

MECH 331A

Introduction to Engineering Materials

Instructor:

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Born in Xi'an, China

2001 B.S. in Tsinghua Univ, China



2000 - 2008 M.S. & Ph.D., Georgia Tech



2008 – 2013 Research Investigator,
DuPont



2013 – 2024 Assistant, then Associate Prof.
Florida International Univ



2024 - present Associate Prof, MECH & SMSE
Colorado State University (CSU)

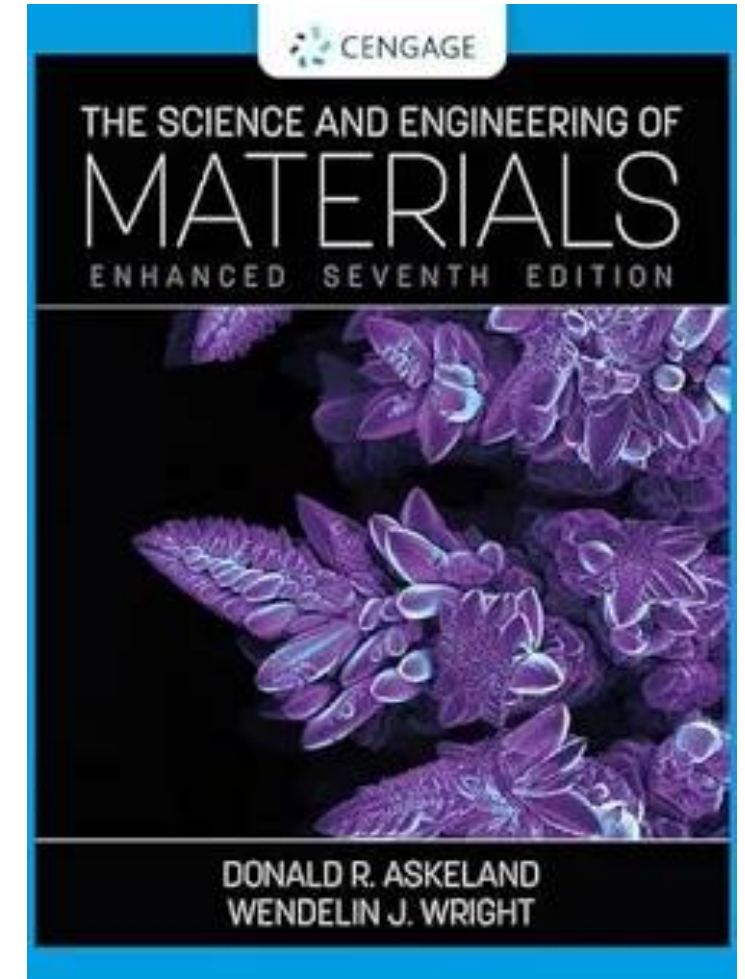


Course Info

TEXTBOOK:

The Science and Engineering of Materials, enhanced 7th Edition,
D. Askeland and W. Wright, CENGAGE Learning, 2022.

Earlier versions OK



Course Objectives and Expected Outcomes

- Understand basic concepts in MSE:
 1. Different **categories** of engineering materials, e.g., metals, ceramics, polymers, composites.
 2. **Structure** of different materials at atomic, molecular, and micro-scale.
 3. **Properties/characteristics** of different materials:
e.g., density, modulus, strength, hardness, electrical conductivity ...
- Understand complex inter-relationships between composition, processing, structure, and properties for engineering materials
- Understand roles of materials in engineering design & application

Help:

- Appreciate complexity of practical engineering materials
- Choose and use materials properly
- Realize design opportunities & constraints with materials
- Recognize potential to improve/develop new engineer materials
- ...

Homework and Quizzes

Homework:

- Posted in Canvas
- Practice concepts & skills covered in lectures.
- Must be hand-written, except for problems **SPECIALLY ASKING FOR AI USE**.
- Must have **hand-written NAME & DATE!**
- Must be uploaded to canvas **as a pdf**
- Finishing on iPad/Tablet OK, but must be hand-written w/ names & date on EVERY page
- Answers & hints would be provided for self-check

Quizzes:

- For quick feedback of how well (some of) lecture contents are received
- In Canvas
- Structured and paced like exam
- Multiple attempts allowed

ACADEMIC HONESTY

Students are required to adhere to the CSU Students Responsibilities

<https://catalog.colostate.edu/general-catalog/policies/students-responsibilities/>

Refer to academic Integrity governing student conduct:

<https://resolutioncenter.colostate.edu/academic-integrity/>

AI:

See later for details

Contents & Schedule

- Fundamentals concepts in materials
- Materials' properties & relationships w/ composition, structure, and processing
- Different categories of materials

Check Canvas regularly for schedule & other resources posted

Course Feature

- Interdisciplinary & **broad** (& shallow)
- Raising awareness & **common sense**
- Some general principles, but every material/application is **unique!**

Some Additional Notes

- Install Canvas on cell phone/iPad/Tablets for **check attendance DURING class**
- Lecture notes provided – save local copies & mark on it; NO need to copy
- Use class time effectively:
 - ~\$500/credit (assuming \$15,000 for 30 credits) → \$1500/entire course → \$30 per class!
- Feel free to ask questions or re-explain

AI Policy

- **Allowed for Hw/Qz & Disclosure Required for Hw**
AI tools may be used in this course as part of the homework problem-solving process. Students remain responsible for understanding, validating, and justifying all final solutions and results. Disclosure of AI use for Hw is required
- **NOT allowed for exams - Do NOT use AI/AR/VR glasses or other “smart” devices**
- ***Example of AI Use Disclosure***
 - *AI Tool(s) Used: ChatGPT*
 - *Purpose: To brainstorm possible solution approaches*
 - *Example Prompt: “List possible methods to analyze an RLC circuit driven by a sinusoidal source.”*
 - *Use of Output: The AI suggested several approaches. I selected the phasor method and completed the full derivation independently.*
 - *Evaluation: Some suggested steps were incomplete and required correction. Final calculations and conclusions were verified manually.*

Chapter 1 Introduction to Materials Science & Engineering (MSE)

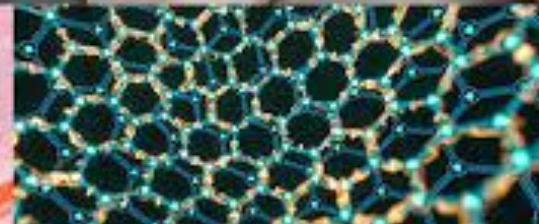
Why MSE?

