Machinability

Machinability

Machinability is the ease with which a given material may be worked with a cutting tool

Machinability ratings (MR) provide and understanding of the severity of a metalworking operation in comparison to B1112 steel

Factors affecting machinability include tool material, feeds, speeds, cutting fluids, and the microstructure, grain size, heat treatment, chemical composition, fabrication methods, hardness, yield strength, and tensile strength of the work piece

Machinability (Tool Life)

The Taylor tool life equation describes the expected tool life of a cutting tool as a function of cutting speed

Inverse slope of the tool life (log/log) – constant for a given tool material

Cutting speed
[m/min] or [ft/min]

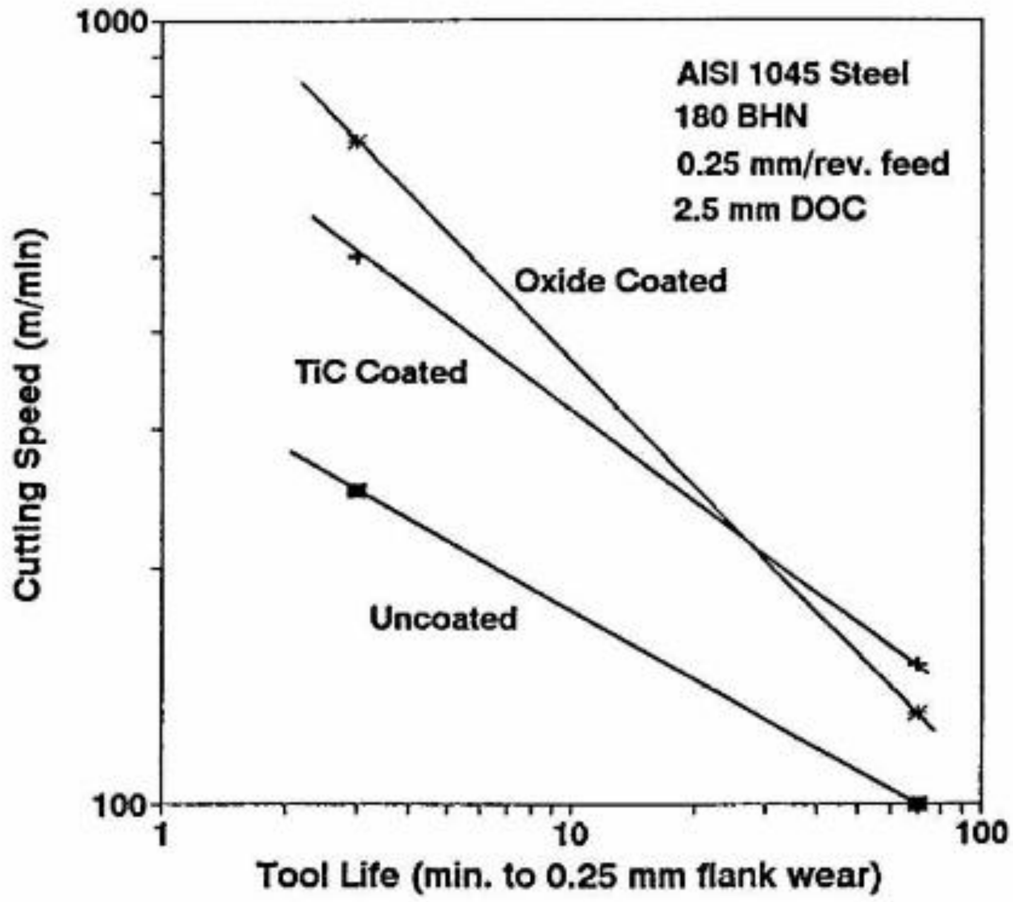
$$vT^n = C$$

Tool life
[min]

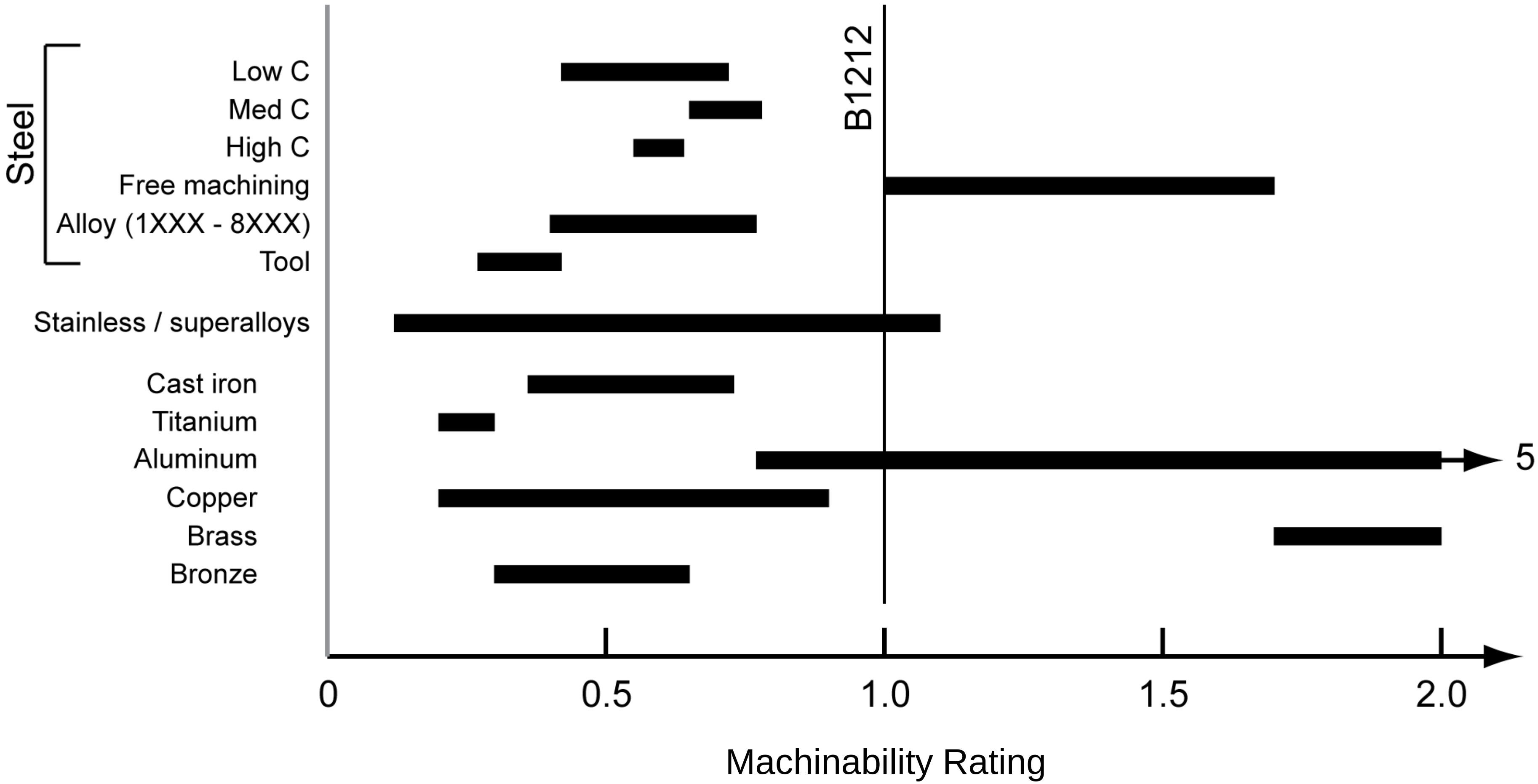
Constant, y-intercept at T=1 min, dependent on tool material, work material, cutting conditions

Machinability (Tool Life)

