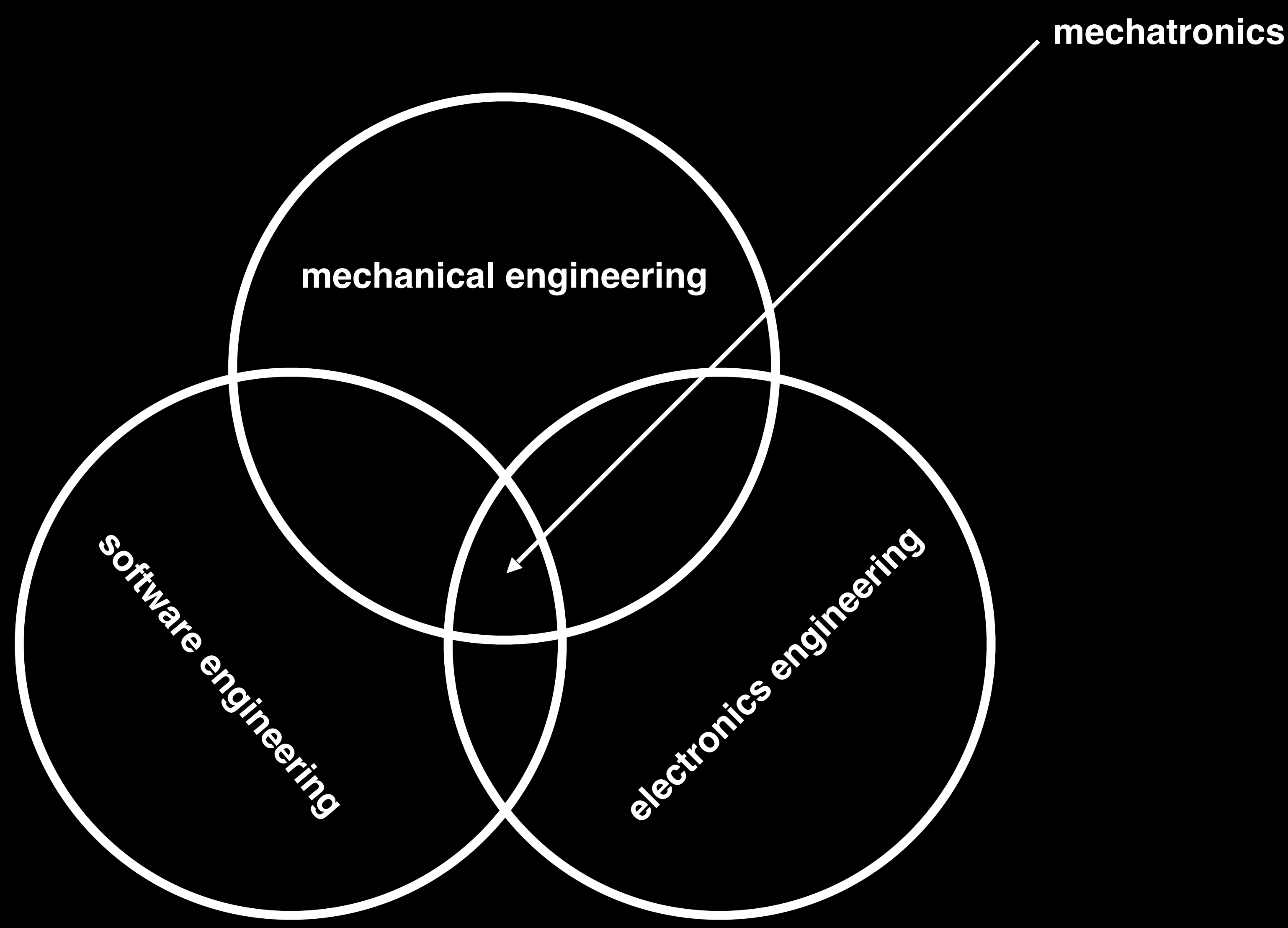
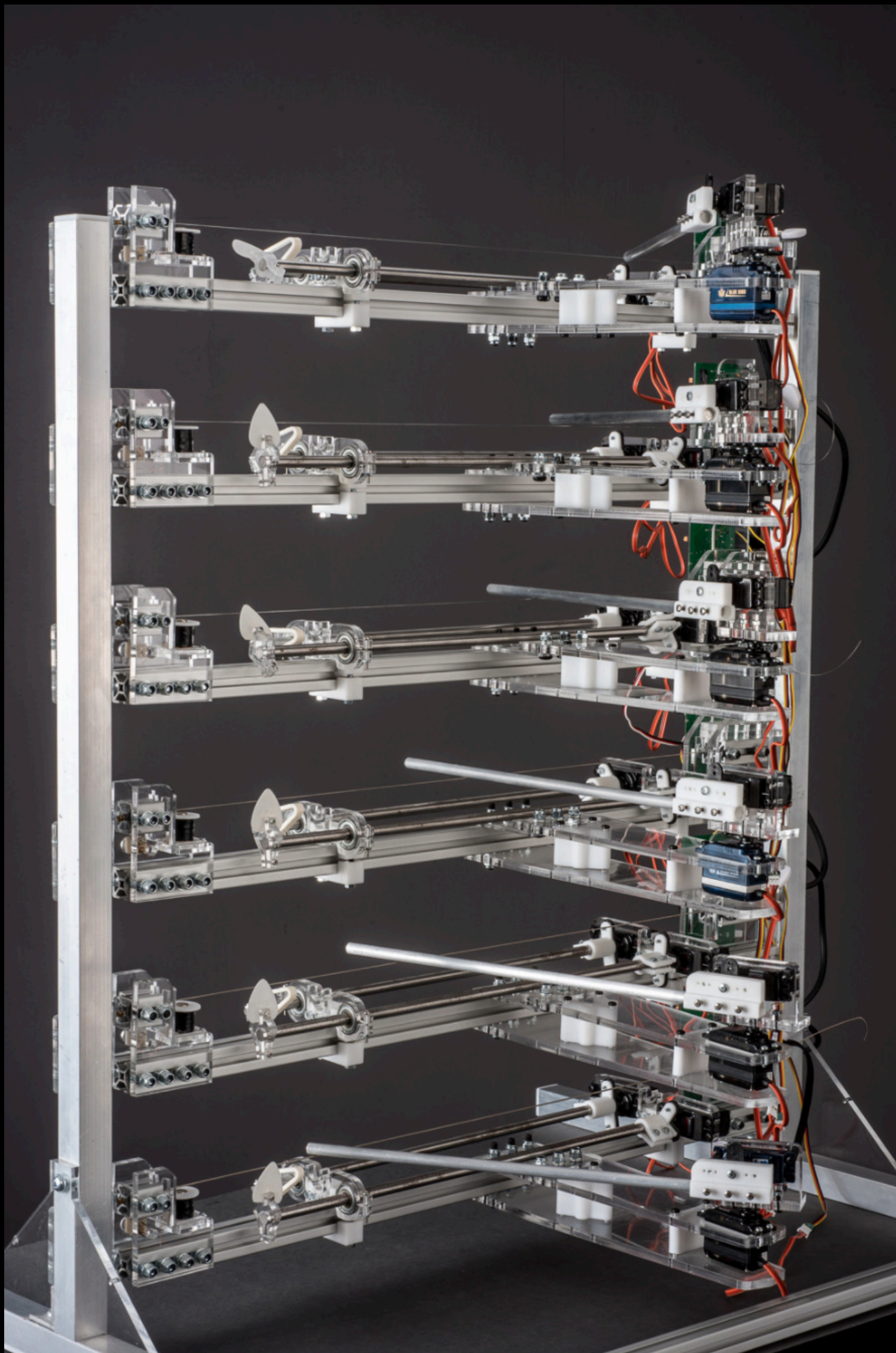