➤ Physical world based on **materials**

- Use & build
- Materials degrade & fail
- Repair/dispose/recycle

➤ **Science** - Why?/understand

➤ **Engineering** - How?/Practical use



Types of Materials – By Chemistry/Composition

- **Metals:** Pure elements or compounds consist only of metallic elements
 - Metallic bond
 - High thermal & electrical conductivity
 - Opaque, reflective, often heavy/dense, strong, high melting point ...
- **Ceramics:** Inorganic solid materials, mostly compounds, consists of at least one non-metallic element (examples: oxides, carbides, nitrides, sulfides...)
 - Ionic or covalent bonding (refractory) ...
 - Brittle, often strong and high melting point
- **Polymers:** Large molecules contain carbon (or Si) as well as other (mostly light) elements such as H, O, N, and S.
 - Covalent bond between atoms
 - Soft, low density, low melting point, often ductile and low strength, ...
- **Composites:** Purposefully mix at least two very different materials to realize optimized properties that take the advantages of each component

Examples for Different Types of Materials

➤ **Metals :**

➤ **Ceramics:**

➤ **Polymers:**

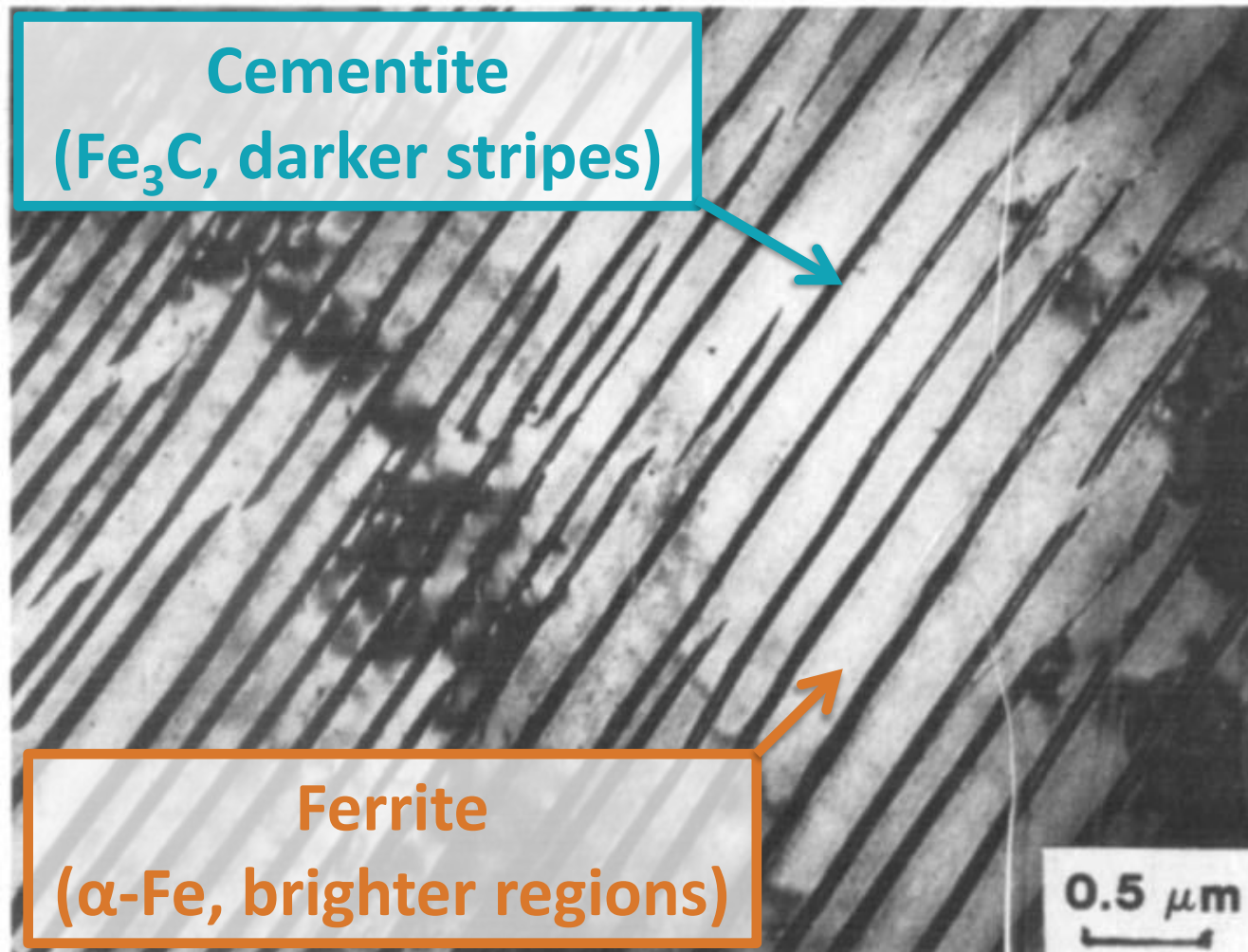
➤ **Composites:**

What type of material is (1 wt.% plain carbon) steel?

By elemental composition: 99 wt.% Fe + 1 wt.% C

→ (Predominantly) **metal (alloy)**

Look deeper (into steel microstructure):



α -Fe (ferrite) + **Fe_3C (cementite)**

(almost pure) Metal
- Give ductility & toughness

Ceramics
- give hardness

→ 2 very different (categories of) materials
→ May be called a “**composite**” as well

But normally considered a **metal alloy**, as Fe_3C ceramic is not added from external - it forms naturally in processing

Attendance Check (if Time Allows)

Types of Materials – Other Classifications

By **application** or function

- Structural materials: beams, support
- Electronic materials: conductor, semiconductor, insulator
- Optical materials: lens, mirror, wave guide
- Magnetic materials
- Biomaterials: teeth, bone
- ...

By certain **property**

- Electrical: conductor; insulator; semiconductor
- Hardness: hard versus “soft”
- Toughness: brittle versus ductile
- ...