Tool life for coated and uncoated WC cermet cutting bits against 1045 steel

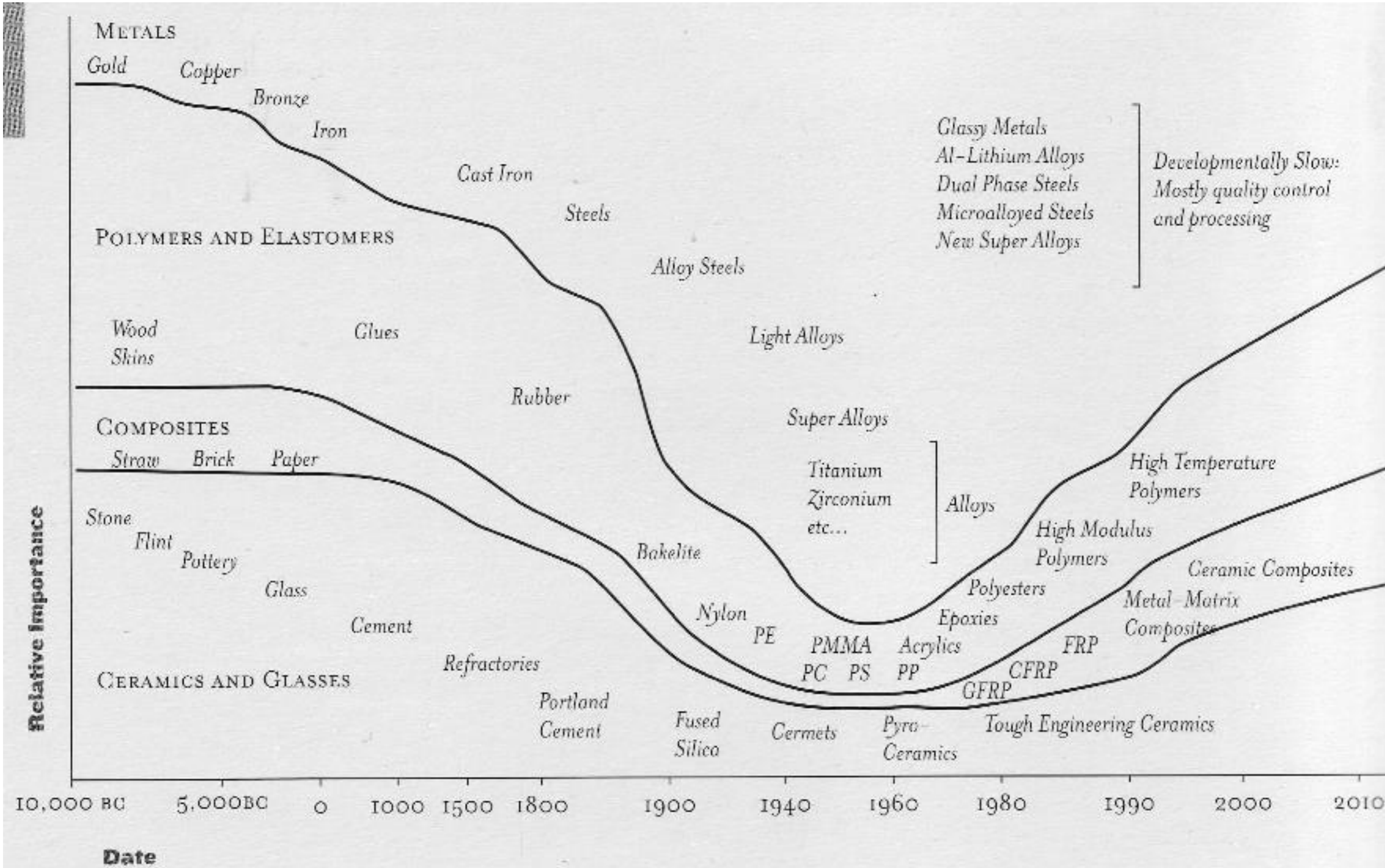


Machinability of Various Metals




Metals

Materials Importance Over Time



Physical Properties of Metals

Strength

Elasticity / stiffness

Brittleness / ductility

Density

Conductivity (electrical and thermal)

Stability (chemical, corrosion, food safety)

Machinability / weldability

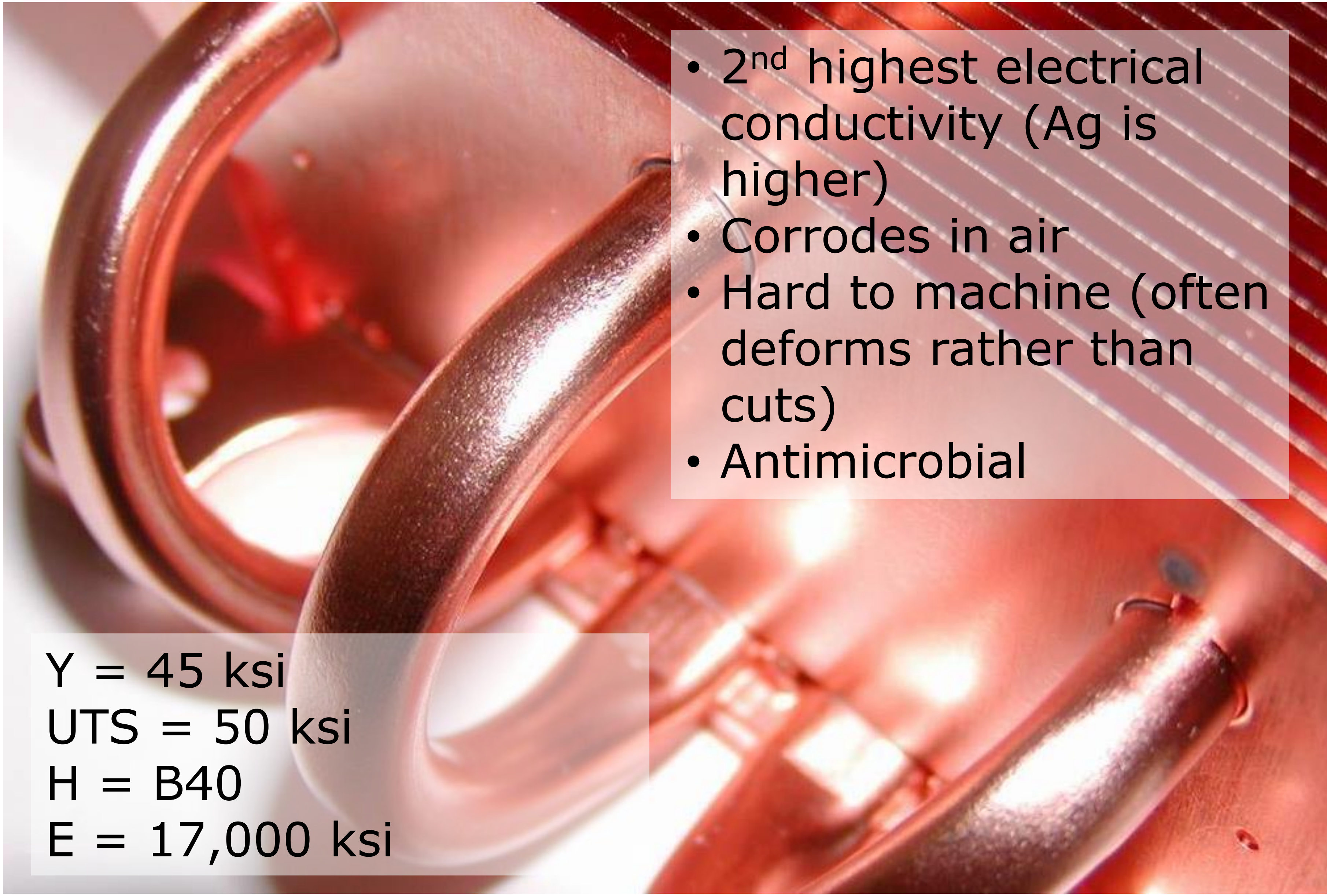
Cost

Combustibility

Melting point

Thermal expansion

Copper



- 2nd highest electrical conductivity (Ag is higher)
- Corrodes in air
- Hard to machine (often deforms rather than cuts)
- Antimicrobial

Y = 45 ksi
UTS = 50 ksi
H = B40
E = 17,000 ksi

Types of Copper

Identification	**Properties**
C10100 (oxygen free copper, OFE)	99.99% pure with less than 0.0005% O, expensive, used in high vacuum components as it does not outgas
C11000 (electrolytic tough pitch, ETP, ultraconductive copper)	Unalloyed, 99.9% pure, high ductility, corrosion resistance, poor machinability, excellent forming characteristics
C14500 (tellurium copper, TelCu)	Corrosion resistant, 0.5% tellurium, 1.0 MR