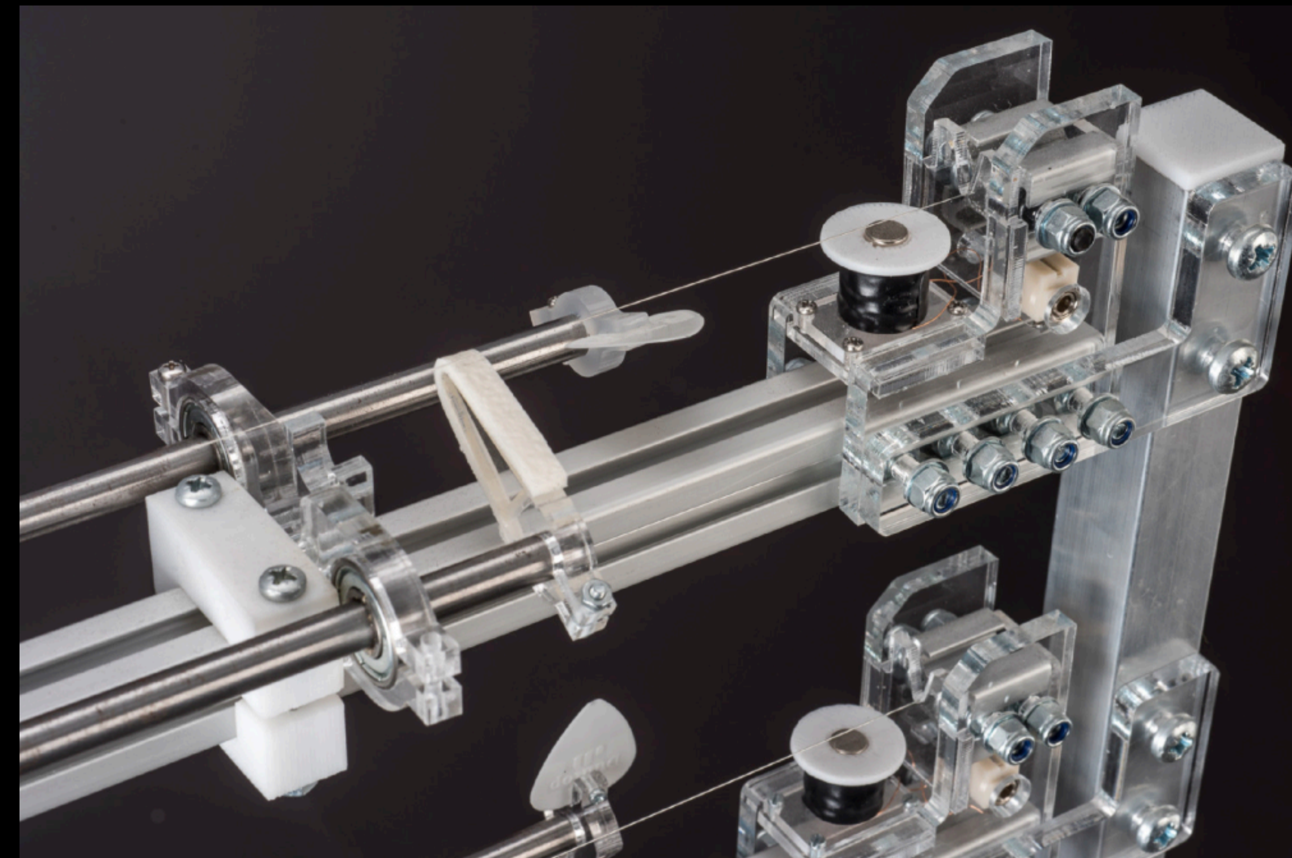
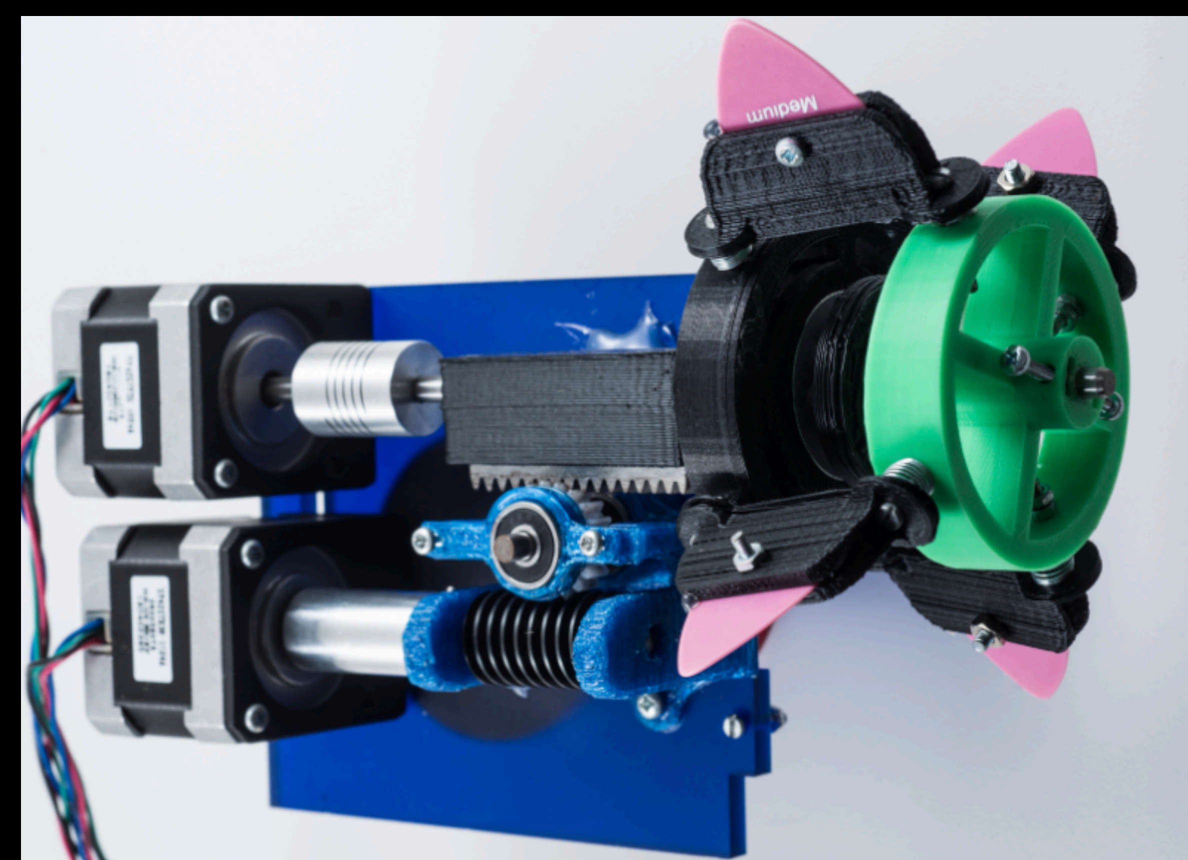
ECEN425