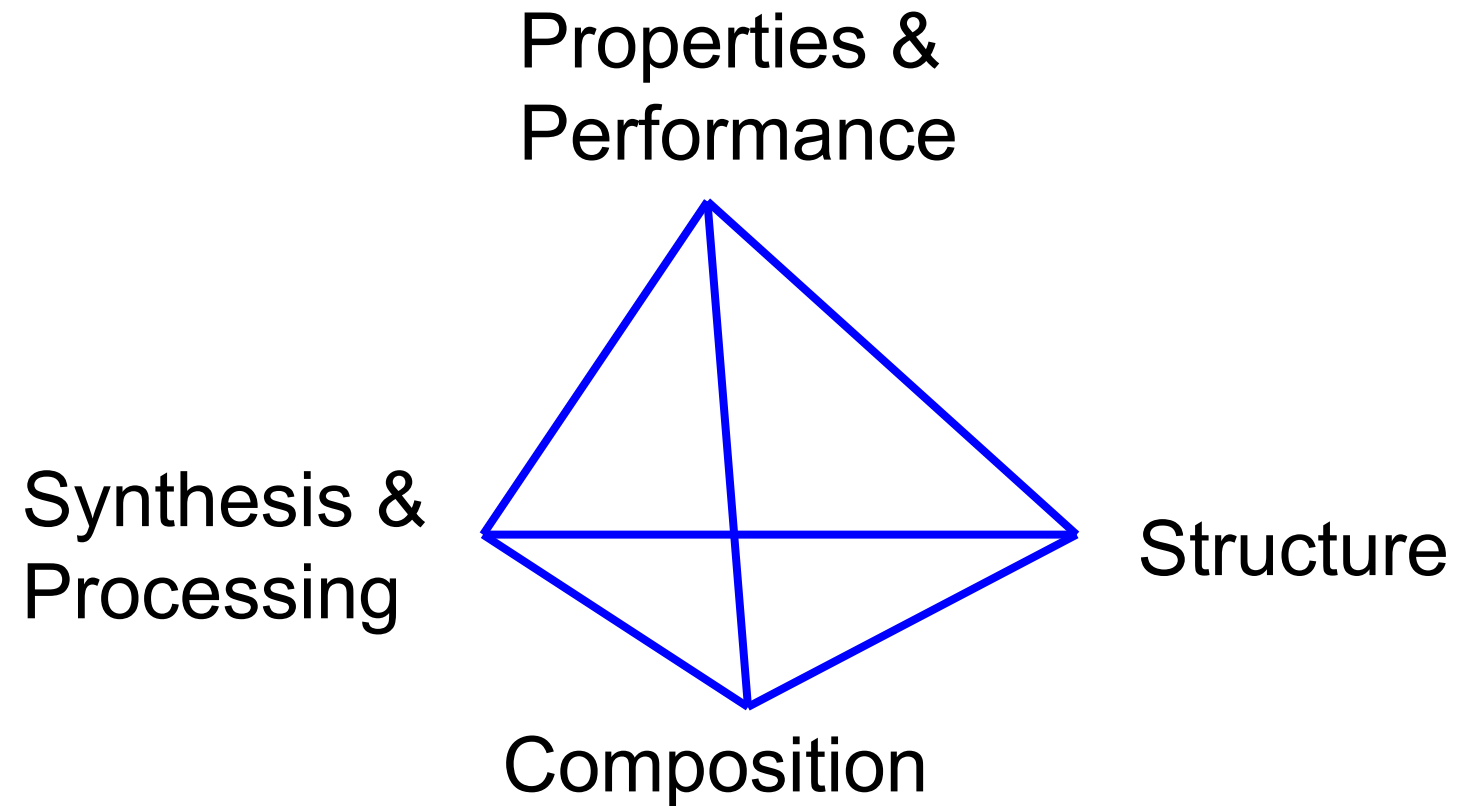
By **source**

- Natural materials
- Man-made

By **...**

Materials Tetrahedron

FOUR (4) basic “aspects” of MSE and their inter-relationships



Materials Composition

Chemical makeup of a material

(Overall) chemistry

- Metal vs. ceramics vs. polymer
- Al vs. Ti vs. Fe ...
- Si_3N_4 vs. c-BN vs. diamond ...
- ...

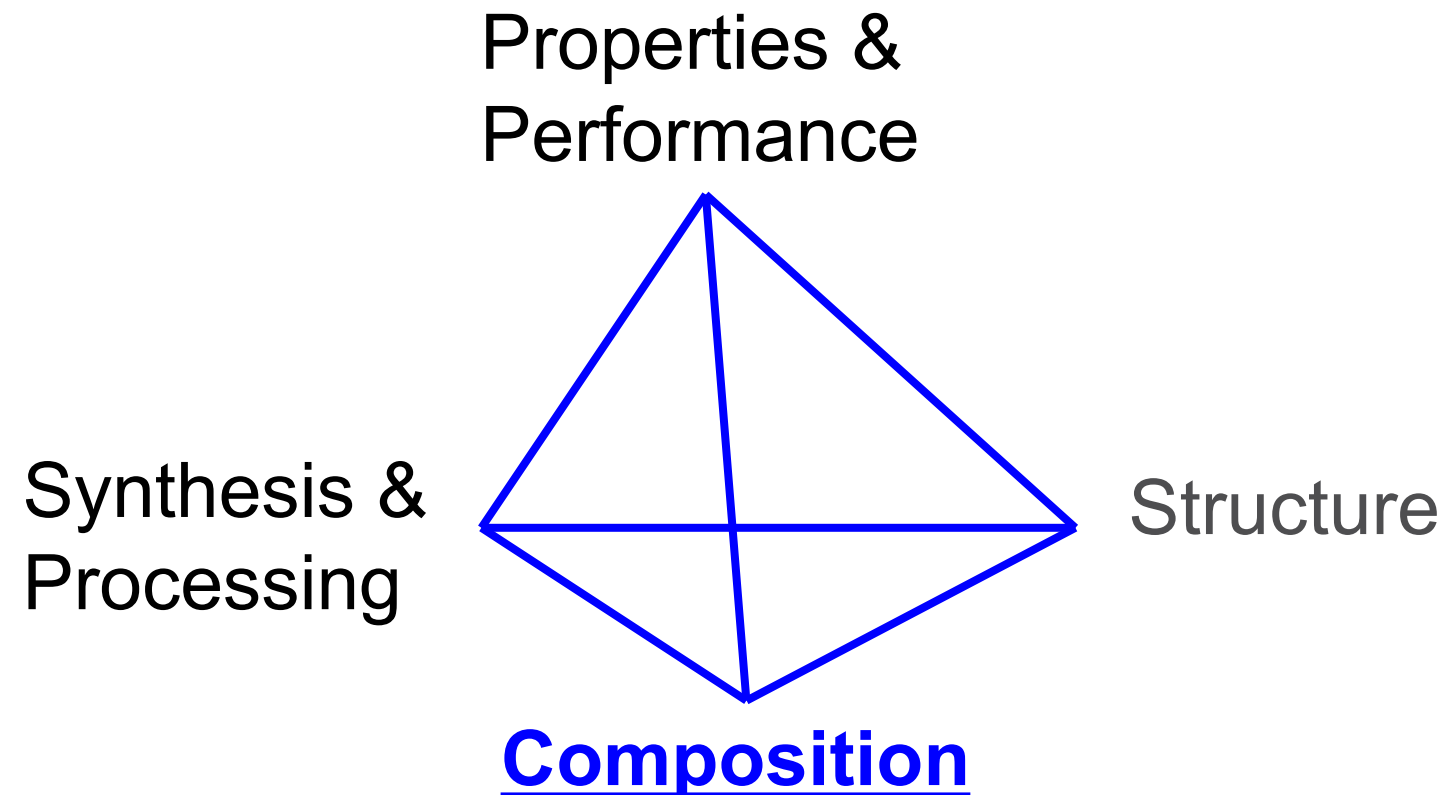
(Atom/molecule) concentration

- C content in iron & steel
- Pb content in Sn-Pb solder
- ...

Phase

- Major phase vs. minor phase
e.g., in steel: matrix (host) $\alpha\text{-Fe}$
plus Fe_3C cementite plus ...
- ...