Brass

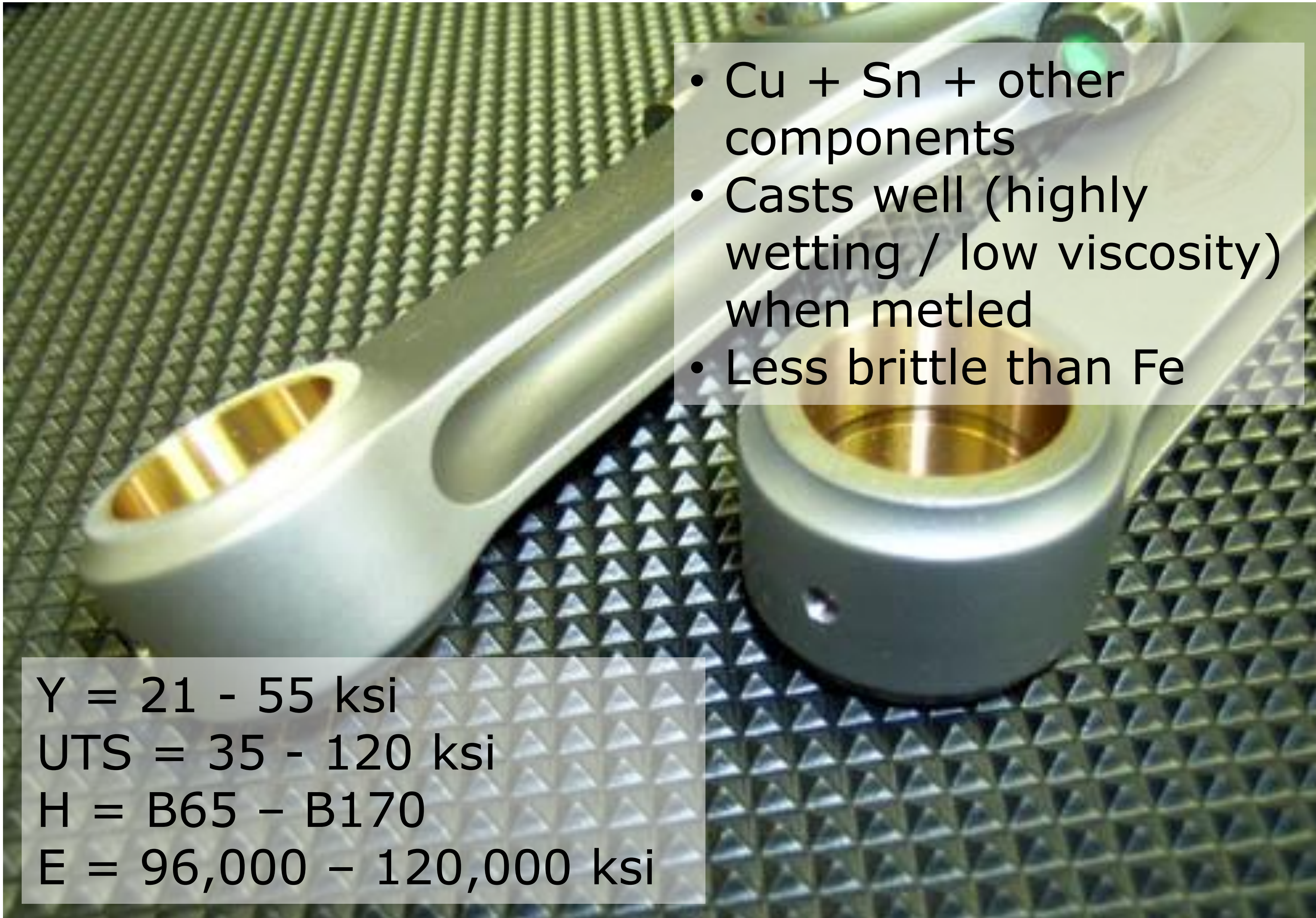
- Alloy of Cu and Zn (Zn ~5 – 50% by wt)
- Can be highly polished and easily plated (Au or Ag)
- Easily machined

Y = 45 – 57 ksi
UTS = 50 – 70 ksi
H = B60 - B100
E = 14,500 – 18,500 ksi

Types of Brass

Identification	**Properties**
230 (red brass)	Reddish in color, Cu (84-86%) / Zn (15%) / Fe (0.05% min) / Pb (0.06% min), high strength brass
260 (yellow / cartridge brass)	Used in shell casings, low MR, good formability and workability, Cu / Zn (28-32%) / Fe / Pb
353, 385, 360 (free machining, ultra-machinable brass)	Cu / Zn (35%) / Fe / Pb (2-4%), easily machinable, poor performance for forming operations
Alloy 485 (high-leaded naval)	Corrosion resistance via Sn, Cu (60%) / Zn (~40%) / Sn(0.7%)

Bronze



- Cu + Sn + other components
- Casts well (highly wetting / low viscosity) when metled
- Less brittle than Fe

Y = 21 - 55 ksi
UTS = 35 - 120 ksi
H = B65 – B170
E = 96,000 – 120,000 ksi

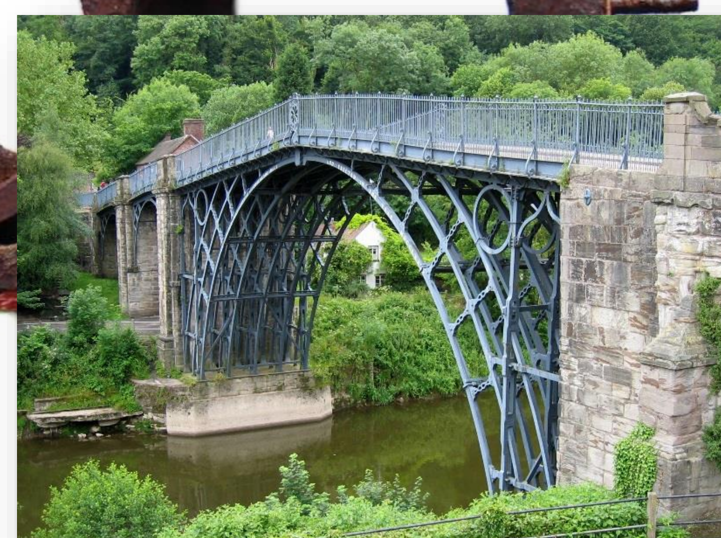
Types of Bronze

Identification	**Properties**
C863 (Manganese bronze)	High strength variant, Cu (60-80%) / Al (3-8%) / Fe (2-4%) / Mn (2-5%) / Zn (~25%)
C932 (Bearing bronze)	Used in bushings and bearings, highly machinable, Cu (81-85%), Sn (6-8%), Pb (6-8%), Zn (2-4%)
C954 (Aluminum bronze)	High strength and corrosion resistance, tarnish resistant, used in marine applications, Cu (83%), Fe (3-5%), Al (10-11.5%)