- jim.murphy@vuw.ac.nz
- 92 Fairlie Terrace, Room 202





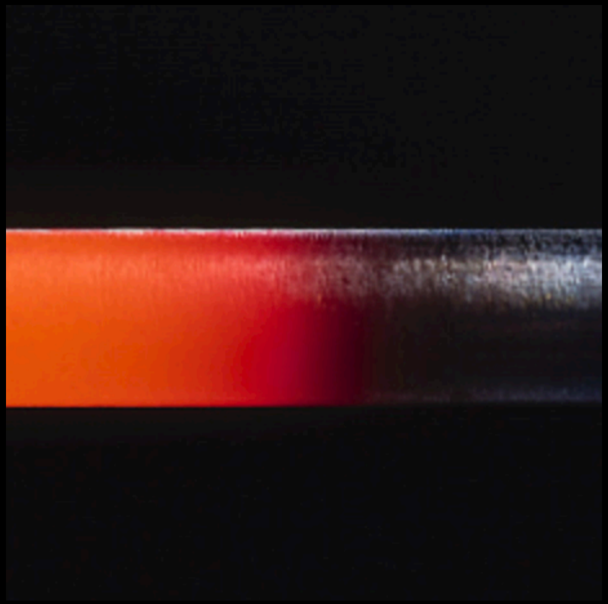

Medium

- jim.murphy@vuw.ac.nz
- 92 Fairlie Terrace Room 202
- No fixed office hours: schedule a meeting via email!
- Lecture notes and assignments will be posted to Blackboard

