Tables taken from "Applied Strength of Materials for Engineering Technology" by Barry Dupen

# Appendix A: Units

## SI System of Units and Prefixes

The SI system of units (Système International), also commonly called the metric system, uses prefixes to indicate scale. Learn the prefixes, and unit conversion will become easy. For example, 1 kN is $10^3$ newtons, 1 MPa is $10^6$ pascals, and 1 Pa is 1 N/m². If you are converting 600 kN/m² to MPa, you can either convert everything to the lowest level of meters and newtons:

$$\frac{600\text{kN}}{\text{m}^2}\left|\frac{10^3\text{N}}{\text{kN}}\right|\frac{\text{MPa m}^2}{10^6\text{N}}=0.6\text{MPa}$$

or you can recognize that 1 MPa is $10^3$ kPa and take fewer steps:

$$\frac{600\text{kN}}{\text{m}^2}\left|\frac{\text{MPa m}^2}{10^3\text{kN}}\right.=0.6\text{MPa}$$

| Prefix | Abbrev. | | Multiplier |
|---|---|---|---|
| nano- | n | = | $10^{-9}$ |
| micro- | μ | = | $10^{-6}$ |
| milli- | m | = | $10^{-3}$ |
| centi- | c | = | $10^{-2}$ |
| kilo- | k | = | $10^{3}$ |
| Mega- | M | = | $10^{6}$ |
| Giga- | G | = | $10^{9}$ |
| Tera- | T | = | $10^{12}$ |

| Quantity | Unit | Symbol | Definition |
|---|---|---|---|
| Length | meter | m | |
| Mass | gram | g | |
| Force or Weight | newton | N | $kg \cdot m/s^2$ |
| Stress or Pressure | pascal | Pa | $N/m^2$ |
| Moment or Torque | newton meter | N·m | |

A very useful SI conversion factor for stress: $1\text{ MPa} = 1\text{ N/mm}^2$

## US Customary System of Units and Prefixes

The US Customary system of units, also commonly called the English system, does not uses prefixes to indicate scale, except for "kips" for "kilopounds" (1000 lb.). Instead, we use conversion factors to go from one scale to the next. US Most customary unit symbols are abbreviations with periods: "ft." not "ft", "in." not "in"; exceptions include "psi" and "ksi" which have no periods.

In the construction trades, the term "yard" is an abbreviation for "cubic yard", so 3 yards of concrete is actually 3 cubic yards, or 27 cubic feet.

| Quantity | Unit | Symbol | Definition |
|---|---|---|---|
| Length | foot | ft. | |
| Mass | slug | S | |
| Force or Weight | pound | lb. | |
| Stress or Pressure | pounds per sq. in. | psi | $lb./in.^2$ |
| Moment or Torque | foot pound | ft.·lb. | |

| Unit | | Equivalent |
|---|---|---|
| 1 ft. | = | 12 in. |
| 1 yd. | = | 3 ft. |
| 1 kip | = | 1,000 lb. |
| 1 ksi | = | 1,000 psi |
| 1 ton | = | 2,000 lb. |

## Conversions Between Unit Systems

| U.S. Unit | | S.I. Unit |
|---|---|---|
| 1 in. | = | 2.54 cm |
| 1 ft. | = | 30.48 cm |
| 1 lb. | = | 4.448 N |
| 1 psi | = | 6,895 Pa |
| 1 psi | = | 6.895 kPa |
| 1 ksi | = | 6.895 MPa |

| SI Unit | | U.S. Unit |
|---|---|---|
| 1 cm | = | 0.3937 in. |
| 1 m | = | 3.2808 ft. |
| 1 N | = | 0.2248 lb. |
| 1 MPa | = | 145 psi |

# Appendix B: Materials Properties

Apply a load to a material and measure the response to obtain *Mechanical Properties* such as yield strength, Young's modulus, elongation, hardness, impact resistance, and fatigue life. All other properties are called *Physical Properties*, including thermal expansion, electrical conductivity, density, color, corrosion resistance, and specific heat. Some properties vary very little, while others have large ranges. For example, published values of Young's modulus for steels vary less than ±1½% because this property is related to bond strength at the atomic level. On the other hand, the yield strength of a particular grade of steel can vary ±15% or more due to variations in composition and processing. The weakest, softest steels have a yield strength below 25 ksi, while the strongest have a yield strength greater than 300 ksi.