Cast Iron

- $Fe + C + Si$
- Brittle
- Low melting point
- Highly machinable
- Often cast

Y = 33 - 108 ksi
UTS = 25 - 135 ksi
H = B130 – B450
E = ~130,000 ksi

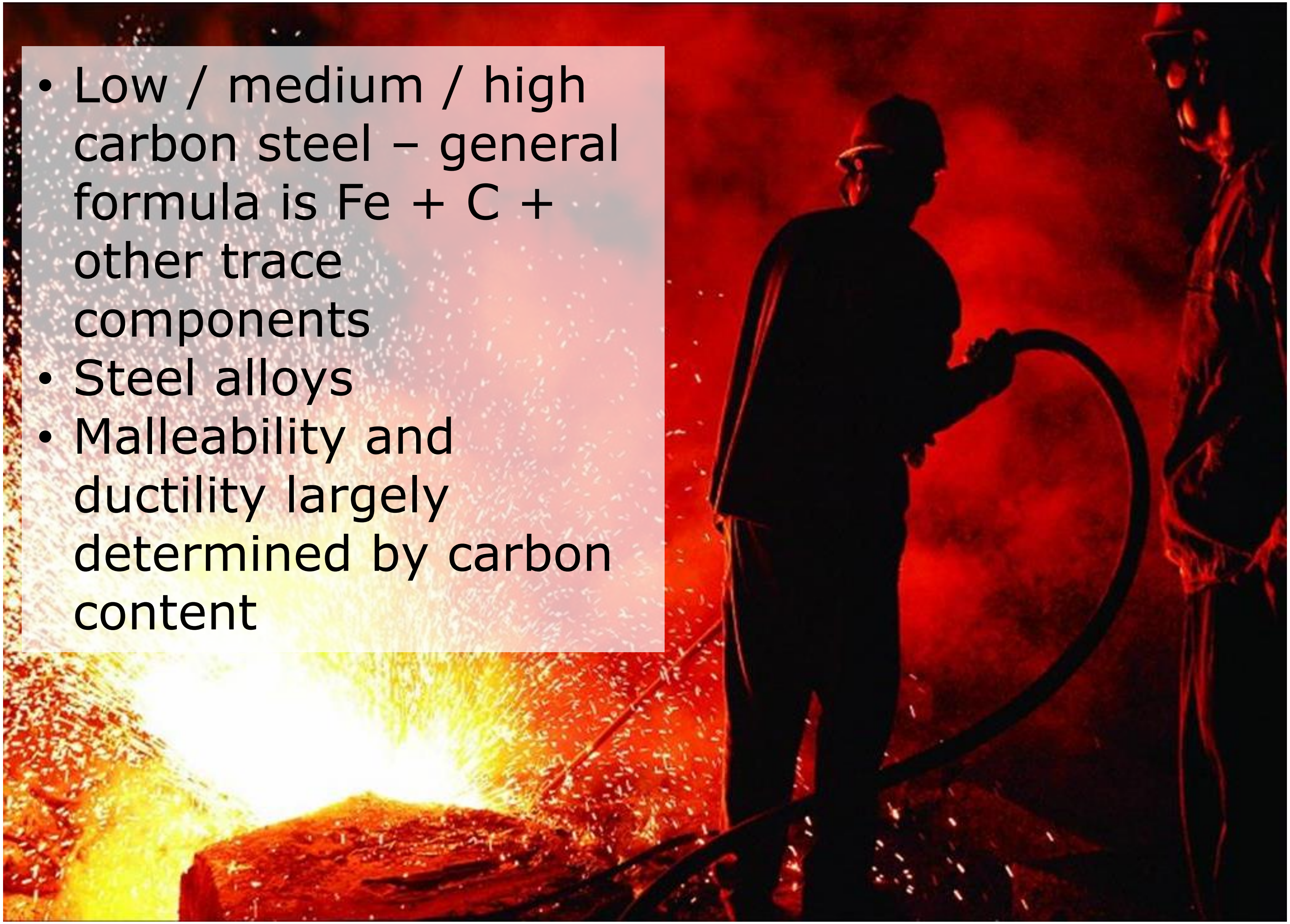


Types of Cast Iron

Identification	**Properties**
A48, Grey cast iron	Moderate hardness (B260), machine tool bases, cylinder blocks, Fe / C (3.4%) / Si (1.8%) / Mn (0.5%)
A47, Malleable iron	Low hardness, gears, crankshafts, Fe / C (2.5%) / Si (1%) / Mn (0.55%)
Ni-hard type 2	High strength applications, Fe / C (3%) / Si (2%) / Mn (1%) / Ni (20%) / Cr (2.5%)

Steel

- Low / medium / high carbon steel – general formula is Fe + C + other trace components
- Steel alloys
- Malleability and ductility largely determined by carbon content