“Materials” Tetrahedron

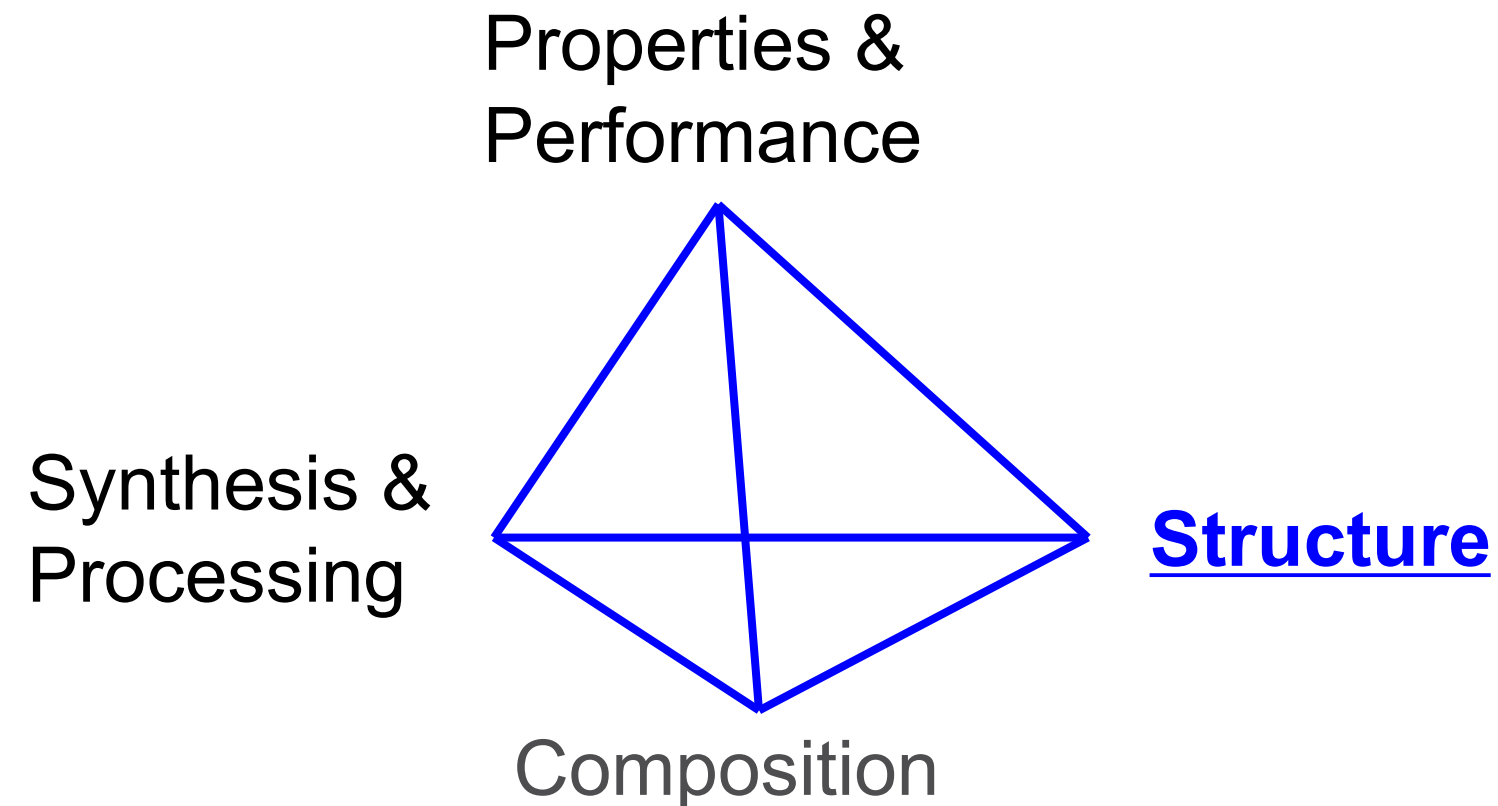


Materials Structure

Structural arrangement, at different (length) scale

- Macro-scale (e.g., ~ 1 mm or 10^{-3} m & above)
 - Block, sheet, rod, ...
- Micro-scale (e.g., ~ 1 μm or $\sim 10^{-6}$ m)
 - Grain and grain boundaries ...
 - Different phases ...
 - Pores and distribution ...
- Atomic scale (e.g., ~ 1 Å or $\sim 10^{-10}$ m)
 - Crystal (or lattice) structure

“Materials” Tetrahedron



Materials Synthesis & Processing

How are materials made/fabricated?

How are they shaped into usable form?

Heat

- Casting, Sintering, Annealing ...

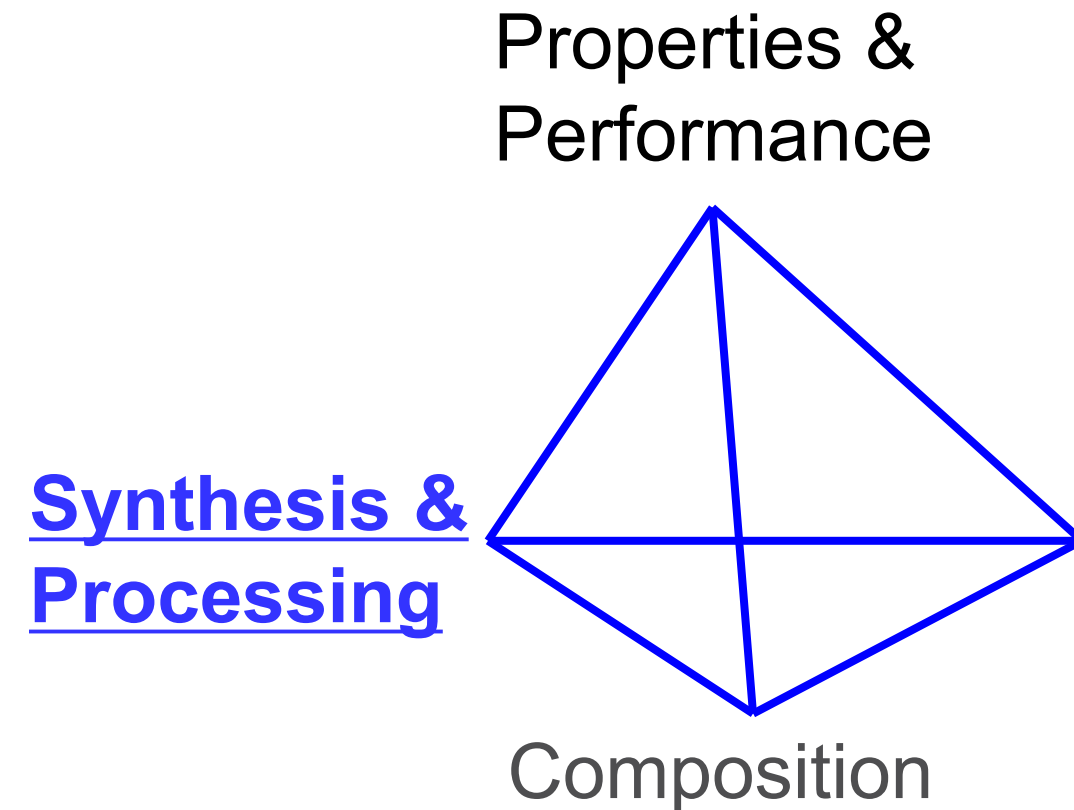
Mechanical

- Forging, Rolling, Cutting, Grinding, Polishing...