The numbers in the tables below are either typical or minimum values, for use in homework problems only. Use standards published by ASTM, SAE, et al., for materials property values before designing anything.

## Metals, Concrete, & Stone

### Table B1: Materials Properties at Room Temperature (U.S. Customary units)

| Material | Specific weight | Yield strength (tension) | Ultimate strength (tension) | Ultimate strength (compression) | Ultimate strength (shear) | Young's modulus | Shear modulus | Thermal expansion coefficient | Poisson's ratio |
|---|---|---|---|---|---|---|---|---|---|
| | $\gamma$ | $\sigma_{YS}$ | $\sigma_{UTS}$ | $\sigma_{UCS}$ | $\tau_{ult}$ | $E$ | $G$ | $\alpha$ | $\nu$ |
| | (lb./in.$^3$) | (ksi) | (ksi) | (ksi) | (ksi) | ($10^6$ psi) | ($10^6$ psi) | ($10^{-6}$ in./(in.·°F)) | - |
| **Steels** | | | | | | | | | |
| ASTM A36 | 0.284 | 36 | 58 | - | - | 30 | 12 | 6.5 | 0.25 |
| ASTM A992 (HSLA) | 0.284 | 50 | 65 | - | - | 30 | 12 | 6.5 | 0.25 |
| AISI 80X (HSLA) | 0.284 | 80 | 100 | - | - | 30 | 11.6 | 6.5 | 0.28 |
| AISI 1020, annealed | 0.284 | 43 | 57 | - | - | 30 | 12 | 6.8 | 0.25 |
| AISI 1020, cold rolled | 0.284 | 48 | 65 | - | - | 30 | 12 | 6.8 | 0.25 |
| AISI 1040, annealed | 0.284 | 51 | 75 | - | - | 30 | 12 | 6.3 | 0.25 |
| AISI 1040, cold rolled | 0.284 | 60 | 90 | - | - | 30 | 12 | 6.3 | 0.25 |
| AISI 4140, annealed | 0.284 | 61 | 95 | - | - | 30 | 12 | 6.8 | 0.25 |
| AISI 8620, annealed | 0.284 | 56 | 78 | - | - | 30 | 12 | 6.2 | 0.25 |
| **Stainless steels** | | | | | | | | | |
| Type 304, annealed | 0.290 | 30 | 75 | - | - | 28 | 12.5 | 9.6 | 0.29 |
| Type 304, cold rolled | 0.290 | 110 | 150 | - | - | 28 | 12.5 | 9.6 | 0.29 |