Steel Production

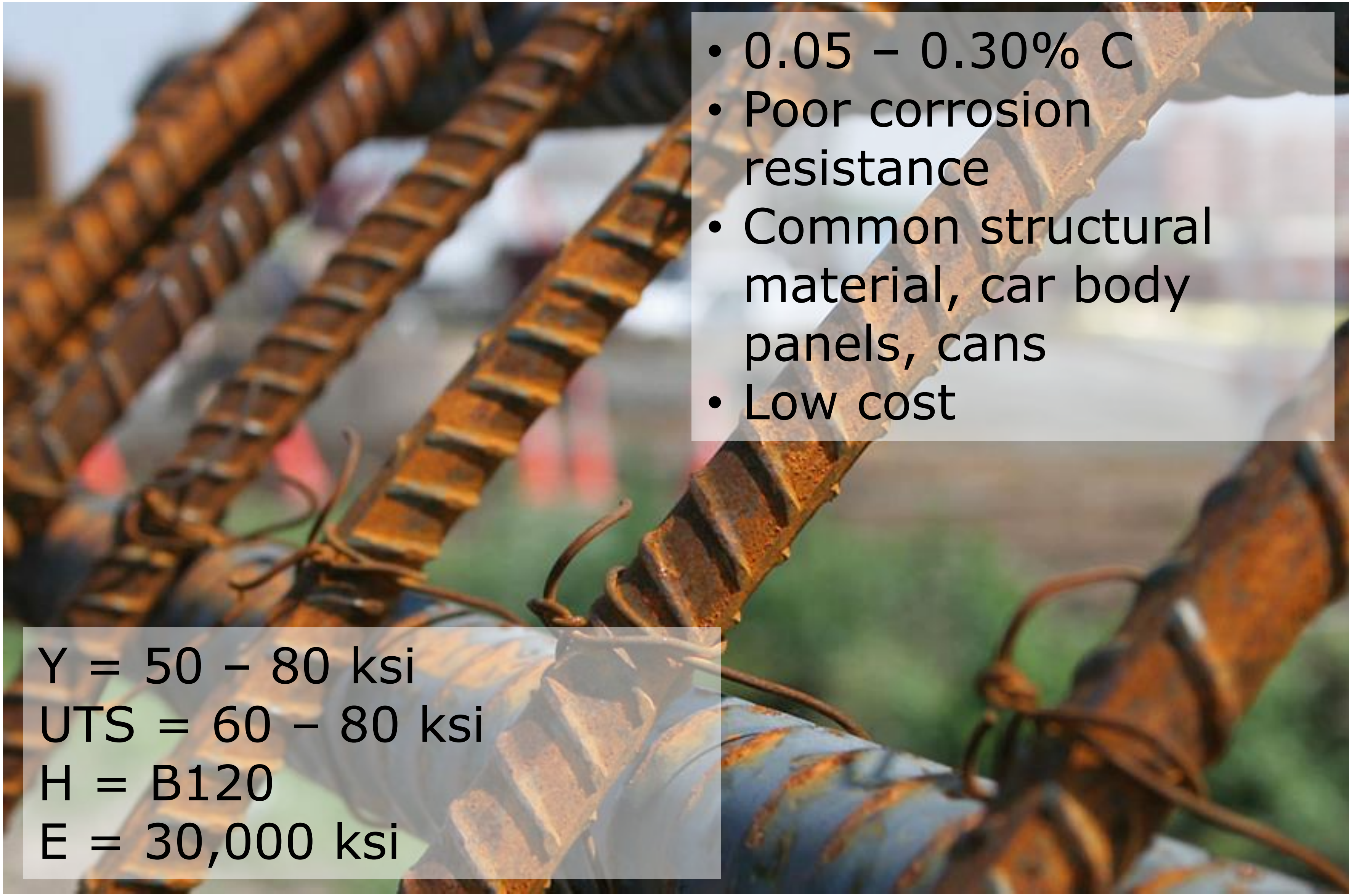
Continuous casting

Hot rolling

Cold rolling = room temperature, work hardening, high quality surface finish

Hot rolling = high temperature, no work hardening, scaly finish

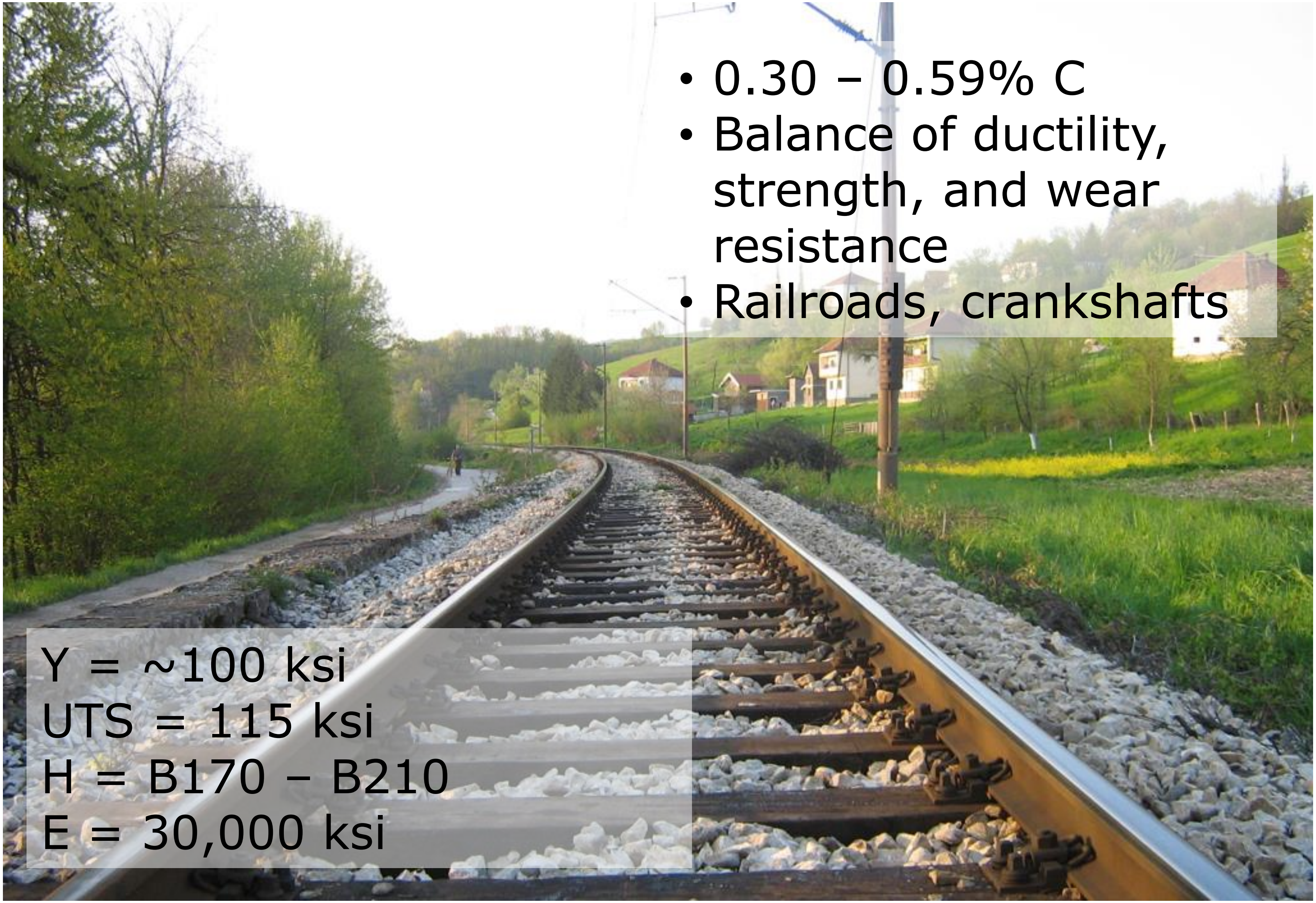
Low Carbon / Mild Steel



- 0.05 – 0.30% C
- Poor corrosion resistance
- Common structural material, car body panels, cans
- Low cost

Y = 50 – 80 ksi
UTS = 60 – 80 ksi
H = B120
E = 30,000 ksi

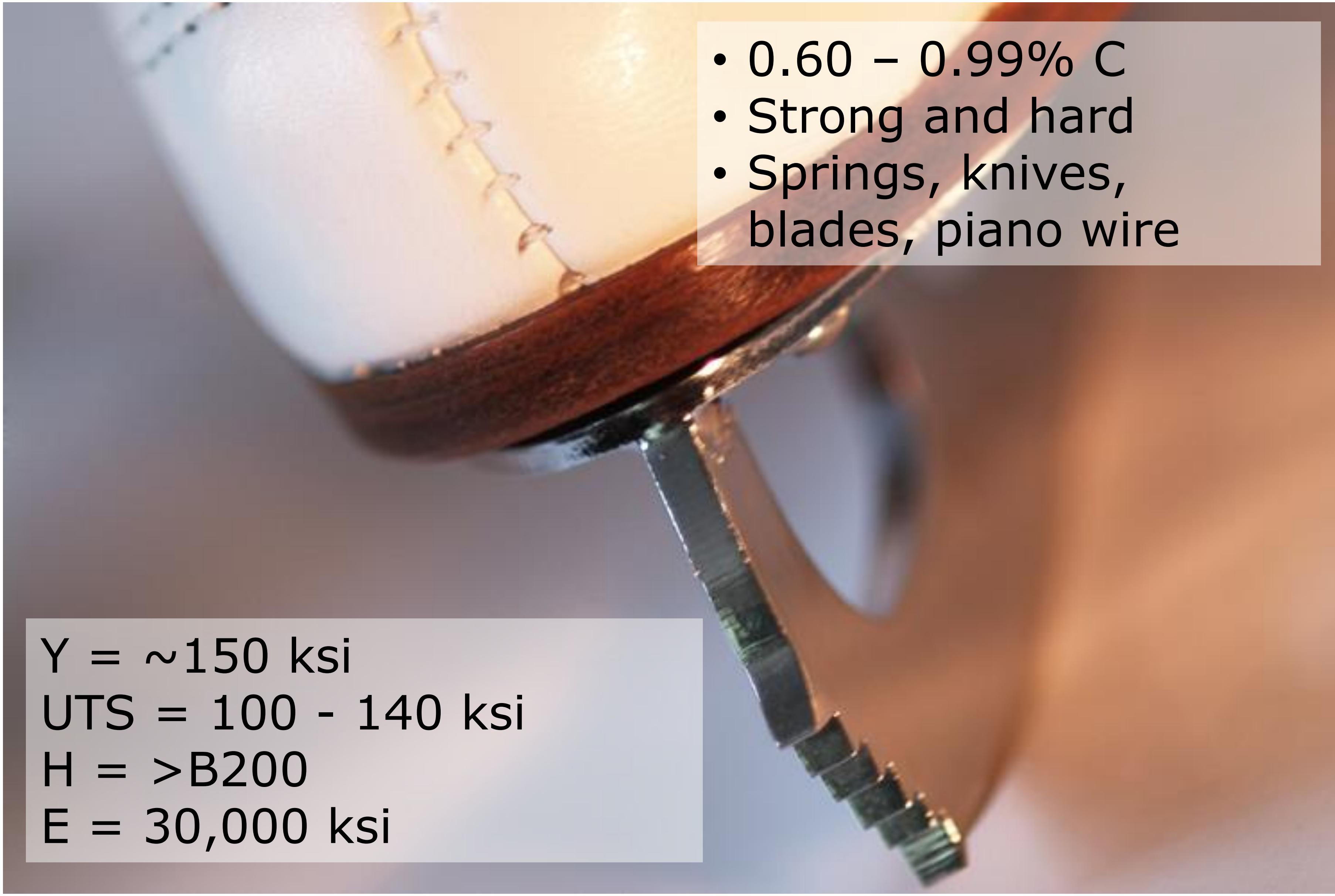
Medium Carbon Steel



- 0.30 – 0.59% C
- Balance of ductility, strength, and wear resistance
- Railroads, crankshafts

