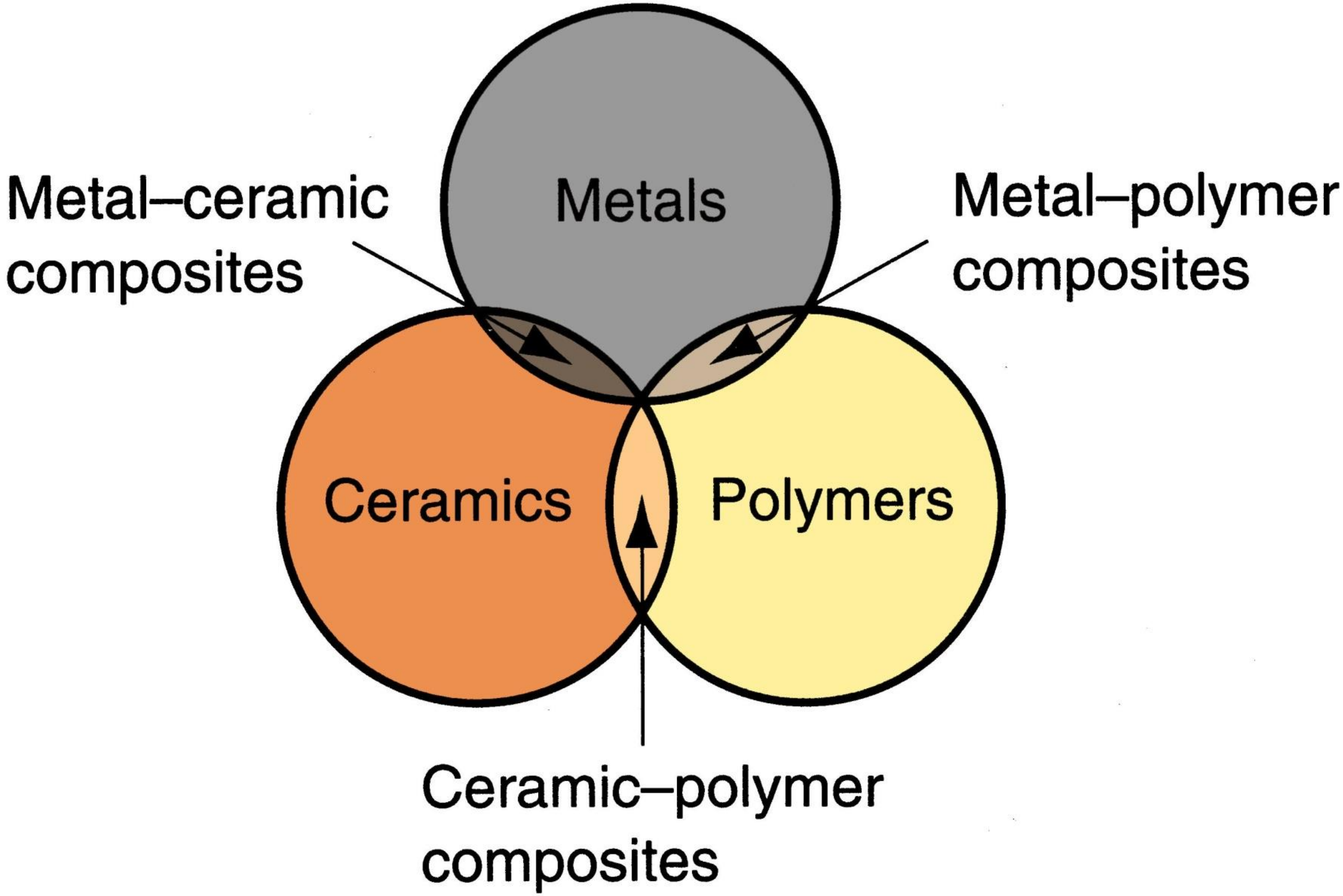
RET Lec 3: Engineering Materials

1) Nature of material
2) Mechanical properties
3) Effect of temperature
4) Metals
5) Polymers
6) Material comparison
7) Effect on manufacturing



Engineering materials: metal, ceramic, polymer

Natural materials: wood, clay, rock, bone…

Engineering materials: metal, ceramic, plastic, natural material and composites

Ranking: 10 (best)

Materials	Metal	Ceramic	Polymers	Natural
Strength (Pa, psi)	8	10	5	3
Hardness (Brinell, Rockwell, Shore…)	7	10	4	2
Ductility (%)	5	1	10	6
Density (g/cm^3, lbm/in^3)	10	6	3	1
Specific strength	3	6	8	10
Isotropy (uniformity)	7	7	9	4
Application temperature (°F, °C)	8	10	6	2

TABLE 3.2 Yield strength and tensile strength for selected metals.