| Type 409, annealed | 0.280 | 30 | 55 | - | - | 29 | 11.3 | 6.5 | 0.28 |
| **Cast irons** | | | | | | | | | |
| Grade 4 austempered ductile iron | 0.260 | 155 | 200 | - | - | 24.4 | 9.4 | 5.9 | 0.25 |
| Class 35 gray cast iron | 0.260 | - | 35 | 125 | 48.5 | 10.9 | 6.4 | 7.2 | 0.29 |
| **Aluminum alloys** | | | | | | | | | |
| 2024-T4 | 0.101 | 47 | 68 | - | 41 | 10.6 | 4.0 | 12.9 | 0.33 |
| 6061-T6 | 0.098 | 40 | 45 | - | 30 | 10.0 | 3.8 | 13.1 | 0.33 |
| 7075-T6 | 0.101 | 73 | 83 | - | 48 | 10.4 | 3.9 | 13.1 | 0.33 |
| **Magnesium alloys** | | | | | | | | | |
| AZ80A, as extruded | 0.065 | 36 | 49 | - | 22 | 6.5 | 2.4 | 14.0 | 0.35 |
| AZ80A, T5 temper | 0.065 | 40 | 55 | - | 24 | 6.5 | 2.4 | 14.0 | 0.35 |
| **Copper alloys** | | | | | | | | | |
| C26000 cartridge brass, annealed | 0.308 | 16 | 48 | - | 34 | 16.0 | 6.0 | 11.1 | 0.38 |
| C26000 cartridge brass, rolled | 0.308 | 52 | 70 | - | 42 | 16.0 | 6.0 | 11.1 | 0.38 |
| C63000 aluminum bronze, annealed | 0.274 | 53 | 111 | - | - | 17.0 | 6.4 | 9.0 | 0.33 |
| **Titanium alloys** | | | | | | | | | |
| Ti-6Al-4V, annealed | 0.160 | 120 | 130 | - | 80 | 16.5 | 6.1 | 8.6 | 0.34 |
| Ti-6Al-4V, heat treated | 0.160 | 160 | 170 | - | - | 16.5 | 6.1 | 8.6 | 0.34 |
| **Concrete & Stone** | | | | | | | | | |
| Unreinforced concrete (range of grades) | 0.0868 | | $0.1\times\sigma_{UCS}$ | 3 to 4 | $0.5\times\sigma_{UCS}$ | 2.5 to 4 | | 5.5 | 0.1 to 0.20 |
| Granite (typical) | 0.0972 | | | 25 | | 7.0 | | 3.6 | 0.28 |
| Limestone (typical) | 0.0961 | | | 8 to 16 | | 6.0 | | 2.8 | 0.21 |
| Sandstone (typical) | 0.0903 | | | 6 | | 2.5 | | 5.2 | 0.28 |

