Bike Frames 2

Monday, January 5, 2026 11:48 AM

Bike Frames Day 2 Learning objectives

- Describe the evolution of bike materials from a materials properties perspective (strength, weight).
- Explain stress and strain conceptually and relate these to strength of bike tubes, tire pressure etc.
- Interpret stress–strain curves (elastic region, yield, UTS, fracture).
- Calculate engineering stress and engineering strain from experimental data.
- Describe how yield strength and UTS differ.
- Explain density and specific strength.
- Compare steel, aluminum, titanium, and carbon fiber bicycle frames.

History of bike frames

1817: - The "Draisine" or "laufmaschine" (precursor to the modern bike) was made of wood.	 https://wide.piaggiogroup.com/articles/products/duecento-anni-in-bicicletta-dalla-draisine-alla-wi-bike/foto1-small.jpg
1820s-1850s: - 3 and 4 wheelers. - Less balance required. - Introduction of pedals, treadles, hand-cranks. - First pedal crank appears in 1853. - "Penny farthing" design with solid rubber tires and high speeds	 https://upload.wikimedia.org/wikipedia/commons/7/70/Bicycle_two_1886.jpg
Late 1800s:	

- Steel tubing introduced.
- Wire spoke tension wheels.
- Shift from expensive toy to utilitarian transportation "Safety bicycle."
- Diamond frame invented by Isaac R. Johnson.
- Step through frames.

https://upload.wikimedia.org/wikipedia/commons/4/48/Whippet_Safety_Bicycle.jpg

1900 - 1940s:

- Aluminum frames become popular.
- Single tube with no lugs.
- "Lu-Min-Num" bike model out of St. Louis Refrigerator and Gutter Co.

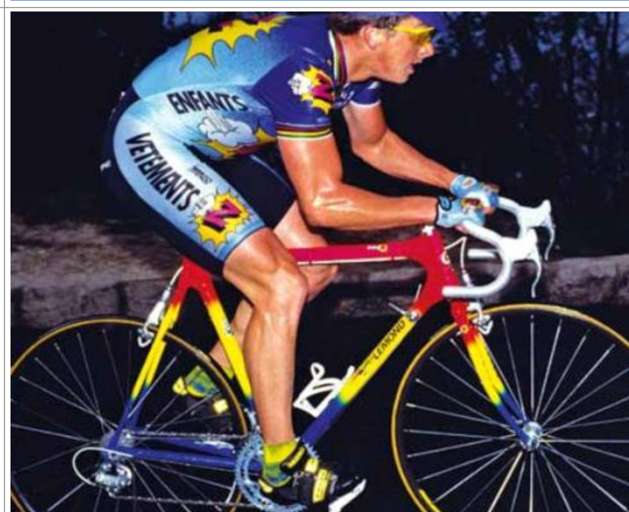
This aluminium machine has a single tube and no lugs.

https://jeffreyrubel.substack.com/p/the-aluminum-bike-frame

1970s:

- plastic bikes "Itera"
- Plastic everything! Chains, hubs, spokes etc
- Claim: "17 lbs and stronger than steel…"
- Not a commercial success

https://upload.wikimedia.org/wikipedia/commons/a/a0/Itera_plas

	tic_bicycle.jpg
1990s: -Titanium frames -Full suspension 1992 Gary Fischer RS-1	 https://www.unicorncycles.com/titanium-road-gravel-bike-frames
Modern era: -Carbon fiber dominates high-performance bikes. -1991 first appears on the Tour de France.	

Stress and strain
This allows us to connect the concepts of force to material strength

Stress is an internal pressure caused by forces
When a force is distributed over a larger area, the stress is reduced

$$\sigma = \frac{F}{A}$$

Pressure has the same units!
Let's convert a bike tire at 25psi to Pa.

What would be the stress of our 160 lb biker on the ground below?

Group activity! Let's calculate the stress on the ground as a function of tire pressure
Nice article from University of Wisconsin-Milwaukee and Harley Davidson [here](#).

How much will a material deform under a stress?
Strain (ϵ) is the percent change in physical dimensions when stress is applied

$$\epsilon = \frac{\Delta L}{L_{initial}}$$

The change in length is $L_{final} - L_{initial} = \Delta L.$

What units does strain have??

Elastic modulus
The strain observed is proportional to the stress and the constant of proportionality is the Elastic modulus, E_y

This property is also sometimes called the Young's modulus or the stiffness.

$$E = \frac{\sigma}{\epsilon}$$

or $\sigma = E\epsilon$

Let's assume a 160 lb person is sitting on a bike and 40% of their weight is directed into the seat tube of the frame. If the tube is a hollow, circular cross section of 30 mm outer diameter, 24 mm inner diameter, what would be the stress on the tube frame material?

If the tube was originally 10 cm tall and made of a steel with a modulus of 200 MPa ($1\ MPa = 1 \times 10^6 Pa$) what would be the dimensions when the person sat on the seat to ride?