Metal	Yield Strength MPa	Yield Strength (lb/in.^{2})	Tensile Strength MPa	Tensile Strength (lb/in.^{2})	Metal	Yield Strength MPa	Yield Strength (lb/in.^{2})	Tensile Strength MPa	Tensile Strength (lb/in.^{2})
Aluminum, annealed	28	(4,000)	69	(10,000)	Nickel, annealed	150	(22,000)	450	(65,000)
Aluminum, CW[a]	105	(15,000)	125	(18,000)	Steel, low C[a]	175	(25,000)	300	(45,000)
Aluminum alloys[a]	175	(25,000)	350	(50,000)	Steel, high C[a]	400	(60,000)	600	(90,000)
Cast iron[a]	275	(40,000)	275	(40,000)	Steel, alloy[a]	500	(75,000)	700	(100,000)
Copper, annealed	70	(10,000)	205	(30,000)	Steel, stainless[a]	275	(40,000)	650	(95,000)
Copper alloys[a]	205	(30,000)	410	(60,000)	Titanium, pure	350	(50,000)	515	(75,000)
Magnesium alloys[a]	175	(25,000)	275	(40,000)	Titanium alloy	800	(120,000)	900	(130,000)

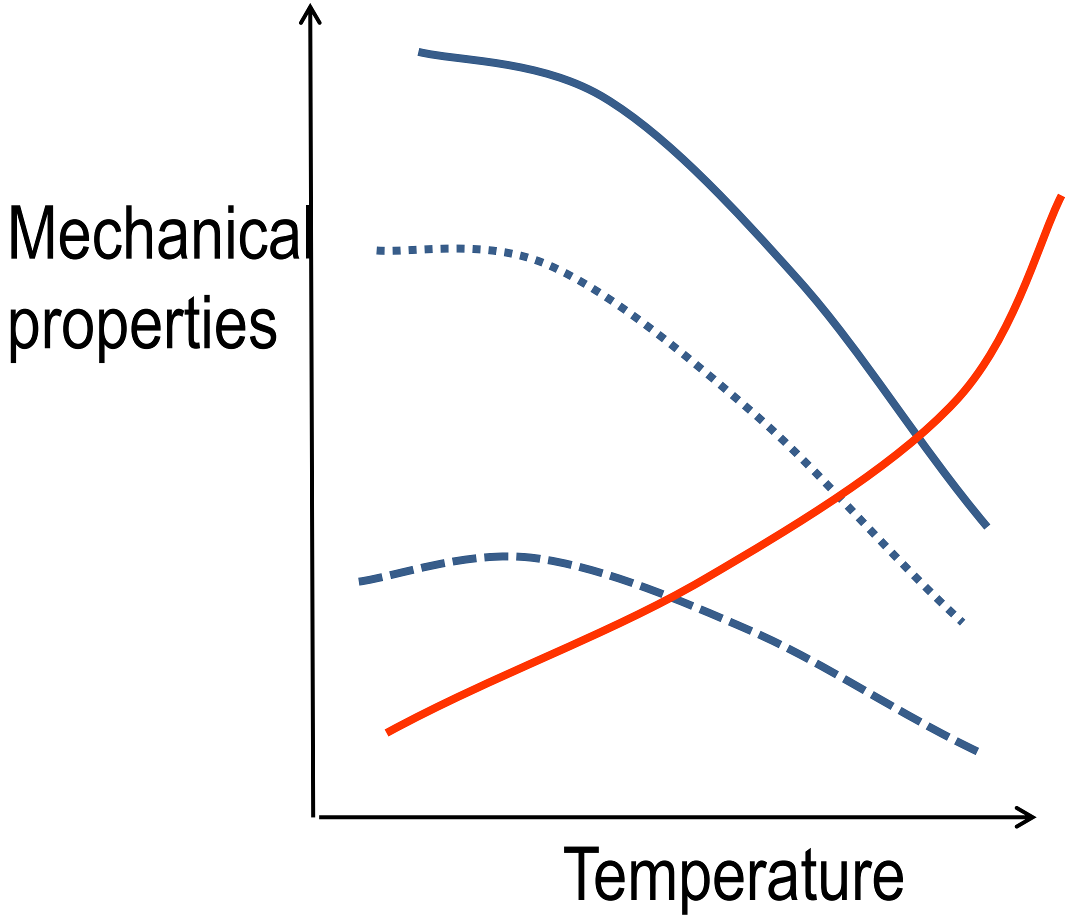
TABLE 3.3 Ductility as percent elongation (typical values) for various selected materials