## Table B2: Materials Properties at Room Temperature (SI units)

| Material | Density | Yield strength (tension) | Ultimate strength (tension) | Ultimate strength (compression) | Ultimate strength (shear) | Young's modulus | Shear modulus | Thermal expansion coefficient | Poisson's ratio |
|---|---|---|---|---|---|---|---|---|---|
| | $\rho$ | $\sigma_{YS}$ | $\sigma_{UTS}$ | $\sigma_{UCS}$ | $\tau_{ult}$ | $E$ | $G$ | $\alpha$ | $\nu$ |
| | (g/cm³) | (MPa) | (MPa) | (MPa) | (MPa) | (GPa) | (GPa) | ($10^{-6}$ mm/(mm°C)) | - |
| **Steels** | | | | | | | | | |
| ASTM A36 | 7.85 | 250 | 400 | - | - | 207 | 83 | 11.7 | 0.25 |
| ASTM A992 (HSLA) | 7.85 | 345 | 450 | - | - | 207 | 83 | 11.7 | 0.25 |
| AISI 80X (HSLA) | 7.85 | 550 | 690 | - | - | 207 | 80 | 11.7 | 0.28 |
| AISI 1020, annealed | 7.85 | 295 | 395 | - | - | 207 | 83 | 11.7 | 0.25 |
| AISI 1020, cold rolled | 7.85 | 330 | 450 | - | - | 207 | 83 | 11.7 | 0.25 |
| AISI 1040, annealed | 7.85 | 350 | 520 | - | - | 207 | 83 | 11.3 | 0.25 |
| AISI 1040, cold rolled | 7.85 | 415 | 620 | - | - | 207 | 83 | 11.3 | 0.25 |
| AISI 4140, annealed | 7.85 | 420 | 655 | - | - | 207 | 83 | 12.3 | 0.25 |
| AISI 8620, annealed | 7.85 | 385 | 540 | - | - | 207 | 83 | 11.1 | 0.25 |
| **Stainless steels** | | | | | | | | | |
| Type 304, annealed | 8.00 | 205 | 515 | - | - | 195 | 86 | 17.2 | 0.29 |
| Type 304, cold rolled | 8.00 | 760 | 1035 | - | - | 193 | 86 | 17.2 | 0.29 |
| Type 409, annealed | 7.80 | 205 | 380 | - | - | 200 | 78 | 11.7 | 0.28 |
| **Cast irons** | | | | | | | | | |
| Grade 4 austempered ductile iron | 7.1 | 1100 | 1400 | - | - | 168 | 65 | 10.6 | 0.25 |
| Class 35 gray cast iron | 7.1 | | 241 | 855 | 334 | 110 | 44 | 13.0 | 0.29 |
| **Aluminum alloys** | | | | | | | | | |
| 2024-T4 | 2.78 | 325 | 470 | - | 285 | 73 | 28.0 | 23.2 | 0.33 |
| 6061-T6 | 2.70 | 275 | 310 | - | 205 | 69 | 26.0 | 23.6 | 0.33 |
| 7075-T6 | 2.80 | 505 | 570 | - | 330 | 72 | 26.9 | 23.6 | 0.33 |
| **Magnesium alloys** | | | | | | | | | |
| AZ80A, as extruded | 1.80 | 250 | 340 | - | 150 | 45 | 17 | 26.0 | 0.35 |
| AZ80A, T5 temper | 1.80 | 275 | 380 | - | 165 | 45 | 17 | 26.0 | 0.35 |
| **Copper alloys** | | | | | | | | | |
| C26000 cartridge brass, annealed | 8.53 | 110 | 330 | - | 235 | 110 | 40 | 19.9 | 0.38 |
| C26000 cartridge brass, rolled | 8.53 | 360 | 480 | - | 290 | 110 | 40 | 19.9 | 0.38 |
| C63000 aluminum bronze, annealed | 7.58 | 370 | 766 | | | 115 | 44 | 16.2 | 0.33 |
| **Titanium alloys** | | | | | | | | | |
| Ti-6Al-4V, annealed | 4.43 | 830 | 900 | - | 550 | 114 | 42 | 4.8 | 0.34 |
| Ti-6Al-4V, heat treated | 4.43 | 1100 | 1170 | - | - | 114 | 42 | 4.8 | 0.34 |
| **Concrete & Stone** | | | | | | | | | |
| Unreinforced concrete (range of grades) | 2.40 | | $0.1\times\sigma_{UCS}$ | 21 to 28 | $0.5\times\sigma_{UCS}$ | 17 to 28 | | 9.9 | 0.1 to 0.20 |
| Granite (typical) | 2.69 | | | 170 | | 48 | | 6.5 | 0.28 |
| Limestone (typical) | 2.66 | | | 55 to 110 | | 40 | | 5.0 | 0.21 |
| Sandstone (typical) | 2.50 | | | 40 | | 17 | | 9.4 | 0.28 |

For most metals, the ultimate strength in compression is equal to the ultimate strength in tension.

Concrete, stone, and gray cast iron are significantly stronger in compression than in tension. The elastic portion of their stress-strain curves are not linear, so Young's modulus is not clearly defined for these materials.