Y = ~100 ksi
UTS = 115 ksi
H = B170 – B210
E = 30,000 ksi

High Carbon Steel



- 0.60 – 0.99% C
- Strong and hard
- Springs, knives, blades, piano wire

Y = ~150 ksi
UTS = 100 - 140 ksi
H = >B200
E = 30,000 ksi

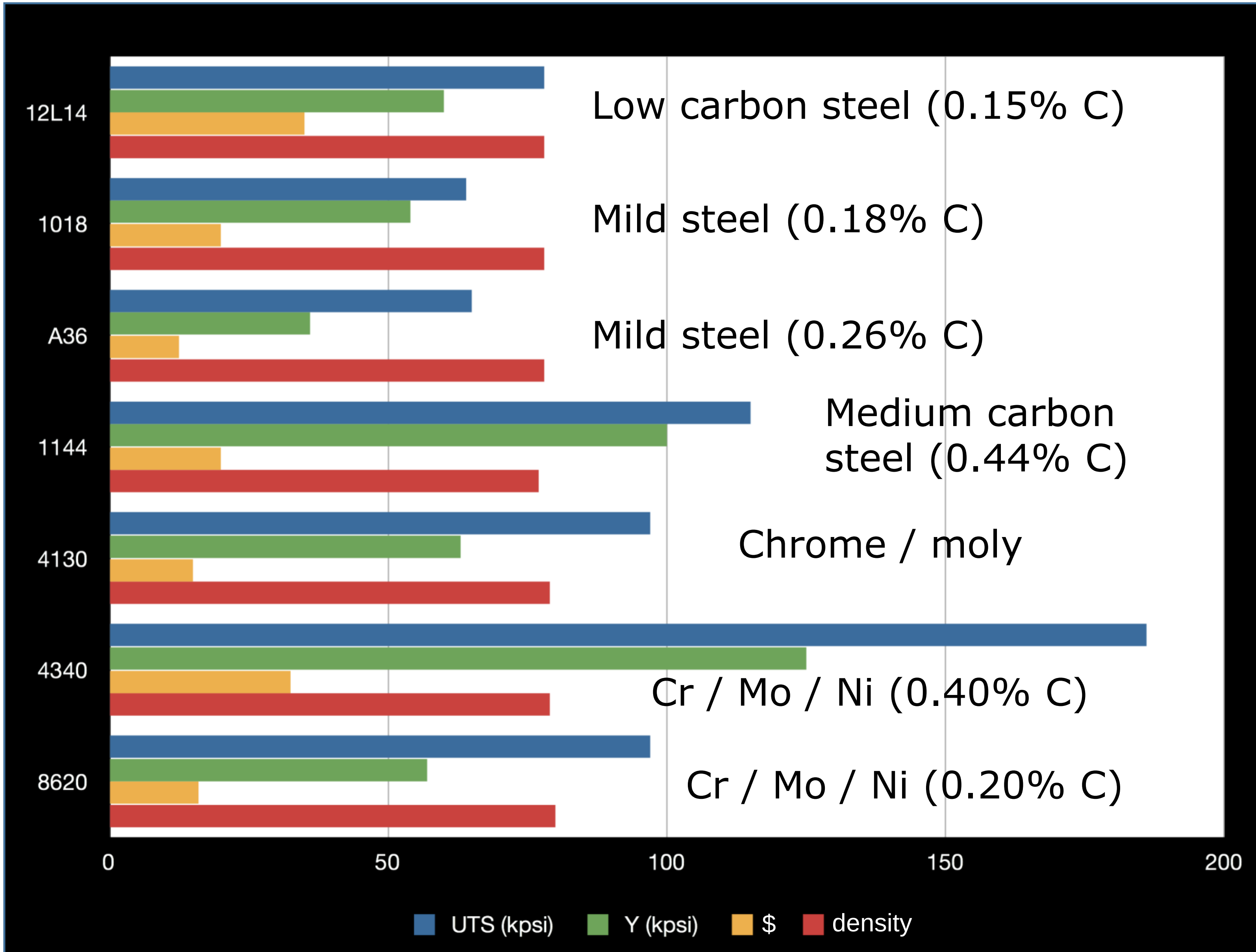
Steel and Alloy Steel Designations

SERIES	***STEEL TYPE***
1XXX, 11XX	**Plain carbon (non alloy) steel**
13XX	**Manganese steel**
2XXX	**Nickel alloy steels**
23XX	**3.5% Nickel**
25XX	**5.0% Nickel**
3XXX	**Nickel/Chrome steels**
4XXX	**Molybdenum steels**
40XX	**Carbon/Moly**
41XX	**Chrome/Moly**
43XX	**Chrome/Moly/Nickel**
46XX or 48XX	**Moly/Nickel**
5XXX	**Chromium alloy steels**
51XX	**Low Chromium content**
52XX	**Medium Chromium content**
53XX	**High Chromium content**
6XXX	**Chromium/Vanadium alloy steels**
86XX or 87XX	**Nickel/Chromium/Moly alloy steels**
92XX	**Manganese/Silicon alloy steels**

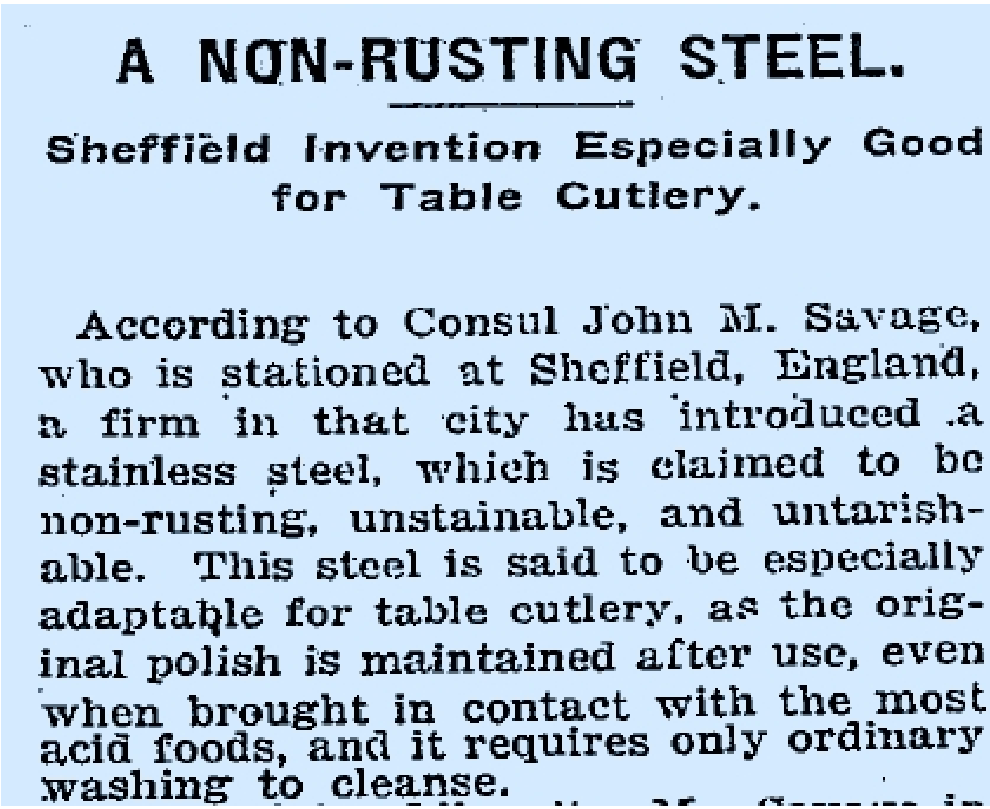
Tool Steels

LETTER	***STEEL TYPE***
A	**Air-hardening steels**
D	**Die steel alloys**
F	**Carbon/Tungsten alloys**
H	**Hot work alloys**
L	**Low alloy**
M	**Molybdenum alloys**
O	**Oil hardening steels**
P	**Mold steel alloys**
S	**Shock resistant alloys**
T	**Tungsten alloys**
W	**Water hardening steel**

Comparison of Steel Properties



Stainless Steel



A NON-RUSTING STEEL.

Sheffield Invention Especially Good for Table Cutlery.