Material	% elongation	Material	% elongation
Metals		***Metals,*** *continued*	
Aluminum, annealed	40	Steel, low C[a]	30
Aluminum, cold worked	8	Steel, high C[a]	10
Aluminum alloys, annealed[a]	20	Steel, alloy[a]	20
Aluminum alloys, heat treated[a]	8	Steel, stainless, austenitic[a]	55
Aluminum alloys, cast[a]	4	Titanium, nearly pure	20
Cast iron, gray[a]	0.6	Zinc alloy	10
Copper, annealed	45	***Ceramics***	0
Copper, cold worked	10	***Polymers***	
Copper alloy: brass, annealed	60	Thermoplastic polymers	100
Magnesium alloys[a]	10	Thermosetting polymers	1
Nickel, annealed	45	Elastomers (e.g., rubber)	1

3. Effects of temperature

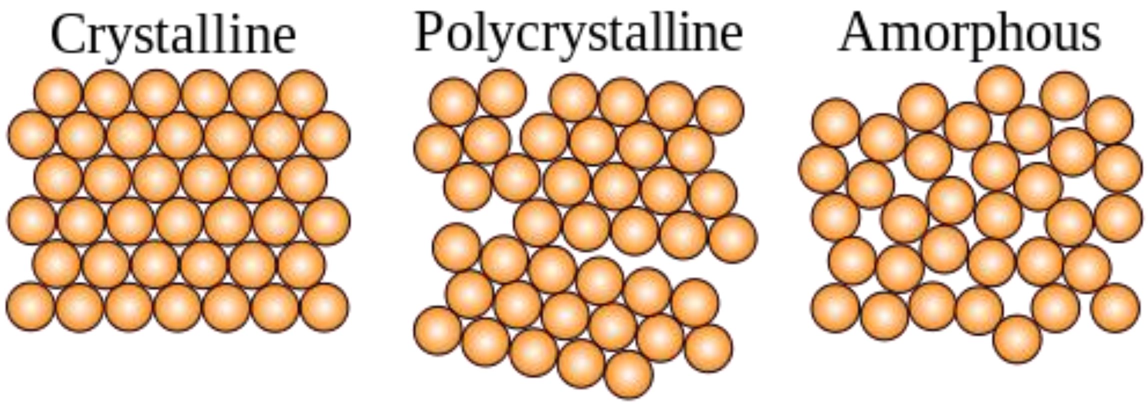
Hot
soft
ductile

Cold
hard
brittle



Metal & ceramic

Form by bonded atoms in space.