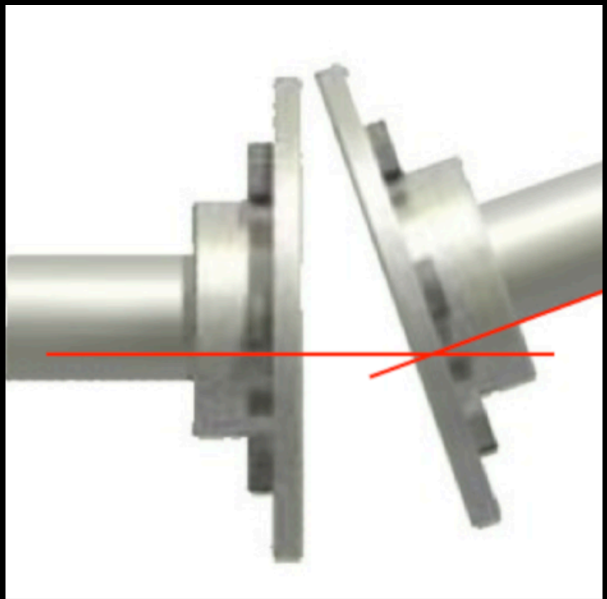
UNCERTAINTIES

CORROSION

WEAR

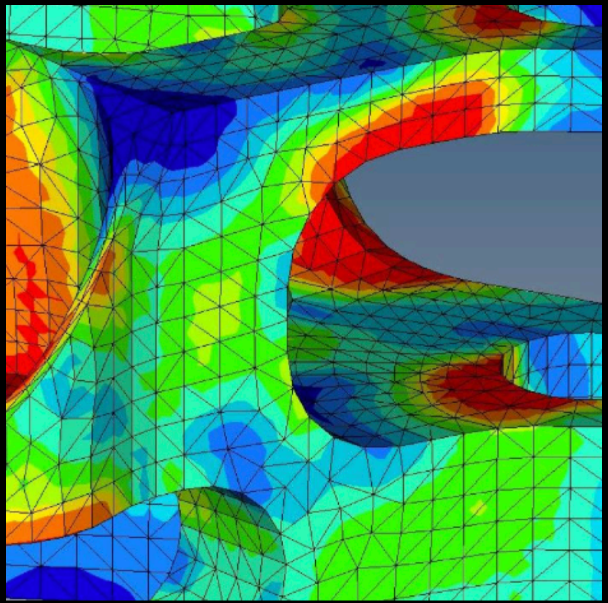


TEMPERATURE



MISALIGNMENT

MANUFACTURING ERRORS



MODEL ERRORS

- One way to deal with these inevitable errors is to use a design factor and safety factor.
- This essentially involves building the system stronger than needed for normal use.
- It can be helpful to be able to estimate the worst case scenario.

DESIGN FACTOR

- Designing with a design factor allows uncertainties to be addressed (so long as *absolute uncertainties* can be estimated)

Design Factor

Point at which the system fails

$$n_d = \frac{\text{loss-of-function parameter}}{\text{maximum allowable parameter}}$$

Parameter to not exceed

Or… given the loss of function parameter and a design factor, we can arrive at a maximum allowable parameter

$$\text{Maximum allowable parameter} = \frac{\text{loss-of-function parameter}}{n_d}$$

DESIGN FACTOR

An electric scooter's maximum load is known to an uncertainty of ±20 percent *(absolute uncertainty 1)*. The load that will cause breakage/failure is known within ±15 percent *(absolute uncertainty 2)*. The load causing failure is nominally 2000 N. Determine the design factor and the maximum allowable load that will offset the absolute uncertainties.

The maximum allowable load must decrease to 1/1.2
(addresses absolute uncertainty 1, ±20 percent)
We might see a loss-of-function load as great as 1/0.85
(addresses absolute uncertainty 2, ±15 percent)

$$n_d = \frac{1/0.85}{1/1.2} = 1.4$$

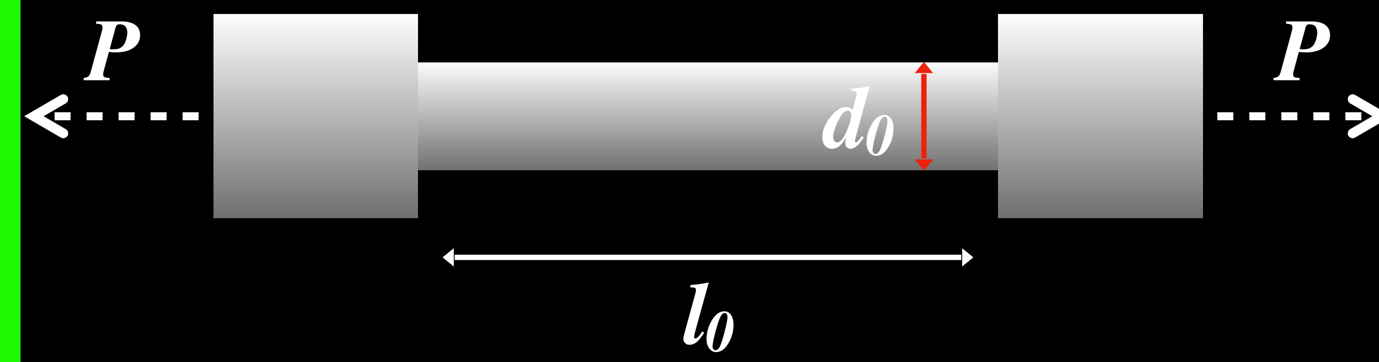
$$\text{Max. allowable load} = \frac{2000}{1.4} = 1428 \text{ N}$$

- This is a deterministic approach. Stochastic (statistics-based) approaches that focus on the design's statistical survivability are also commonly used. These require many samples.