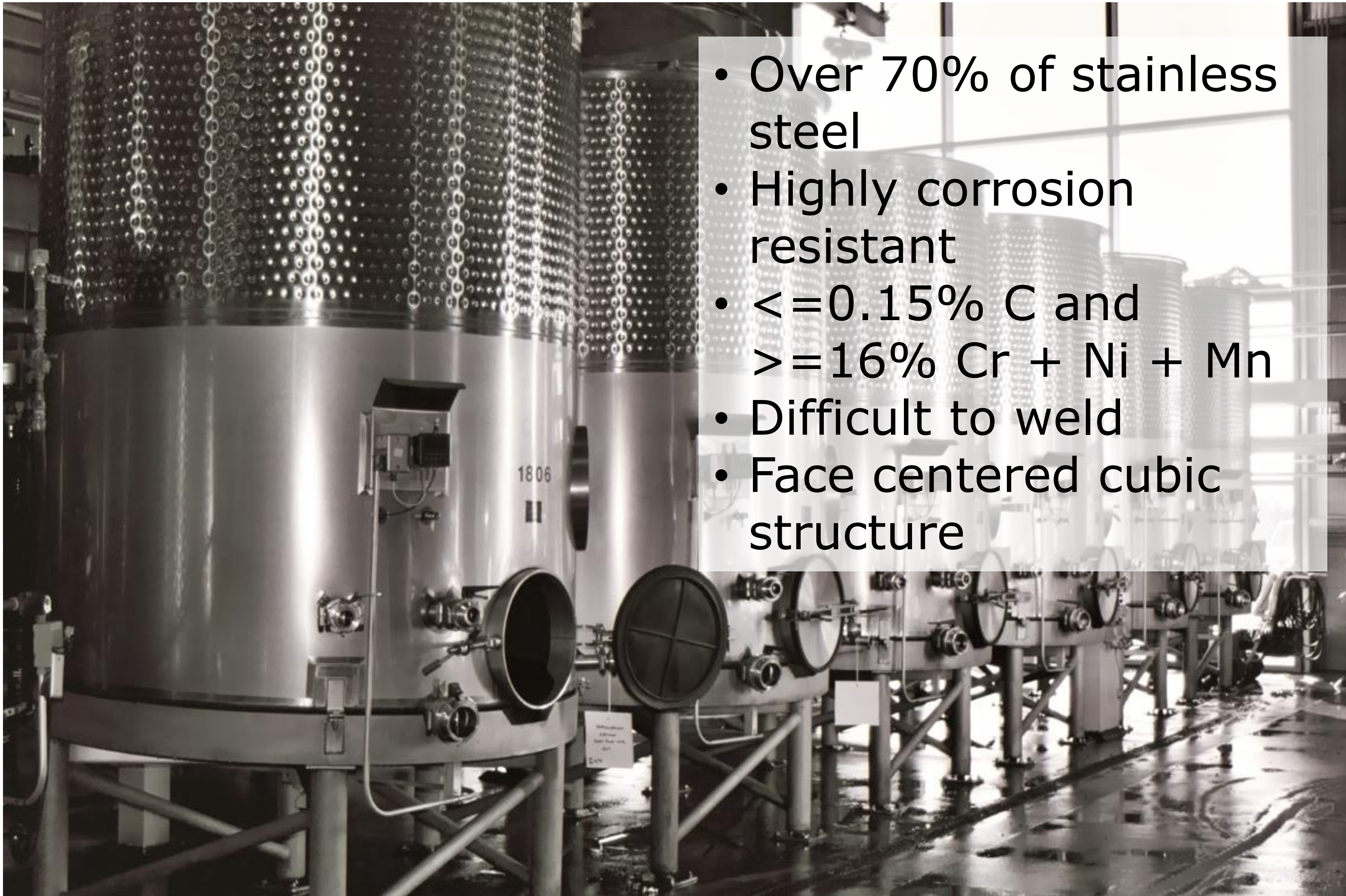
According to Consul John M. Savage, who is stationed at Sheffield, England, a firm in that city has introduced a stainless steel, which is claimed to be non-rusting, unstainable, and untarishable. This steel is said to be especially adaptable for table cutlery, as the original polish is maintained after use, even when brought in contact with the most acid foods, and it requires only ordinary washing to cleanse.

New York Times, Jan. 31, 1915

- Minimum 10% Cr by mass
- Corrosion-resistant
- Higher strength
- Higher cost
- Hard to machine

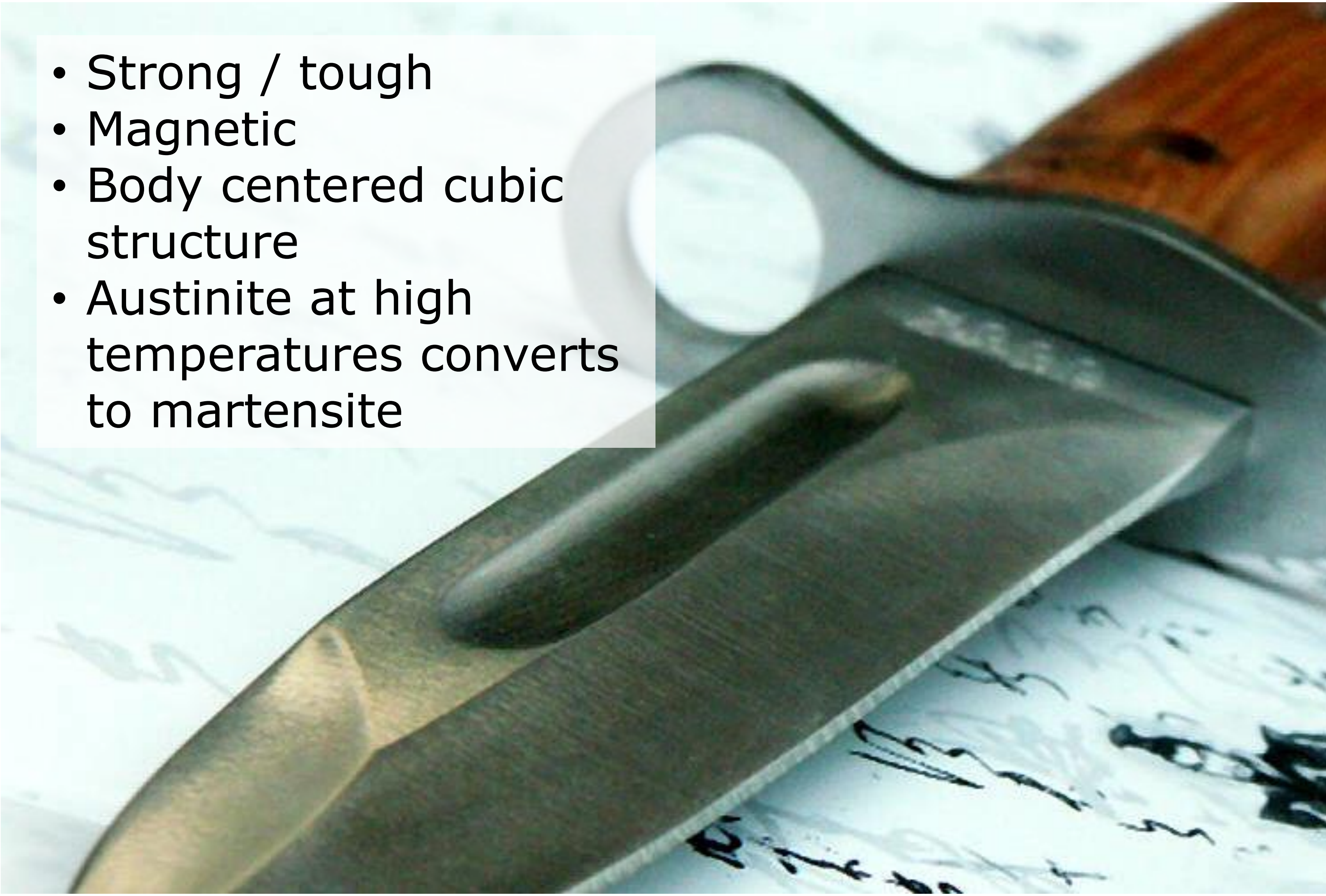
St. Louis Gateway Arch (1965)

Austinitic Stainless Steel



- Over 70% of stainless steel
- Highly corrosion resistant
- <=0.15% C and >=16% Cr + Ni + Mn
- Difficult to weld
- Face centered cubic structure