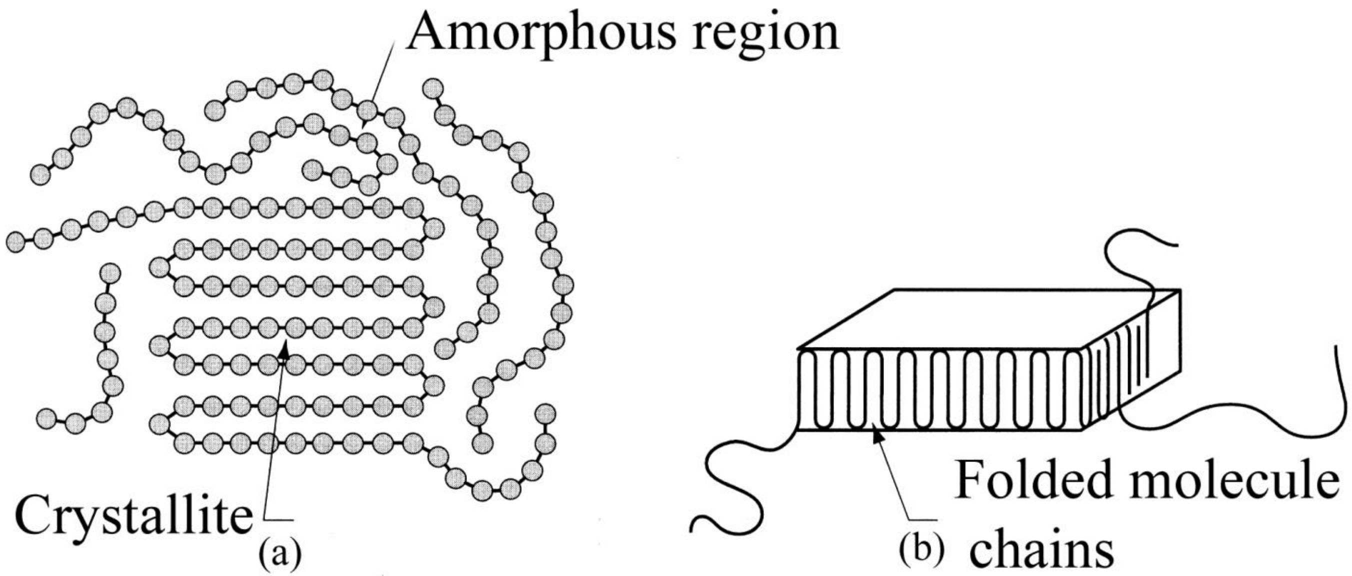


en.wikipedia.org

- Crystalline structure
  - ordered
  - 3D
  - metals, ceramics
- Amorphous structure
  - random
  - 3D
  - polymers, ceramics

Polymers

- Basic elements: C, H, O, N
- Polymerization: combine carbons and others to chain molecules.



More crystallinity → metal like

- Polymer types
  - Thermoplastics — Repeat heating/cooling, linear chains
  - Thermoset — Heat/cool once, cross-linked chains
  - Elastomers — Stretch >10x, coiled chains