Other (Chemical, Electrical, etc.)

- Sputtering, Electrodeposition ...

“Materials” Tetrahedron



Materials Properties & Performance

Properties

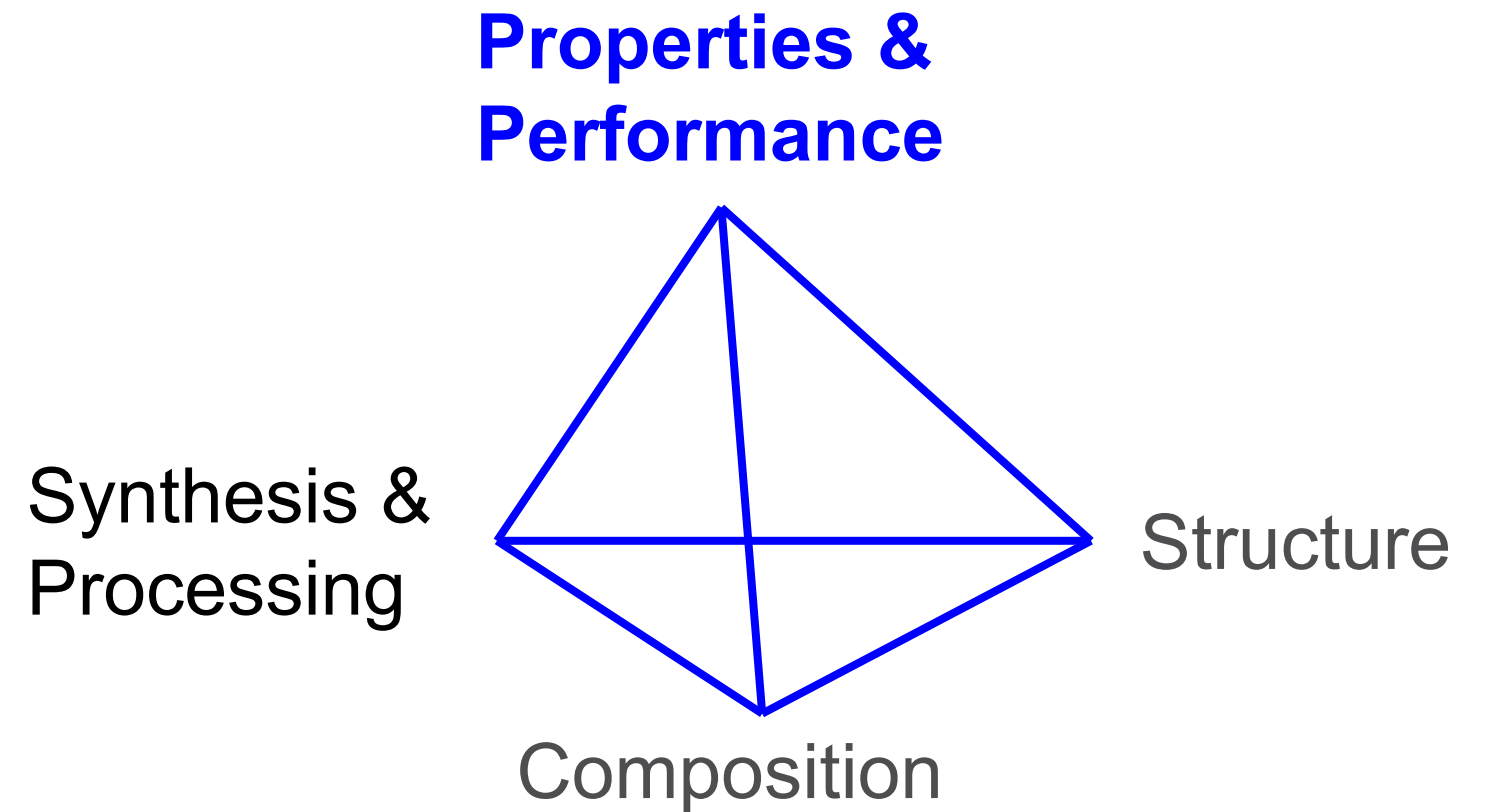
Mechanical, Electrical, Thermal

Optical, Magnetic ...

Performance

Cost, lifetime ...

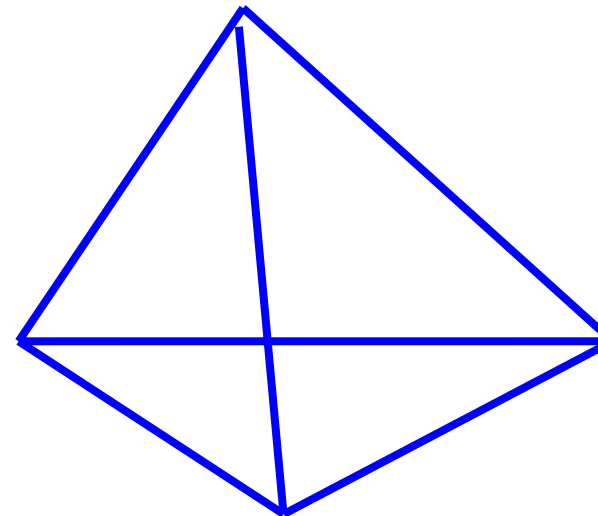
“Materials” Tetrahedron



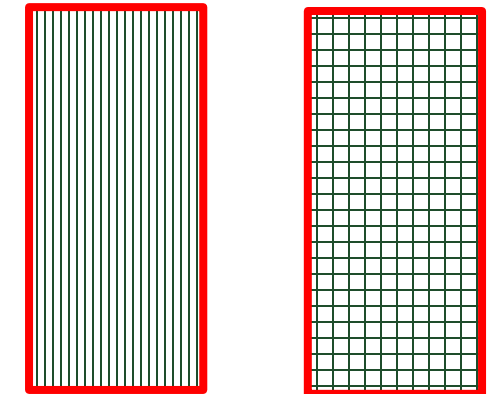
MSE Tetrahedron for Wind Turbine Blade Example

Properties
(mechanical...)
Cost, Lifetime...

