Commentary

Metals

Most metals exhibit some ductility. They yield by plastic deformation before they break. Metal properties of yield strength (σ_y or YS) and ultimate tensile strength (σ_u or UTS or just TS) are measured with standardized tensile tests, as we encountered in Unit 1. To avoid plastic deformation, the engineer determines the maximum stress expected, σ_{max}, using handbook formulae or finite element computer modeling. The application is then designed to keep this maximum stress less than the yield stress by a specified safety factor (SF). That is,

$$\sigma_{MAX} = \frac{\sigma_y}{(SF)}$$

For static loads, a safety factor of 2 is common.

We note that for a given alloy, a range of yield stress values is possible. Metals strain harden so that parts formed by plastic deformation will have higher yield strength after forming than before they were shaped. Further, many alloys, including steel, aluminum, and magnesium alloys, have compositions that are heat treatable. They can be soft (low yielding) for fabrication, and subsequently strengthened by heat treatment.

Polymers

While some thermosetting plastics are brittle, most plastics are ductile, and their properties can be determined by pulling tensile samples, as with metals. In many cases though, the tensile test curves for polymers are distinctly different than those for metals. Thermoplastic polymers can exhibit long stable necking down as the polymer molecules are forced into alignment. This was shown in the video about Teflon® tape in Unit 2.

Ceramics

Ceramic materials usually cannot be pulled in a tensile test machine. Being brittle, they would likely fracture in the machine grips. We can, however, indirectly obtain numbers for both yield strength and fracture strength.

Yield stresses are deduced from hardness measurements. In Unit 1, a measurement defined as “true hardness” was reported to be approximately three times the yield stress. This indicates that ceramics have very high yield strengths. However, these numbers are not useful for designing engineering parts. Long before they yield, ceramics fail by fast fracture.

Controlled fracture of brittle materials is usually done in **three-point bending**. A long beam of the brittle material is supported at each end, and a load is applied at the center of the opposite face. This causes compressive stresses on the load side of the beam, and tensile stresses on the supported side. The load is gradually increased until fracture occurs in the region of maximum tension, which is in the outer fibers on the supported side. The stress at fracture is reported as the **modulus of rupture** (σ_r), or as the **flexural strength** of the material.

Unreinforced concrete is weak, with σ_r in the range of 1–5 MPa. Traditional manufactured ceramics like brick, pottery, and porcelain are about an order of magnitude stronger, with σ_r in the range of 10–100 MPa. Engineering ceramics like carbides, nitrides, alumina, and zirconia are yet another order of magnitude stronger, with σ_r in the approximate range of 200–1000 MPa.

Composites

We cannot generalize about composites and plastic deformation. In addition to different constituent materials, we have different manufacturing methods such as fiber alignment and layering. Composites may neither plastically deform nor fail by fast fracture. Failure may be by modes unique to composites, such as loss of bonding between fibers and matrix.