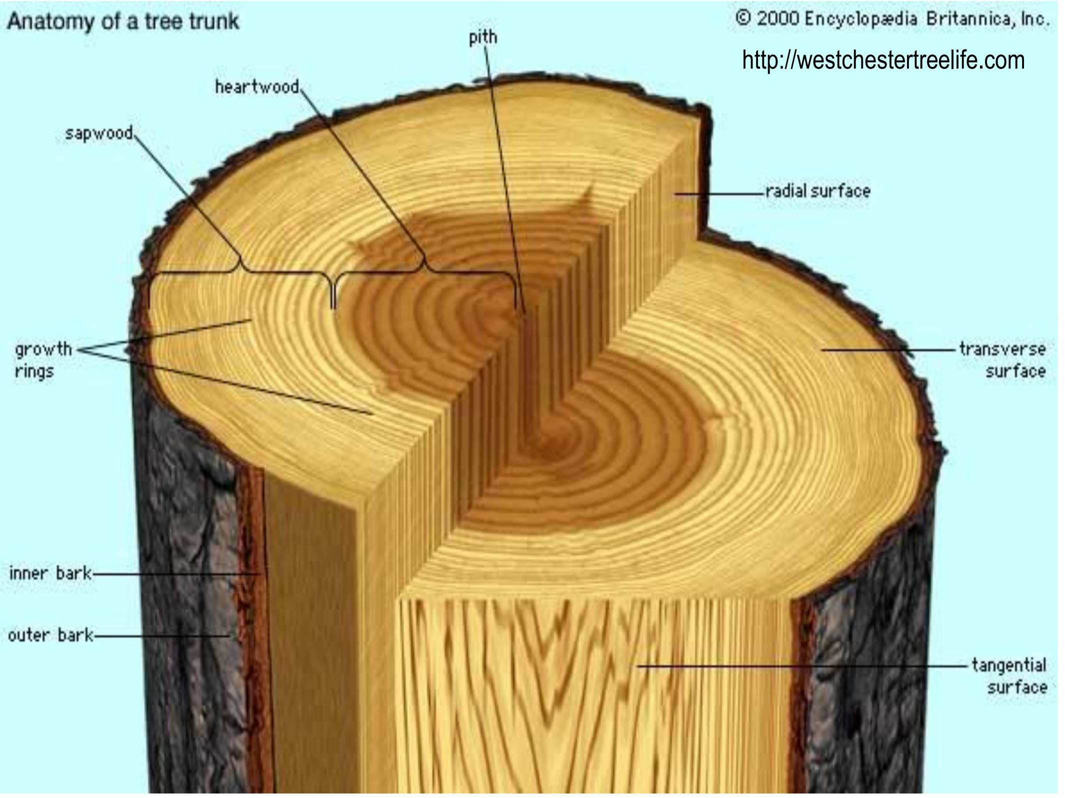
- Pro's & Con's

+ Low Tm for processing
+ High ductility
+ Light
+ No rust

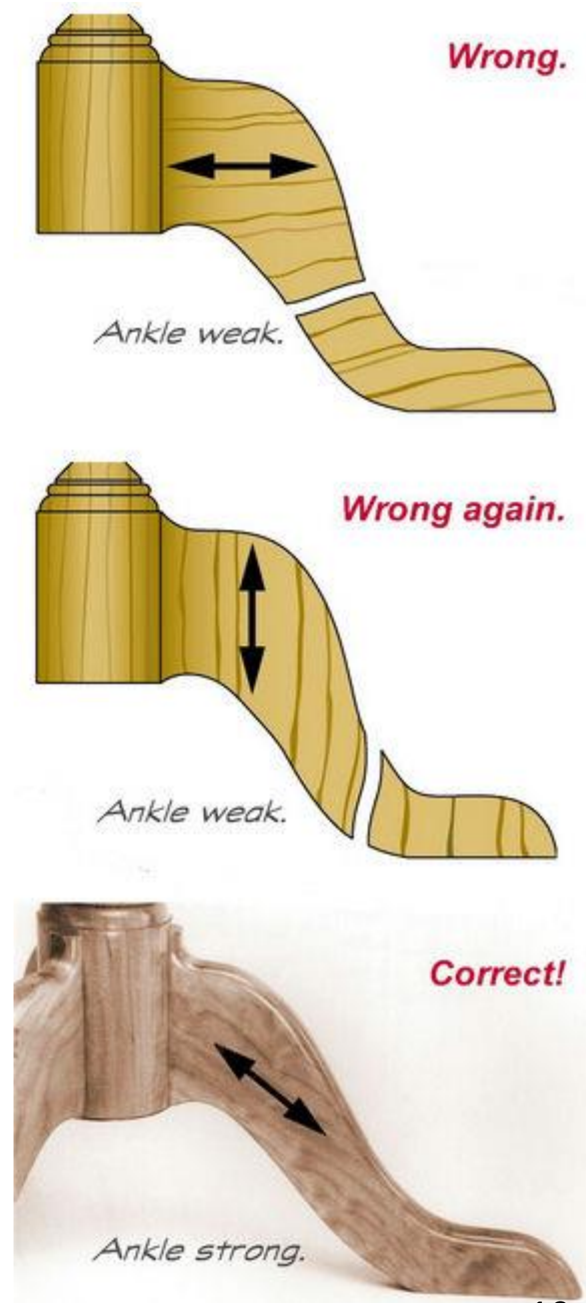
– Temp limited
– Low strength, hardness
– Degraded by UV light
– Nonconductive

Natural materials: wood, rock, sand, clay, bone, cotton…

- Hardwoods from deciduous trees (e.g., ash, beech, birch, mahogany, maple, oak, teak, and walnut).
- Softwoods from evergeen (coniferous) trees (e.g., cedar, cypress, fir, pine, spruce, and redwood).



- Wood is anisotropic. Its strength depends on loading directions (along or across the grains), or content of moisture /chemical treatment.



http://workshopcompanion.com/KnowHow/Design/Nature_of_Wood/3_Wood_Strength/3_Wood_Strength.htm

NORTH AMERICAN HARDWOODS

Wood Species	Specific Gravity*	Compressive Strength (psi)	Bending Strength (psi)	Stiffness (Mpsi)	Hardness (lb)
Alder, Red	0.41	5,820	9,800	1.38	590
Ash	0.60	7,410	15,000	1.74	1,320
Aspen	0.38	4,250	8,400	1.18	350
Basswood	0.37	4,730	8,700	1.46	410
Beech	0.64	7,300	14,900	1.72	1,300
Birch, Yellow	0.62	8,170	16,600	2.01	1,260
Butternut	0.38	5,110	8,100	1.18	490
Cherry	0.50	7,110	12,300	1.49	950
Chestnut	0.43	5,320	8,600	1.23	540
Elm	0.50	5,520	11,800	1.34	830
Hickory	0.72	9,210	20,200	2.16	†
Maple, Hard	0.63	7,830	15,800	1.83	1,450
Maple, Soft	0.54	6,540	13,400	1.64	950
Oak, Red	0.63	6,760	14,300	1.82	1,290
Oak, White	0.68	7,440	15,200	1.78	1,360
Poplar	0.42	5,540	10,100	1.58	540
Sassafras	0.46	4,760	9,000	1.12	†
Sweetgum	0.52	6,320	12,500	1.64	850
Sycamore	0.49	5,380	10,000	1.42	770
Walnut	0.55	7,580	14,600	1.68	1,010

http://workshopcompanion.com/KnowHow/Design/Nature_of_Wood/3_Wood_Strength/3_Wood_Strength.htm