Properties & Performance



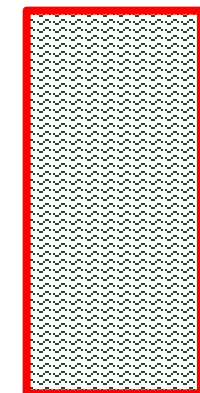
Structure



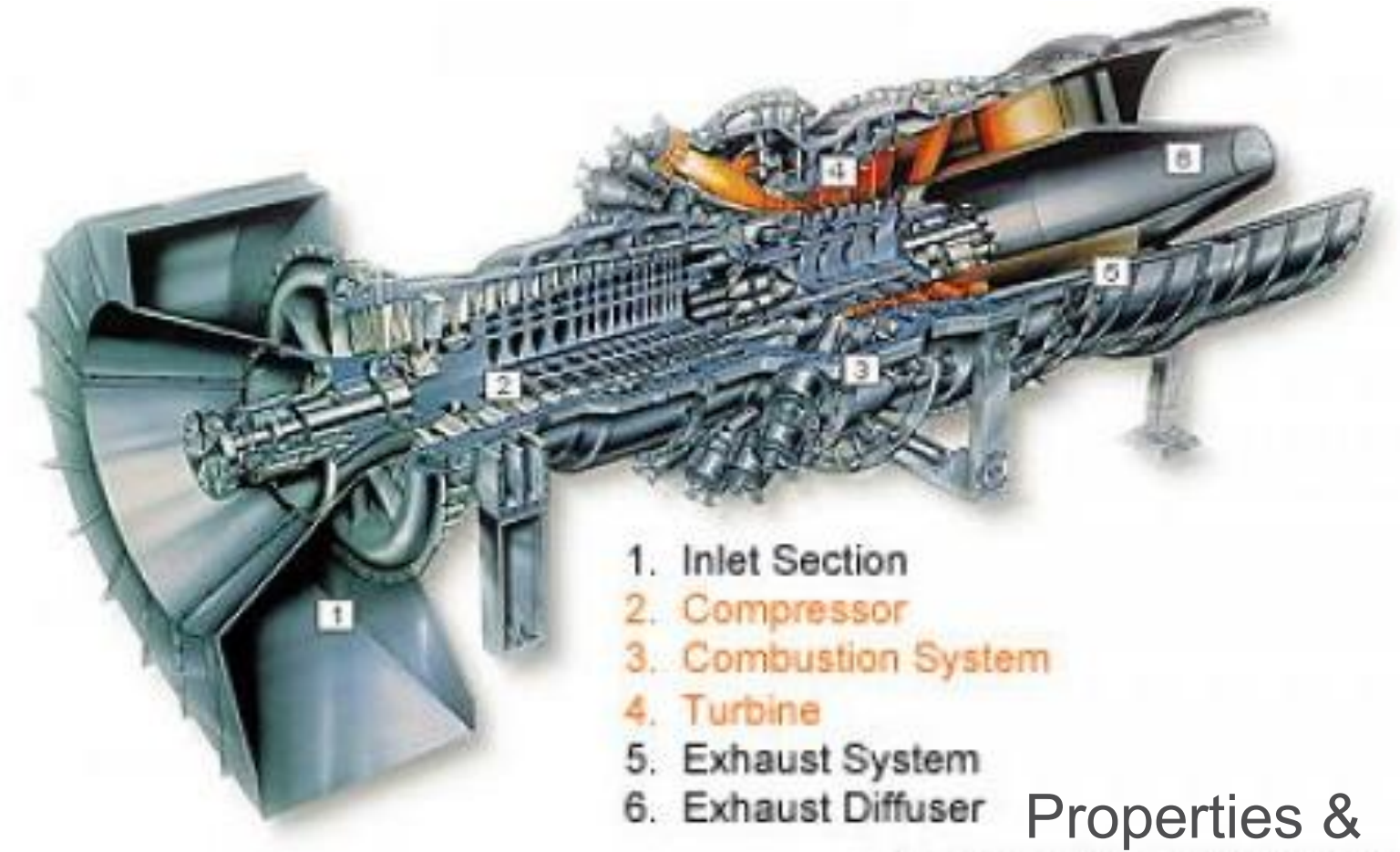
Synthesis & Processing

Composition

Carbon fiber or glass fiber?
Volume ratio of fiber to polymer?