MATERIALS

- Deciding upon a material is a crucial step (often the first) in a design process.
  - This affects everything from cost to dimension to manufacturing process.
- To arrive at an understanding of allowable stresses in a component, we need to know how a material behaves.
  - What & how are the points where the material fails when subjected to stresses?

Tensile Test

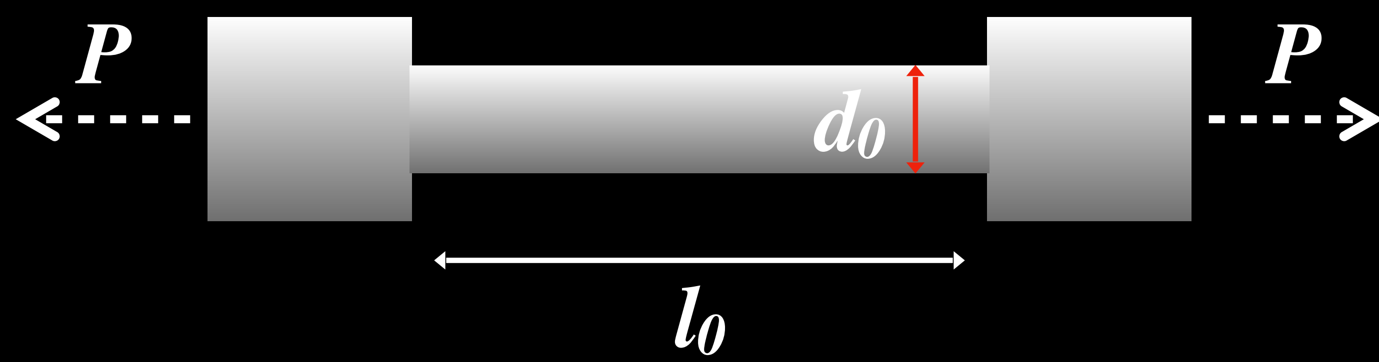


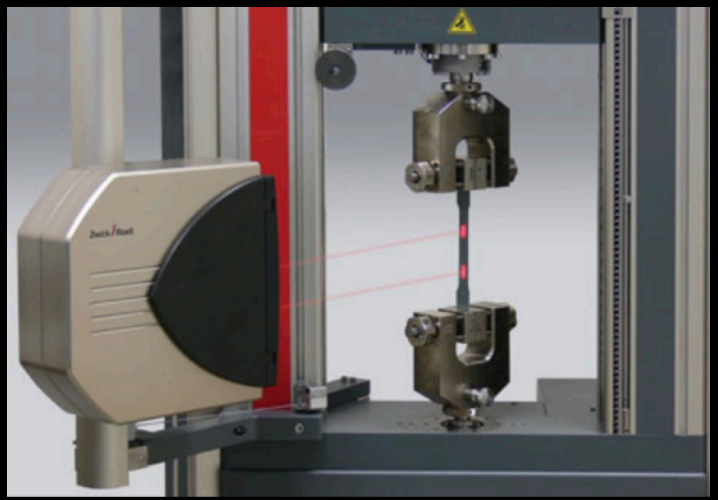
Load P is converted to stress σ by

$$\sigma = \frac{P}{A_0} \quad \text{where} \quad A_0 = \frac{1}{4}\pi d_0^2$$

By measuring how the material responds to this stress, the relationship between input stress σ and strain ϵ can be determined

