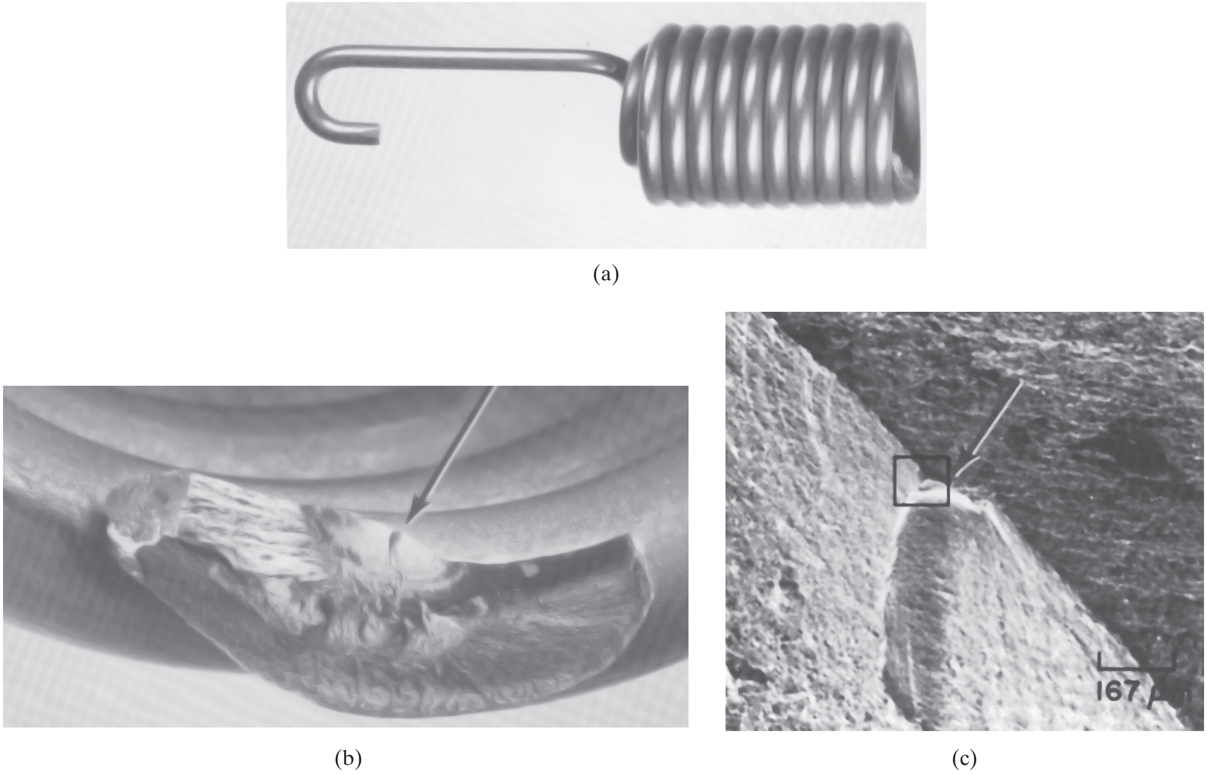

FIGURE 8.14 *Characteristic fatigue fracture surface. (a) Photograph of an aircraft throttle-control spring ($1\frac{1}{2}\times$) that broke in fatigue after 274 h of service. The alloy is 17–7PH stainless steel. (b) Optical micrograph ($10\times$) of the fracture origin (arrow) and the adjacent smooth region containing a concentric line pattern as a record of cyclic crack growth (an extension of the surface discontinuity shown in Figure 8.11). The granular region identifies the rapid crack propagation at the time of failure. (c) Scanning electron micrograph ($60\times$), showing a closeup of the fracture origin (arrow) and adjacent "clamshell" pattern. (From* Metals Handbook*, 8th ed., Vol. 9: Fractography and Atlas of Fractographs, American Society for Metals, Metals Park, OH, 1974.)*

alloy, the resistance to fatigue will be increased by prior mechanical deformation (cold working) or reduction of structural discontinuities (Figure 8.17).