NORTH AMERICAN SOFTWOODS

Wood Species	Specific Gravity*	Compressive Strength (psi)	Bending Strength (psi)	Stiffness (Mpsi)	Hardness (lb)
Cedar, Aromatic Red	0.47	6,020	8,800	0.88	900
Cedar, Western Red	0.32	4,560	7,500	1.11	350
Cedar, White	0.32	3,960	6,500	0.80	320
Cypress	0.46	6,360	10,600	1.44	510
Fir, Douglas	0.49	7,230	12,400	1.95	710
Hemlock	0.45	7,200	11,300	1.63	540
Pine, Ponderosa	0.40	5,320	9,400	1.29	460
Pine, Sugar	0.36	4,460	8,200	1.19	380
Pine, White	0.35	4,800	8,600	1.24	380
Pine, Yellow	0.59	8,470	14,500	1.98	870
Redwood	0.35	5,220	7,900	1.10	420
Spruce, Sitka	0.40	5,610	10,200	1.57	510

http://workshopcompanion.com/KnowHow/Design/Nature_of_Wood/3_Wood_Strength/3_Wood_Strength.htm

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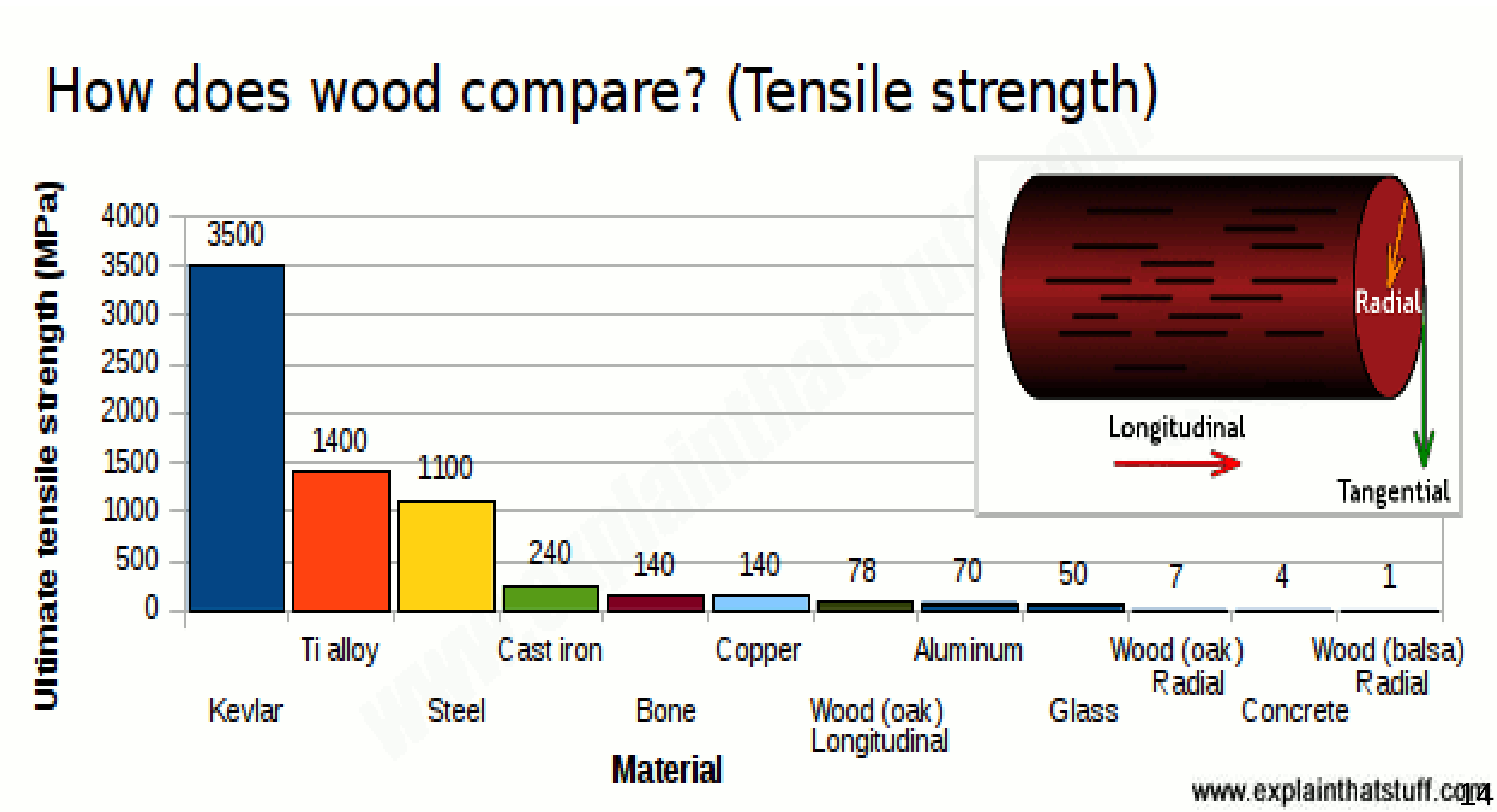
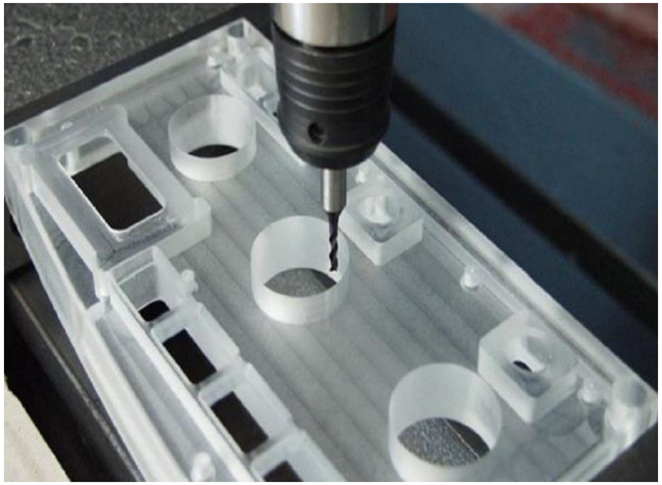
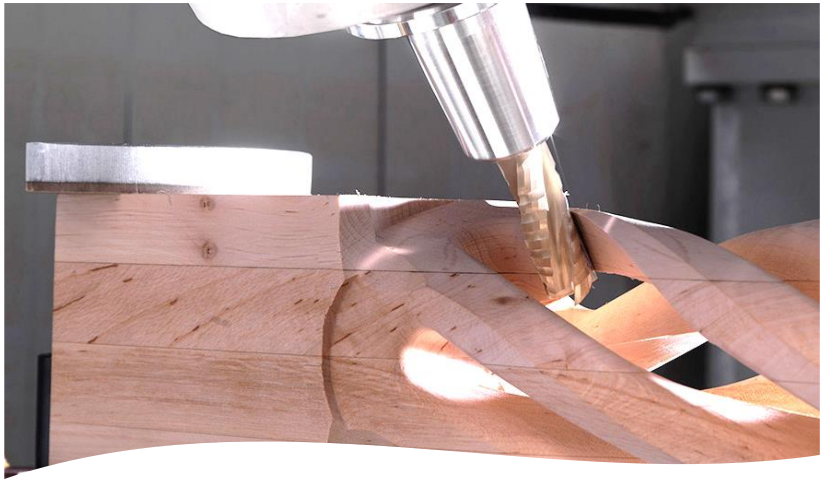


Machinability

- Metals. Machinery Handbook offers comprehensive lists of speed and feed. Cutting fluids should be used.
- Ceramic. Most are difficult to be machined by traditional methods.
- Polymers. These can be cut, but rather difficult to machine and control dimensions. High speed steel tools with sharp edge can be used in compressed air to control cutting temperature
- Natural materials. These can be cut, but care must be practice to control cutting temperature and cracks due to the material anisotropy.
- Composite materials. Composites can be very challenging to be machined due to different component properties.



https://www.cnclathing.com/guide/how-to-achieve-perfect-finish-on-plastic-parts-tips-for-cnc-plastic-machining-cnclathing



https://www.woodworkingnetwork.com/product/panel-processing-solid-wood-machining/5-axis-cnc-machining