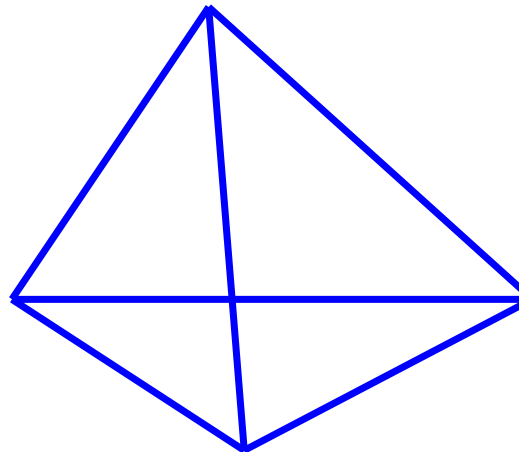
MSE Tetrahedron for Gas Turbine Example



1. Inlet Section
2. Compressor
3. Combustion System
4. Turbine
5. Exhaust System
6. Exhaust Diffuser

Properties &
Performance

Synthesis &
Processing

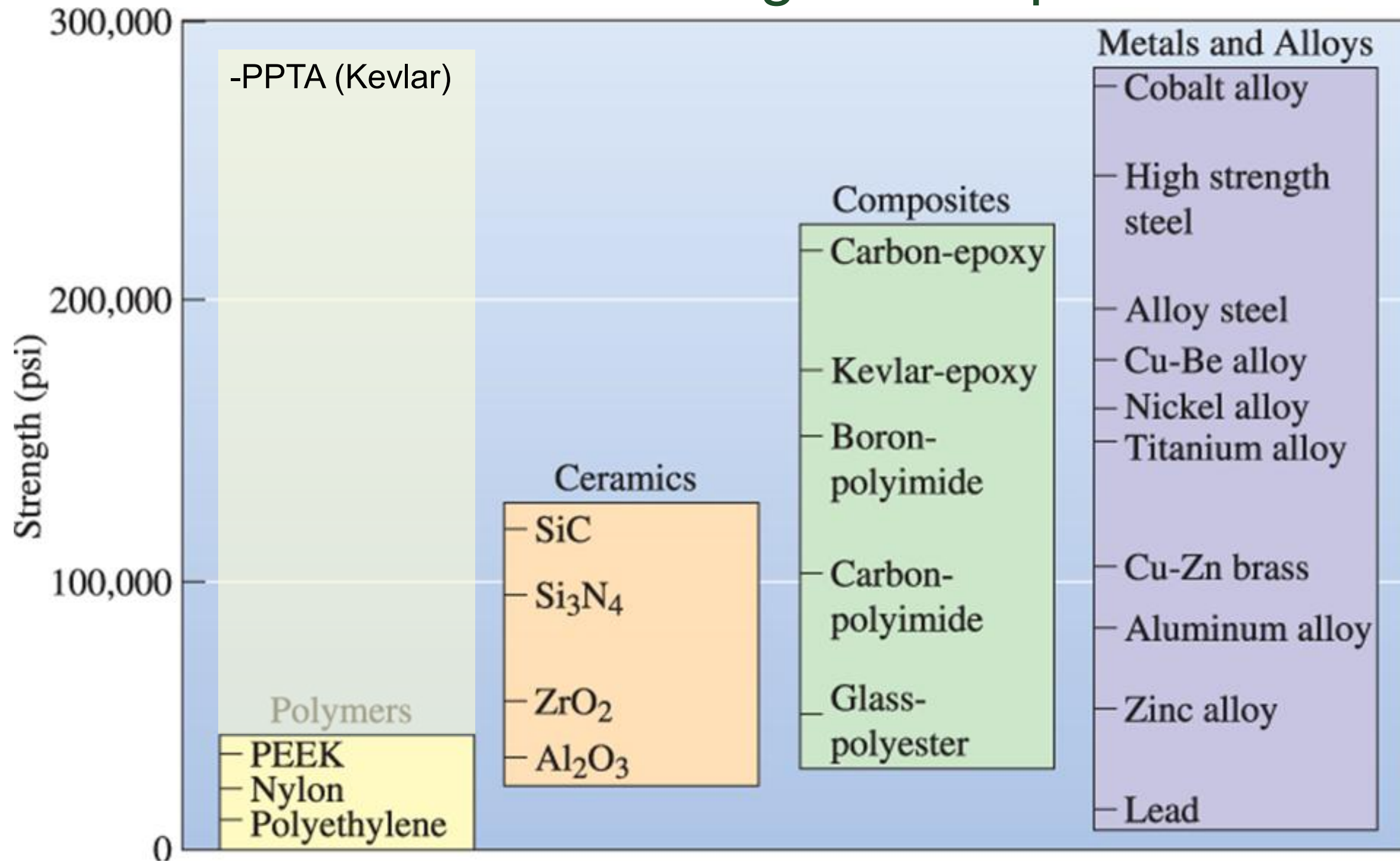


Structure

Composition

- Power generation or propulsion
- Properties needed for each part?
- What materials to use & their (micro-) structure?
- How to process/form the parts?
- Improve via better materials?
 - Power & efficiency
 - Cost
 - Lifetime & reliability

Materials Properties Vary Broadly, Even within Same Category: Tensile Strength Example



For the “Same” Material, Properties May Change

Due to (slight) composition change

Example: carbon content on steel

- Hardness
- Strength
- Ductility
- Paper clip or metal can vs. Knife, file, saw blade ...

Due to structure change/difference

Same composition, different processing → different structure → different properties

- Graphite vs. diamond
- Quenching of iron/steel



Environmental & Other Effects

Temperature



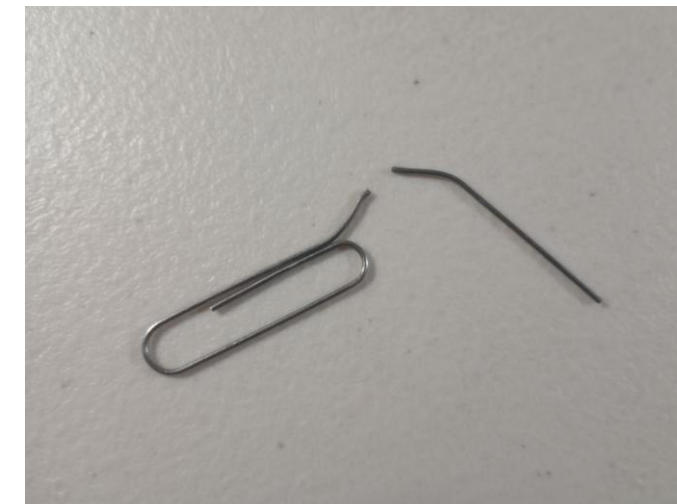
Atmosphere



Combined



Others: e.g., way of Use & Time - Fatigue Example



A Material can Have Many Applications

Carbon steel

- Tool
- Auto
- Construction
- ...

Copper

- Electrical conductor (e.g., wire)
- Coin
- Container
- ...

Diamond

- Jewelry
- Cutting/grinding
- Optical
- ...

Polyethylene (PE)

- Plastic bags
- Milk jar
- Body armor
- ...

Same Application can Choose Different Materials

Tennis racket

- Aluminum
- Carbon fiber composite
- ...

Airplane body

- Aluminum
- Titanium
- Carbon fiber composite
- ...

Artificial teeth

- Metal
- Ceramics
- ...

Solar cell absorber material

- Si
- CdTe
- $\text{Cu}_2\text{InGaSe}_4$
- GaAs
- ...

- Different aspects (properties, cost) need to be considered when choosing material
- Each candidate offers advantages & disadvantages
- Compromise often needed

Homework 1.0

Carefully review chapter 1 lecture slides and, if time allows, read textbook sections (Askeland chapter 1) and give an honor statement confirming the reading

Homework 1.1

1. Ask a question related to engineering materials that you are interested or confused about.

For example, "why have people replaced glass lenses with epoxy lenses for eyeglasses?"

2. Raise that question to an online AI tool such as ChatGPT and paste the answer.

For example, for the above question, I got the following from ChatGPT:

Great question — the shift from glass lenses to epoxy (plastic/polymer) lenses in eyeglasses is mainly due to a combination of weight, safety, and performance advantages that modern polymers offer over traditional glass. Let's break it down clearly:

- 1. Weight and Comfort Plastic/epoxy lenses are much lighter than glass — typically half the weight for the same prescription and thickness. This greatly improves comfort for all-day wear and makes it easier to design larger or thicker lenses without them feeling heavy.*
- 2. Impact Resistance and Safety Glass lenses can shatter easily on impact (e.g., if dropped or during sports), posing a risk to the eyes. Modern epoxy-based polymers (like CR-39, polycarbonate, or Trivex) are highly impact-resistant — they bend instead of breaking, dramatically improving eye safety. This is a key reason most countries now discourage or regulate against glass lenses in children's or safety eyewear.*
- 3. Manufacturing and Coating Advantages Epoxy and similar polymer lenses are easier to mold, cut, and coat than glass. They can be made with built-in tints, UV-blocking, or anti-reflective coatings during production. Photochromic ("transition") and polarized coatings adhere more effectively to plastic substrates.*
- 4. Optical Quality High-quality plastic resins now achieve excellent optical clarity, almost comparable to glass for most users. Though glass still has a higher refractive index and scratch resistance, modern coatings (like hard coats) largely mitigate those drawbacks.*
- 5. Cost and Versatility Polymers can be mass-produced more cheaply with complex prescriptions or shapes (e.g., progressive or aspheric lenses). They allow customization — lightweight lenses even for strong prescriptions, which would be thick and heavy in glass.*

(continue)

(continue from previous)

In Summary,

Property	Glass Lenses	Epoxy/Plastic Lenses
Weight	Heavy	Light
Impact resistance	Low (can shatter)	High (safe)
Scratch resistance	Excellent	Moderate (improved with coating)
Optical clarity	Excellent	Very good
UV protection	Low (needs coating)	High (often built-in)
Manufacturing	Hard to mold	Easy, versatile



In short: Epoxy and polycarbonate lenses dominate because they're safer, lighter, and more versatile, while maintaining good optical performance — making them better suited to modern eyewear needs. Would you like me to explain the chemical or materials science aspect of epoxy lens resins (e.g., CR-39 vs polycarbonate vs Trivex)?