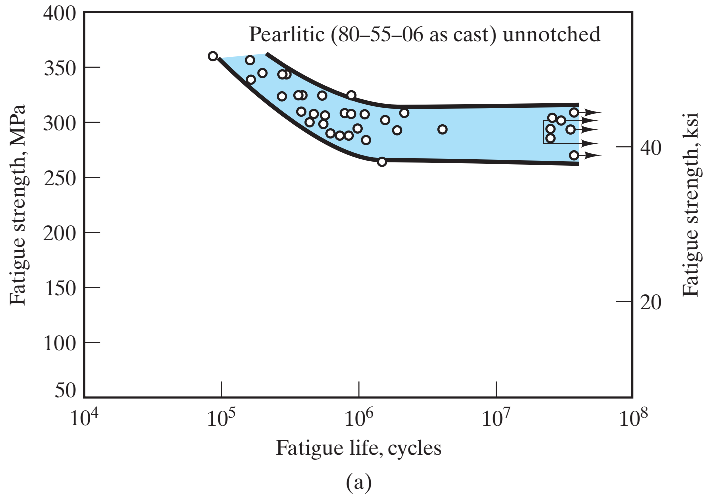

FIGURE 8.15 *Comparison of fatigue curves for (a) ferrous and (b) nonferrous alloys. The ferrous alloy is a ductile iron. The nonferrous alloy is C11000 copper wire. The nonferrous data do not show a distinct endurance limit, but the failure stress at $N = 10^8$ cycles is a comparable parameter. (After* Metals Handbook, *9th ed., Vols. 1 and 2, American Society for Metals, Metals Park, OH, 1978, 1979.)*

TABLE 8.4

Comparison of Fatigue Strength (F.S.) and Tensile Strength (T.S.) for Some of the Alloys of Table 6.1

Alloy	F.S. (MPa)	T.S. (MPa)
1. 1040 carbon steel	280	750
2. 8630 low-alloy steel	400	800
3. a. 304 stainless steel	170	515
7. a. 3003-H14 aluminum	62	150
8. b. AM100A casting magnesium	69	150
9. a. Ti–5Al–2.5Sn	410	862
10. Aluminum bronze, 9% (copper alloy)	200	652
11. Monel 400 (nickel alloy)	290	579
12. AC41A zinc	56	328

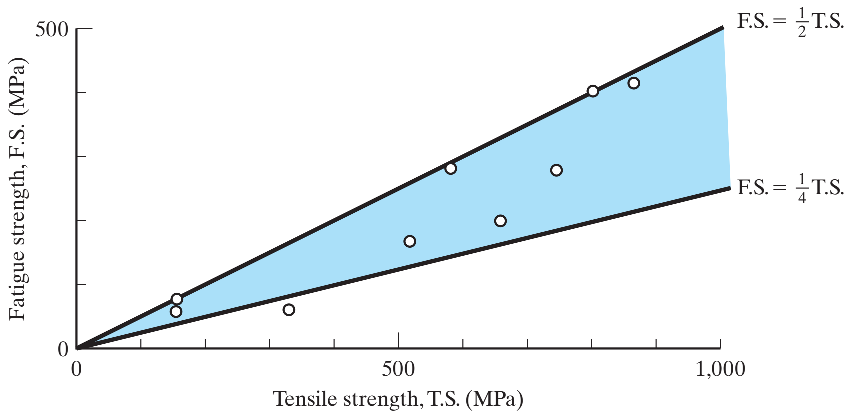

FIGURE 8.16 *Plot of data from Table 8.4 showing how fatigue strength is generally one-fourth to one-half of the tensile strength.*

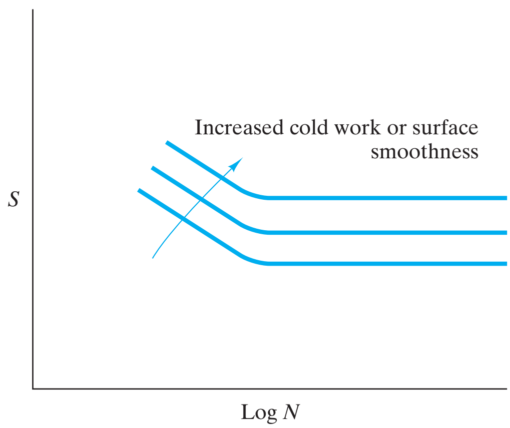

FIGURE 8.17 *Fatigue strength is increased by prior mechanical deformation or reduction of structural discontinuities.*