How do the properties of metals vs ceramics vs composites compare?

Metals are typically…

Ceramics are typically…

Plastics are typically…

Composites are materials made up of two or more different classes of materials typically to get the "best of both worlds"

Group activity:

1. Which material would you expect to have **strongest** bonds?

Let's draw typical Stress-strain curves for different materials

We can identify some key regions on this plot

- Elastic deformation = deformation that is non-permanent (will bounce back)
- Plastic deformation = permanent deformation
- Yield strength = strength corresponding to 0.02 residual strain (2% left over even when stress released)
- Ultimate tensile strength = highest stress supported during testing
- Failure strength = stress at failure
- Elastic modulus = slope of stress vs strain in elastic region
- Toughness = area under the curve before fracture
- Resilience = area under the curve before plastic deformation

Group activity: Let's test the stress and strain of some real materials!!

Engineering stress/strain vs true stress/strain
As a material elongates (under tensile load) it will also get skinnier. Therefore, the cross-sectional area is changing during the strain. True stress and strain takes into account this instantaneous cross-sectional area, whereas engineering stress/strain is calculated with the unloaded cross-sectional area.
"Engineering stress is for designing parts; true stress is for research and failure analysis."

Density
Why is steel so heavy while aluminum is so light? Why is titanium somewhere in-between?

Density (ρ): How dense stuff (mass) is packed into a certain amount of space (volume)

$$\rho = \frac{m}{V}$$

Units are usually grams/cubic centimeter or g/cc or kg/m^3
Water has a density of 1 g/cc

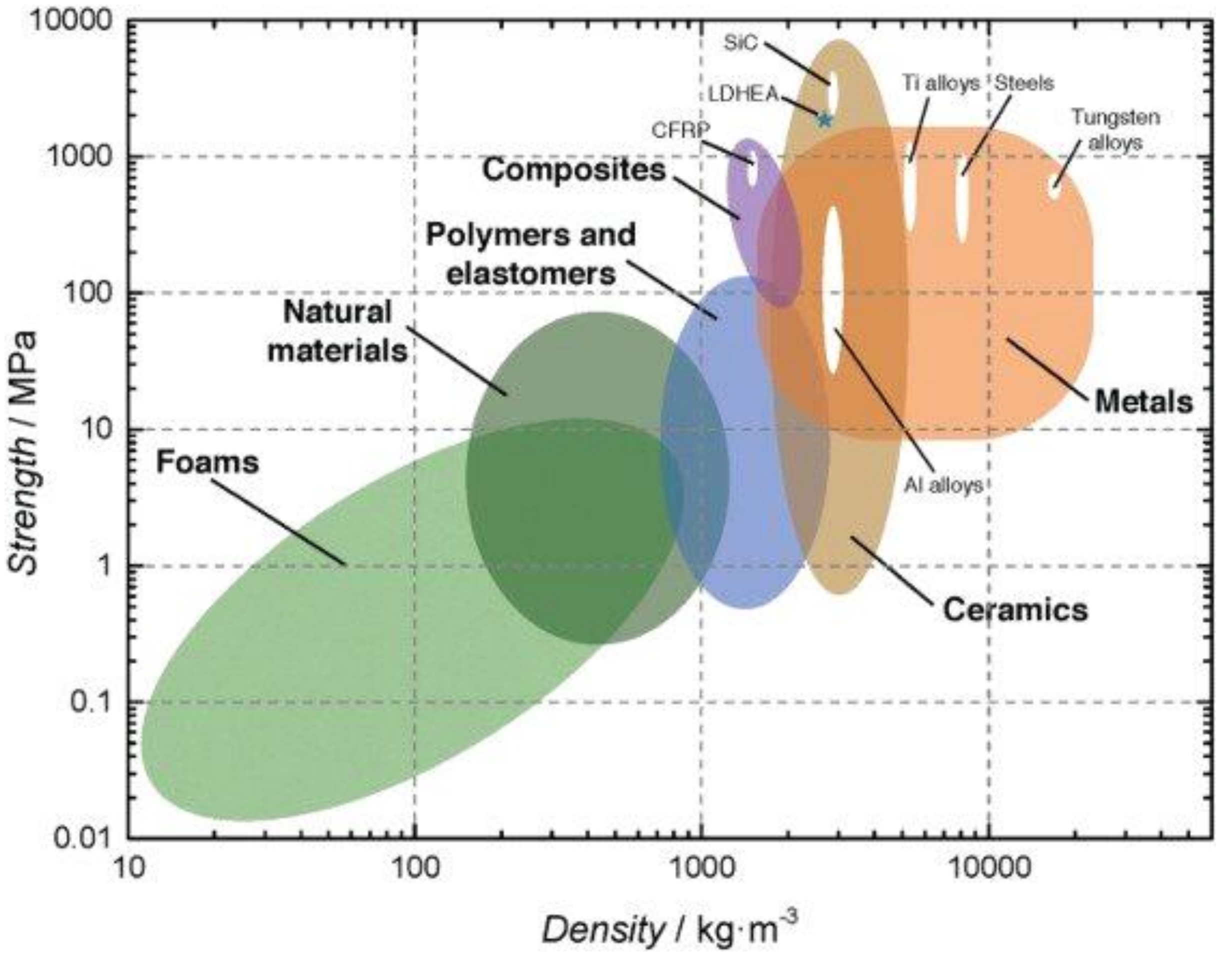
Let's try converting $1\ lb/ft^3$ to g/cc