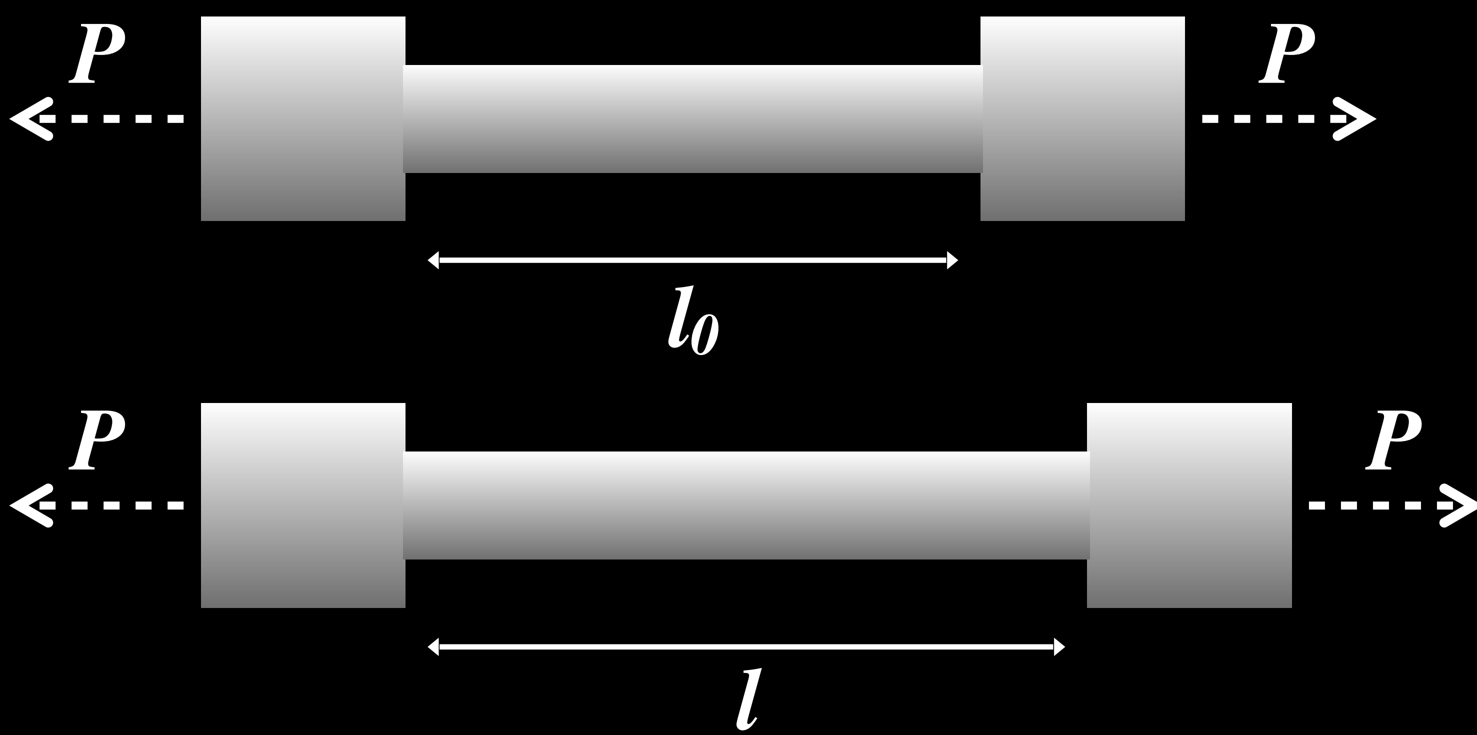
TENSION TEST

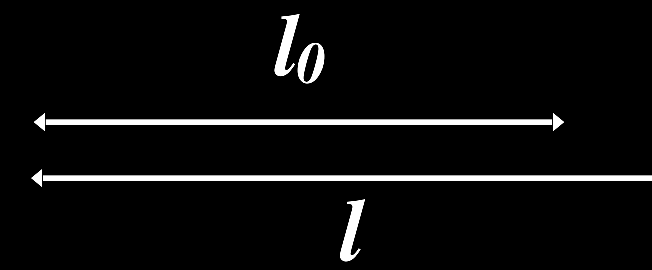




- The relationship between stress and strain can be measured with a tension tester unit.
    - This places the sample between two arms that compress/extend.
    - Change in material length l is measured
        - Measurement is conducted with an extensometer.