3. Comment on whether the answer from AI makes sense or not and why; Ideally, discuss w/ it to find out more.

For the previous example, I continued with one more question “All your answers are too qualitative. Can you be more quantitative, when doing the comparison, in terms of materials properties & cost?”

(continue from previous)

Here's a quantitative, materials-property and cost-oriented comparison showing why glass was largely replaced by epoxy/plastic lenses in eyeglasses:

1. Key Materials & Their Properties

Property	Optical Crown Glass	CR-39 Plastic	Polycarbonate Plastic	Trivex Plastic
Refractive index (n)	~1.52	1.498	1.586	~1.53
Abbe number (V _d) <i>(higher = less chromatic dispersion)</i>	~58.5	~59.3	~30	~43–45
Density (g/cm ³) <i>(proxy for weight)</i>	~2.56	~1.31	~1.20	~1.10
UV protection (built-in)	None (cutoff ~320 nm)	Partial (cutoff ~355 nm)	~100 %	~100 %
Relative impact resistance	Low	Moderate	High (≈10× standard plastic)	High
Scratch resistance (uncoated)	Best	Good	Poor	Better than polycarbonate

Interpretation

Weight:

Glass lenses are ~2× heavier than CR-39 and over 2× heavier than polycarbonate/Trivex for the same size. This makes glasses with glass lenses noticeably heavier on the face.

(continue from previous)

Weight:

Optics:

- *Glass and CR-39 both have **Abbe** $\approx 58-59$, meaning lower chromatic aberration (less “color fringe” and distortion) compared to polycarbonate (≈ 30) which has far more dispersion.*

Thickness/Size:

- *Higher refractive index materials (e.g., polycarbonate 1.586 > CR-39 1.498) bend light more efficiently. That means for a given prescription, a high-index plastic lens can be made **up to ~30 % thinner** than standard plastic or glass of the same prescription.*

Impact Resistance:

- *Plastic lenses, and especially polycarbonate and Trivex, are engineered to be much tougher than glass. Polycarbonate can be **an order of magnitude more impact resistant** than conventional plastics and vastly more so than glass, making them much safer in everyday wear and for children.*

2. Cost Comparison (Typical Market Prices)

(Estimated retail lens component costs — subject to variation by retailer, coatings, prescription, etc.)

Lens Type (single-vision)	Relative Material Cost	Typical Add-On Costs
CR-39 plastic	Base / lowest	Often includes scratch coat; UV coating may be extra <small>Even Realities</small>
Polycarbonate	Base + \$30–\$100	Scratch-resistant coating normally included <small>Even Realities</small>
High-Index Plastic	Base + \$50–\$200+	Often includes AR coating <small>Even Realities</small>
Glass lenses	Often more expensive than CR-39	Harder to source and fabricate <small>eyecaresuperior...</small>

(continue from previous)

Interpretation

- *Glass lenses generally cost more than basic CR-39 plastic because they are heavier, more difficult to process, and increasingly rare in modern labs.*
- *Polycarbonate (though more expensive than CR-39) is still a moderate-cost plastic alternative with safety benefits.*
- *High-index plastics, developed to reduce thickness in strong prescriptions, cost the most but are lighter and cosmetically thinner.*

3. Why the Shift from Glass?

✓ Weight Reduction

- *Glass: $\sim 2.56 \text{ g/cm}^3$*
- *Plastic: $\sim 1.31 \text{ g/cm}^3$ ($\sim 49\%$ lighter than glass)*
- *Polycarbonate: $\sim 1.20 \text{ g/cm}^3$ ($\sim 53\%$ lighter than glass)*
- *Trivex: $\sim 1.10 \text{ g/cm}^3$ ($\sim 57\%$ lighter than glass)*
→ *Plastic lenses are significantly **lighter**, improving comfort for daily wear.*

✓ Safety / Impact Resistance

- *Glass can shatter on impact.*
- *Polycarbonate/Trivex have high impact resistance, meeting safety standards for children's eyewear and sports.*

✓ Thinner Profiles for Same Prescription

- *Higher index plastics like polycarbonate reduce lens thickness by up to **$\sim 30\%$ or more** compared to CR-39 or glass at higher prescriptions, making them more attractive cosmetically and functionally.*

✓ UV Protection

- *Polycarbonate and Trivex block **$\approx 100\%$ of UVA/UVB** inherently.*
- *Glass typically does not block UVA without coatings.*

✗ Downsides of Plastics (Quantitative Limits)

- *Lower Abbe values (e.g., ~ 30 for polycarbonate vs ~ 59 for glass/CR-39) mean **more chromatic aberration**.*
- *Pure plastic surfaces scratch more easily than glass, requiring coatings to approach glass's scratch resistance.*

(continue from previous)

Summary

Feature	Glass Lenses	Plastic (Polymeric) Lenses
Weight	Highest ($\approx 2.56 \text{ g/cm}^3$)	Lower ($\sim 1.1\text{--}1.3 \text{ g/cm}^3$)
Optical Clarity	Excellent (high Abbe)	Good to moderate (Abbe $\sim 30\text{--}60$)
Impact Resistance	Poor (shatters)	High (very safe)
Thickness (for same prescription)	Moderate	Thinner (esp. high-index)
UV Protection	Needs coating	Often inherent (for polycarbonate/Trivex)
Cost	Often higher	Lower to moderate
Scratch Resistance (uncoated)	Best	Requires hard coat

Conclusion

- *Eyeglass manufacturers — and most consumers — have moved from glass to epoxy/plastic lenses because plastics **offer a quantitatively superior combination of lightweight comfort ($\approx 50\%$ reduction in weight), much higher impact resistance, integrated UV protection, and competitive cost, even if some optical properties (like chromatic dispersion) are slightly worse without coatings.***
- *If you want, I can also break down how these properties influence **lens thickness for different prescriptions** (e.g., -2.00 vs -6.00 vs $+4.00$ diopters) with actual formulas.*

The conversation could still go on, such as I could continue with question like “Some numerical data are still missing or vague, such as impact resistance: what values and units for each materials? How are they measured? Can you do better?” ...