A few typical material densities

- Steel ≈ 7.8 g/cm^3
- Titanium ≈ 4.5 g/cm^3
- Aluminum ≈ 2.7 g/cm^3
- Carbon fiber composite ≈ 1.6 g/cm^3

Specific strength: A measure of how strong a material for its weight

$$\frac{\sigma}{\rho}$$



Pros and cons of specific materials

Steel:

- Pro: High strength, low cost, easy to repair. Cons: Heavy and prone to rust (unless alloyed).
- Corrosion resistant variations (chromoly 4130, "Reynolds 531")
  - If you don't know if steel is high quality or not, tap on it with fingernail and listen for ring (high-quality) or thunk (low quality).
- Decent vibration damping for good ride "feel"
- Joining tubes

    - Classically connected with lugs (thick sections the tubes slide into) where tube is brazed onto the lug. Easy to repair/replace.
    - Welding also possible. Care to ensure the welding won't weaken the steel (more on this later)
- Butted tubing can reduce weight and increase cost
- **Fatigue limits** ~0.3-0.6 of yield strength
- New super steel alloys causing a bit of a comeback for steel. For example, Reynolds 531 invented in 1935 had tensile strength of ~800MPa but Reynolds 853 released in ~2000 is air-hardened (so you can weld it) and has strength of 1200MPa, next gen Reynolds 953 has strength up to 2000MPa!
- Typical density 7.85g/cc, stiffness ~200GPa, strain 25% for 4130 (10-15% for low quality steel), strength 460MPa yield, 560MPa ultimate,

Aluminum:
- Pros: Lightweight, corrosion-resistant, affordable. Cons: Lower fatigue resistance and stiffness.
- Better overall strength to weight ratio than steel
    - Optimal is actually 200:1 diameter to wall thickness ratio but this would be like a beverage can; too fragile for impacts so larger tubes are used impacting aerodynamics but improving resistance to impacts.
- No fatigue limit, so the material gets weaker as it's cycled due to microcrack growth
- Challenging to join (TIG welding possible)
- Not always lighter than steel
- Typical density 2.7g/cc, stiffness 70GPa, strain 6-12%, strength 270MPa yield, 310MPa ultimate,

Titanium:
- Pros: Corrosion-resistant, durable, and lighter than steel. Cons: Expensive and harder to work with.
- Most common alloys is Ti-3Al-2.5V (3% Al, 2.5% V) followed by Ti-6Al-4V (6% Al, 4% V)
- Tubes can be cold-drawn and hydroformed into many complex shapes for internal cabling.
- TIG required because prone to bad welds and breakage
- Not as stiff, a bit "flexy"
- Typical density 4.58g/cc, stiffness 100GPa, strain 15-30%, strength 500MPa yield, 620MPa ultimate,

Carbon Fiber:
- Pros: Extremely lightweight, high stiffness, customizable. Cons: Expensive, less durable under impact, harder to recycle.
- **Anisotropy** possible (different properties in different directions). Can achieve low vertical stiffness, high lateral stiffness.
- Prone to damage even from overtightening or improper installation of parts
- Cracking at interlaminar regions or adhesion points
- Can add other additives like metallic boron, graphene, kevlar etc to modify properties
- Typical density 1.55g/cc, stiffness 130GPa (Very anisotropic!), strain 2% (Achilles heel), strength 2500MPa ultimate (but only along fiber direction!)

Other materials?

- Magnesium. A few bikes are made of this alloy. It has 64% density of Aluminum so you can get real weight savings.
  - In 1980s Frank Kirk designed a die cast one piece made of I-beams rather than tubes! Out of business 1992. Not really a popular option.
- Sc alloys. This is aluminum with a very small amount of Scandium (0.5%) so this is mostly marketing. It does improve welding characteristics and fatigue resistance allowing smaller tubes and more frame design options.
- Bamboo and wood, but these are uncommon.
- Combinations of materials for different components in the bike is very common

Example problem

A carbon bike frame weighs 900 g at a density of 1.6 g/cm^3. A steel frame of the same volume would weigh how much?

Group Activity: Let's look up different bike frames and make a plot of weight vs cost