STRAIN

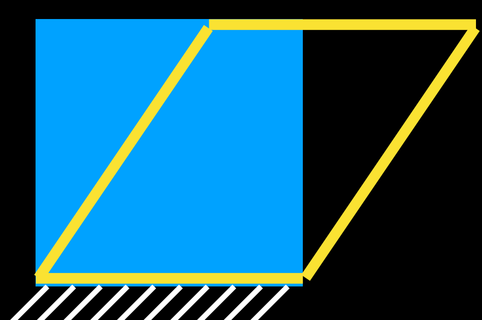




$$\delta = l - l_0$$

Deformation

Normal strain



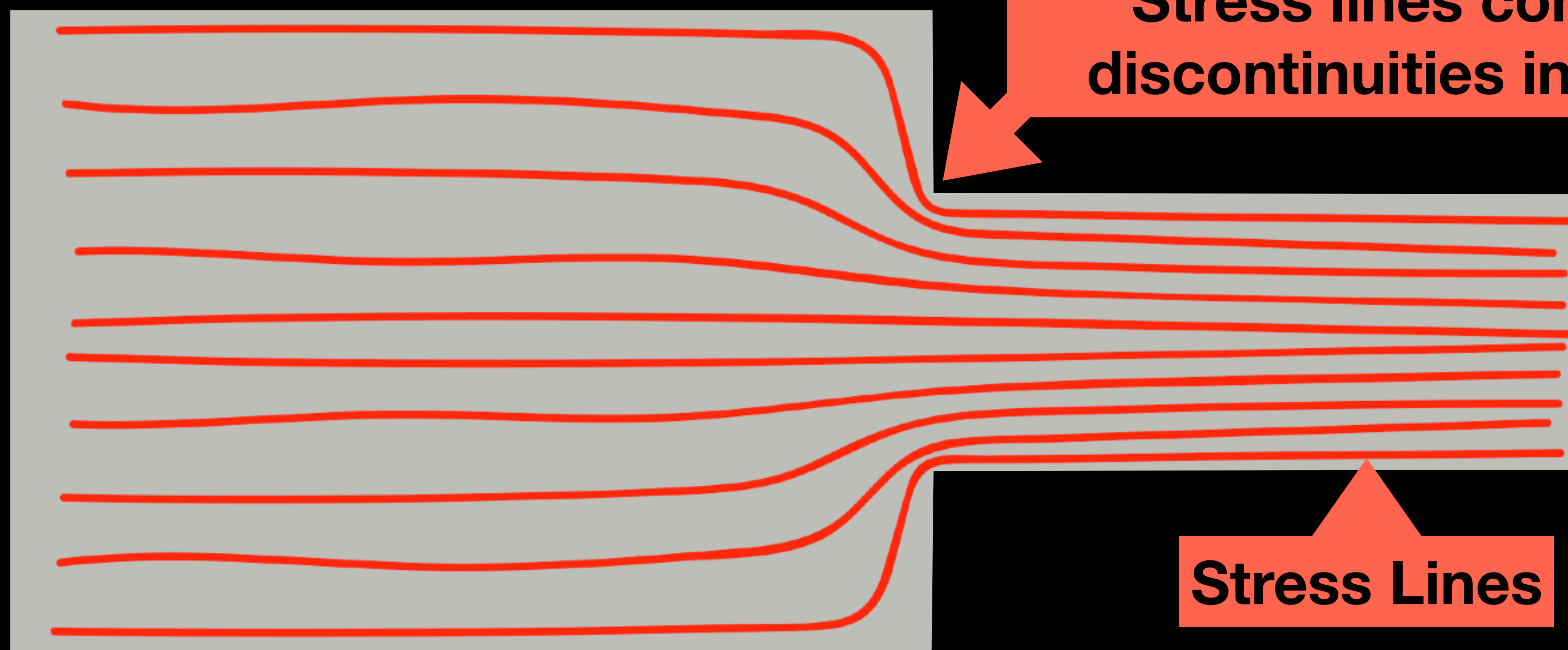
Shear strain

Rather than be described by the actual deformation length ($l-l_0$), normal strain **ϵ** is described by the change in unit length of the material

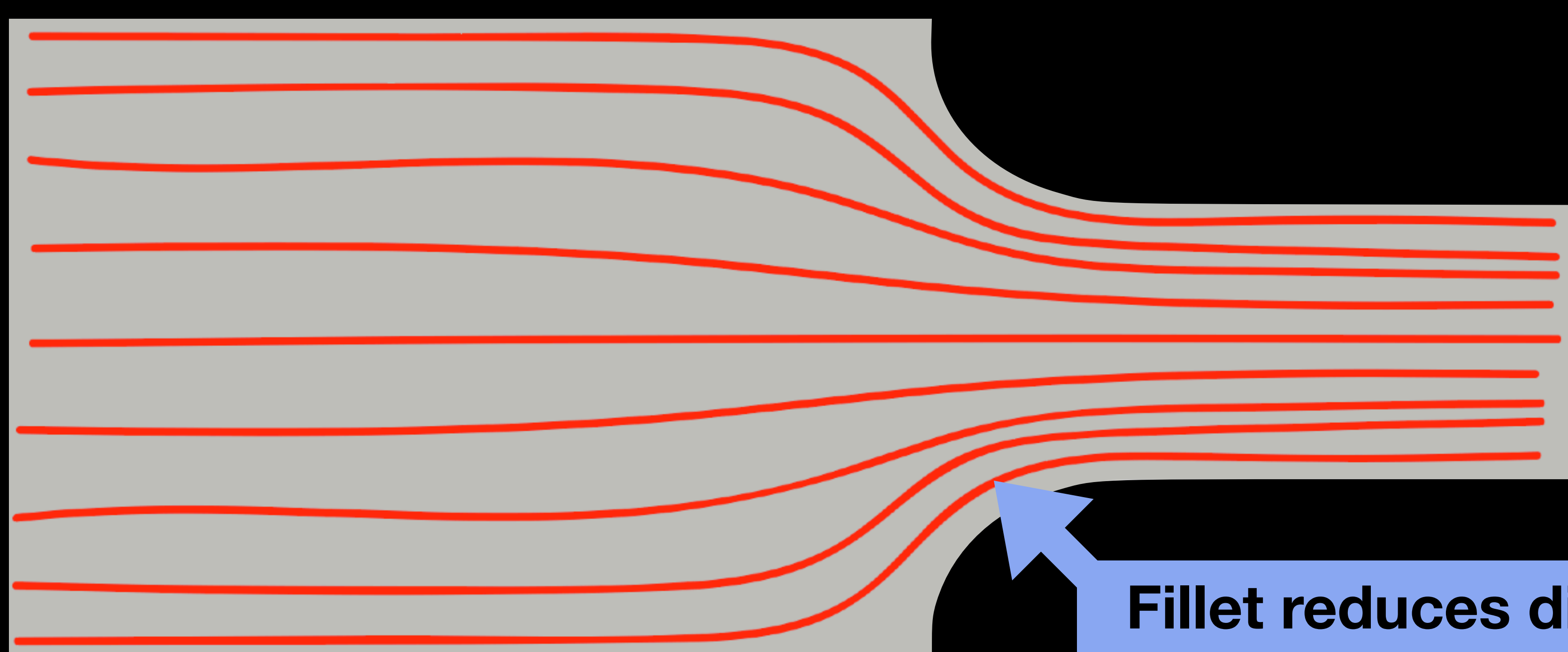
$$\epsilon = \frac{\delta}{l_0}$$

STRESS CONCENTRATION

Stress lines concentrate near abrupt discontinuities in a body ('stress risers')