## Table B3: Descriptions of Materials and their Common Uses

| | |
|---|---|
| **Steels** | |
| ASTM A36 | Low-carbon, low-strength, low-cost rolled structural steel used for W-beams, I-beams, C-channels, etc. |
| ASTM A992 (HSLA)<br>AISI 80X (HSLA) | High-strength, low-alloy steels contain grain-refining elements such as boron which create very small grains. The smaller the grain, the stronger the steel. Reheating to welding temperatures causes grains to grow, ruining the strength of the steel. Used for structural steel applications in buildings and large trucks. Must be bolted or riveted, never welded. By definition, few alloying elements are added, keeping costs low. |
| AISI 1020 | Low-carbon steel containing 0.20% carbon, 0.45% manganese. Cold rolling increases strength & decreases ductility. |
| AISI 1040 | Medium-carbon steel containing 0.40% carbon, 0.75% manganese. Added carbon makes the alloy stronger than AISI 1020. Cold rolling further increases strength and decreases ductility. |
| AISI 4140 | Add 0.95% chromium, 0.20% molybdenum, and a little manganese to AISI 1040 steel. Cost and strength increase. Quench & temper heat treatment can raise yield strength above 230 ksi. Used for machine parts. |
| AISI 8620 | Add 0.55% nickel, 0.50% chromium, 0.20% molybdenum, and a little manganese to AISI 1020 steel. Cost and strength increase. Used for gears and bearings which are carburized to create a hard, wear-resistant high-carbon surface. |
| **Stainless steels** | |
| Type 304 | Most common stainless steel, with 18% Cr, 8% Ni for corrosion resistance. Used for food handling equipment (cutlery, pots and pans), tubing, cryogenic equipment. Not magnetic. Hardenable by cold work (rolling, drawing, etc.), but not through heat treatment. |
| Type 409, annealed | Contains 11% Cr, ½% Ni, therefore cheaper than type 304, with less corrosion resistance. Widely used for stainless exhaust pipes on cars and trucks. Magnetic. |
| **Cast irons** | |
| Grade 4 austempered ductile iron | Contains 3 to 4% carbon in the form of spherical graphite particles which reduce stress concentrations within the alloy. Austempering heat treatment further strengthens the material, giving it the strength and wear resistance of steels with the low cost and castability of cast irons. Used for crankshafts and other machine parts. |
| Class 35 gray cast iron | Contains 2.5 to 4% carbon in the form of graphite flakes which help absorb vibration, but create stress concentrations which reduce strength. Widely used for engine blocks and machinery bases. Gray cast iron does not have a linear elastic stress-strain curve, so yield strength is not reported. The stress-strain curve is a continuous arc. |
| **Aluminum alloys** | |
| 2024-T4 | Contains 4.4% copper, 1.5% magnesium, 0.6% manganese. Used widely in the aircraft industry owing to its high strength to weight ratio. T4 heat treatment quadruples yield strength of the soft annealed condition. |
| 6061-T6 | Contains 1% magnesium, 0.6% silicon, 03% copper, 0.2% chromium. Used in canoes, trucks, pipelines, and other structural applications where good strength to weight ratio, corrosion resistance, and weldability are needed. T6 heat treatment increases yield strength 2½ times that of the soft annealed condition. |
| 7075-T6 | Contains 5.6% zinc, 2.5% magnesium, 1.6% copper, 0.23% chromium. Used widely in the aircraft industry owing to its high strength to weight ratio and corrosion resistance. T6 heat treatment quadruples yield strength of the soft annealed condition. |
| **Magnesium alloys** | |
| AZ80A | Contains 8.5% aluminum, 0.5% zinc. Commonly used as an extrusion. T5 heat treatment increases strength about 10%. |
| **Copper alloys** | |
| C26000 cartridge brass | Contains 70% copper, 30% zinc. Cold work (rolling) and heat treatment can substantially change mechanical properties. Widely used in electrical, hardware, ammunition (hence the name), plumbing, and automotive industries. Susceptible to stress-corrosion cracking in the presence of ammonia. |
| C63000 aluminum bronze | Contains 82% copper, 10% aluminum, 5% nickel, 3% iron. Used for pump parts, valve seats, faucet balls, gears, cams, and steam condensers. |
| **Titanium alloys** | |
| Ti-6Al-4V | Titanium alloys are expensive to produce, in part because liquid titanium is explosive in air. Ti-6-4 is widely used in the aerospace industry because it has half the density of steel, but higher strength and stiffness (Young's modulus and shear modulus) than aluminum aerospace alloys. |
| **Concrete & Stone** | |
| Unreinforced concrete | 10 times stronger in compression than in tension; commonly reinforced with steel to improve tensile strength. Wet curing increases strength as the concrete ages; 90% of strength reached within 28 days of pouring. |
| Granite | Igneous rock. Hard, strong, durable material used for building exteriors and curbstones. Resistant to acid rain. |
| Limestone | Sedimentary rock. Softer than granite, used for building exteriors and gravel for paving. Sensitive to acid rain. |
| Sandstone | Sedimentary rock. Easier to carve than other rock. Used for paving and building exteriors. |

For more information, consult ASTM Standards, SAE Standards, the ASM Handbook series published by ASM International, and other engineering handbooks.