Martensitic Stainless Steel

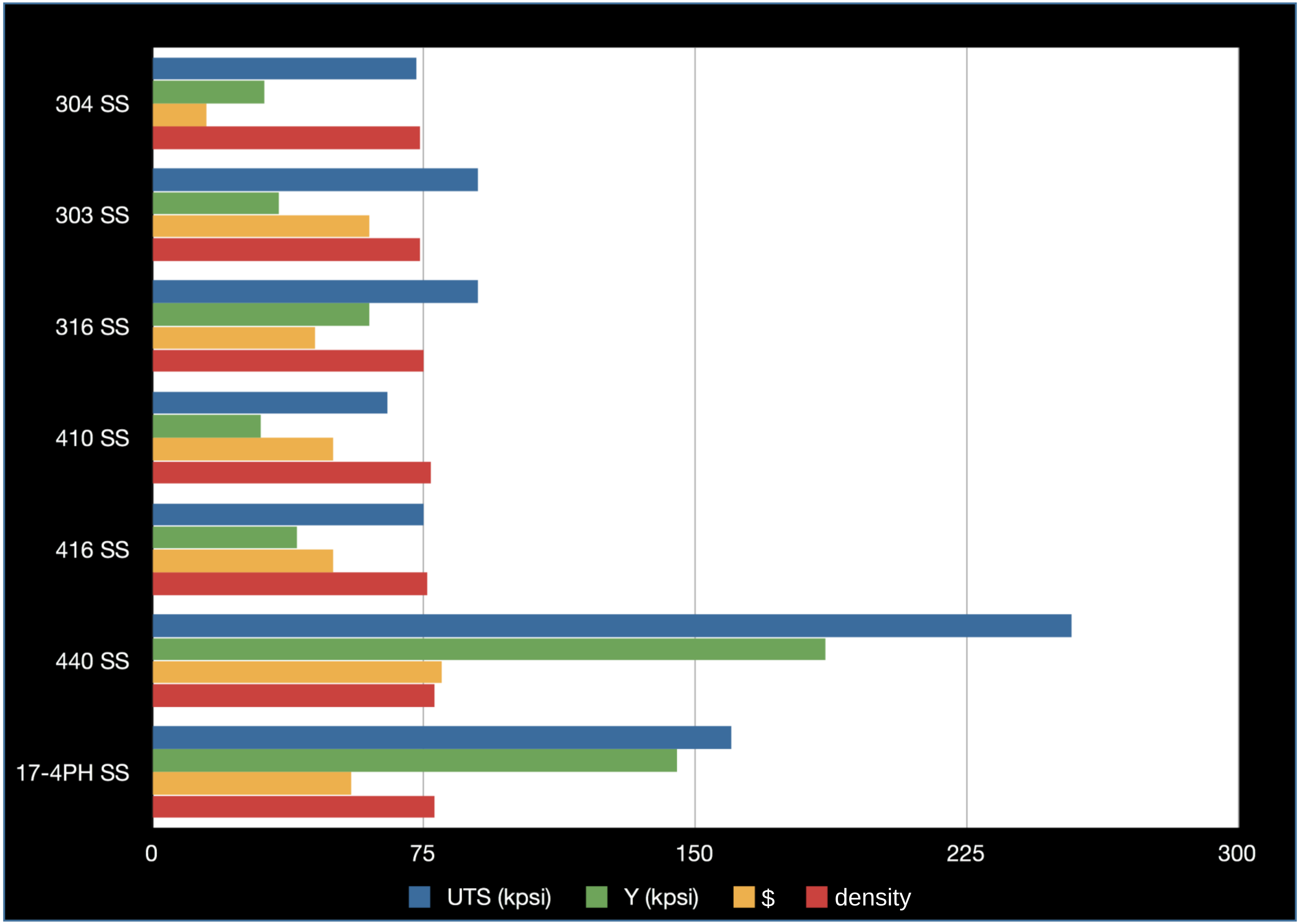


- Strong / tough
- Magnetic
- Body centered cubic structure
- Austinite at high temperatures converts to martensite

Types of Stainless Steel

Identification	Properties
303 (aus)	304 + S + P, free machining, difficult to weld
304 or 18/8 (aus)	Most common grade, forks, knives, weldable, corrodes in saltwater environments, 18% Cr and 8% Ni
316 (aus)	Marine grade, Mo provides corrosion resistance, food/surgical uses, machinability similar to 304
410 (mart)	Wear resistant, machinable, poor corrosion resistance
416 (mart)	+Si + S for easier machining
440 (mart)	Razor blade steel, high carbon content, poor machinability and weldability
17-4PH (mart)	Precipitation hardening, aircraft industry

Comparison of SS Properties



Aluminum

- Most abundant metallic element on Earth’s crust
- Annealed state is “gummy”
- Often alloyed with Si, Mg, Zn, and/or Cu to improve physical properties
- Inexpensive

Y = 40 – 80 ksi
UTS = 45 – 80 ksi
H = B95
E = 10,000 ksi

Types of Aluminum

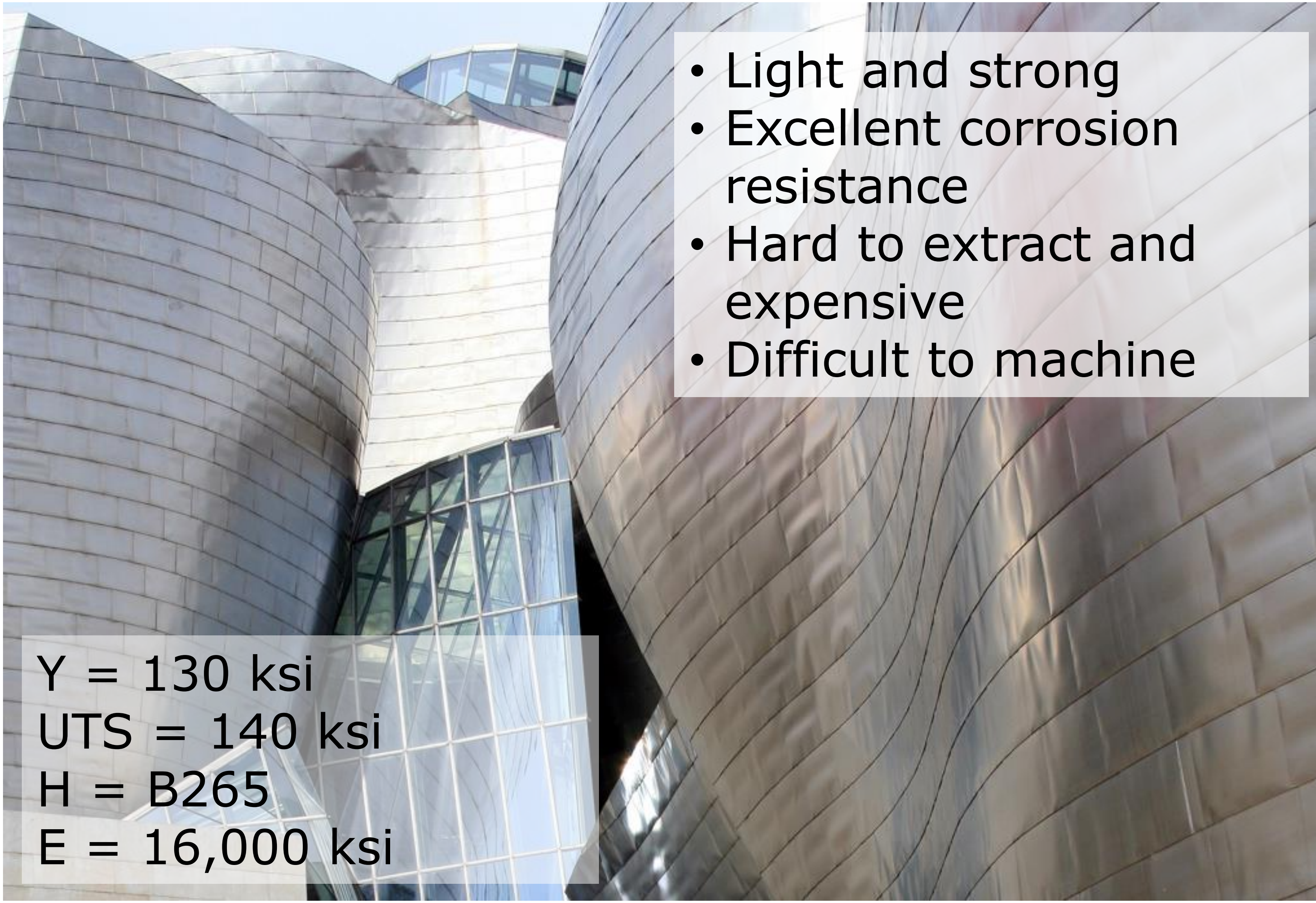
Identification	Properties
2024	High strength, fatigue resistance, susceptible to corrosion (due to Cu), not weldable, +Cu (4.4%), Mg (1.4%), Mn (0.5%), traces of Si, Zn, Ni, Cr, Pb, Bi
6061	Most common, highly machinable, weldable, can be anodized, +Si (0.4 – 0.8%), Fe (0.7%), Cu (0.4%), Mn (0.15%), Mg (1%), Cr, Zn, Ti
7075	Aircraft grade, high strength, Zn (6%), Mg (2.3%), Cu (1.4%), traces of Si, Fe, Mn, Ti, Cr +others

Magnesium

- Best strength/weight ratio of all structural materials (1/4 weight of steel, 1/3 weight of Al)
- Chips highly flammable
- Used in engine blocks (Porsche, BMW, Corvette) and German military aircraft (WWI and WWII)

Y = 7 ksi
UTS = 53 ksi
H = B70
E = 70,000 ksi

Titanium



- Light and strong
- Excellent corrosion resistance
- Hard to extract and expensive
- Difficult to machine

Y = 130 ksi
UTS = 140 ksi
H = B265
E = 16,000 ksi