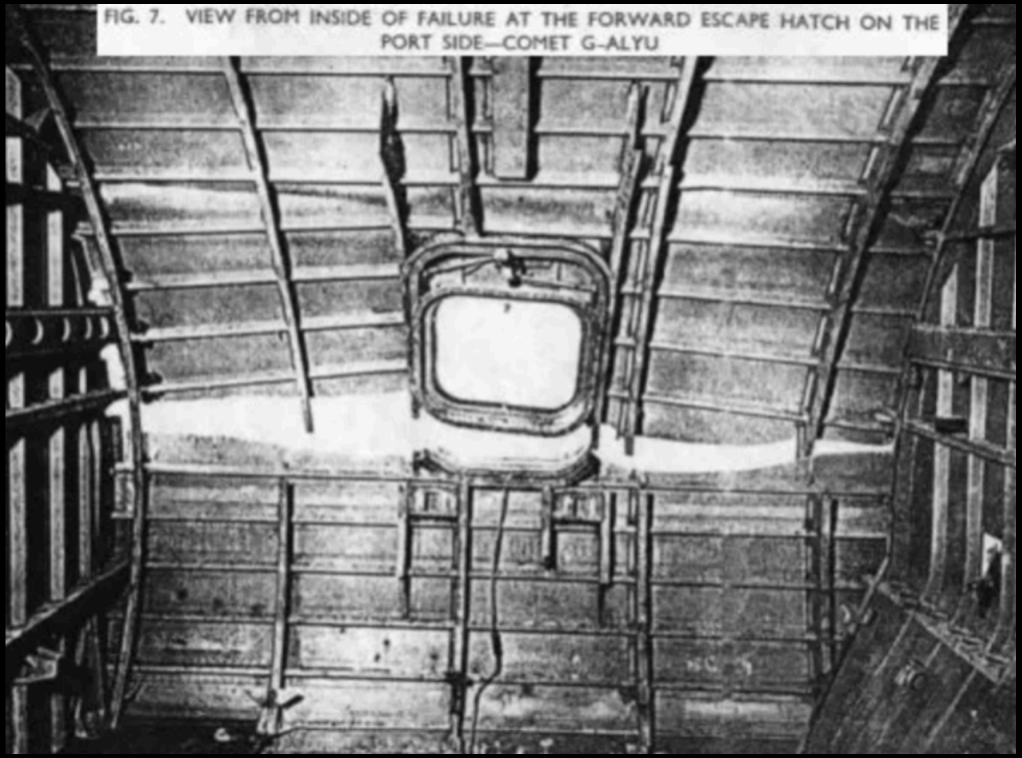
Stress Lines



Fillet reduces discontinuity's abruptness

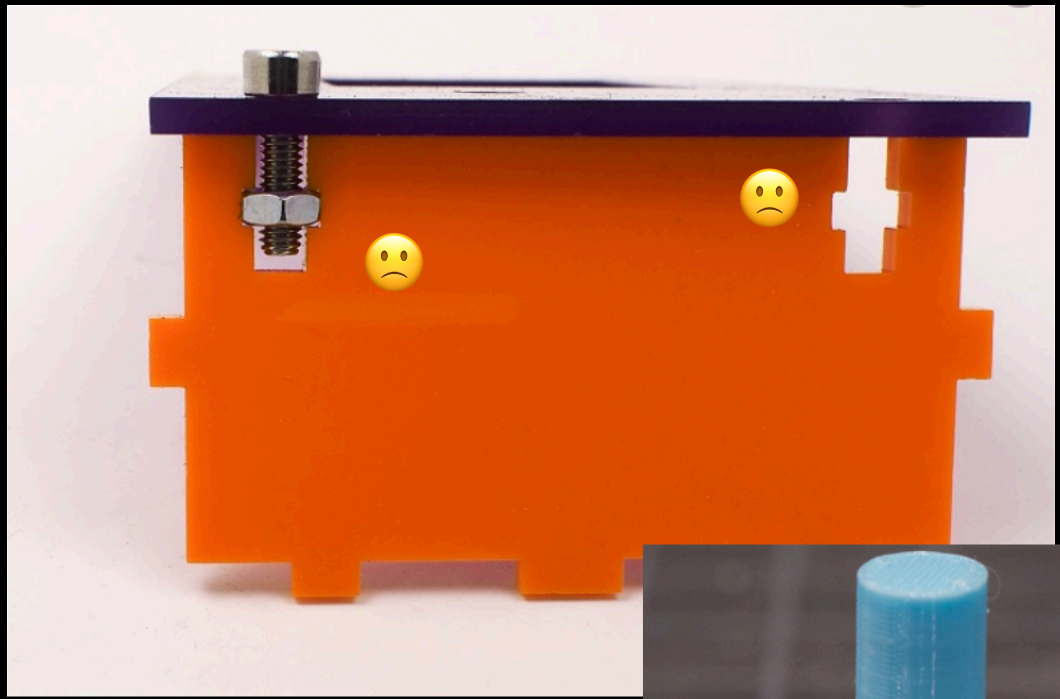
- Using force lines, we can illustrate the stresses in a body.
- These can be calculated (usually using FEA approaches).
- They can provide an intuitive, qualitative visualisation of regions in a body where stresses rise.

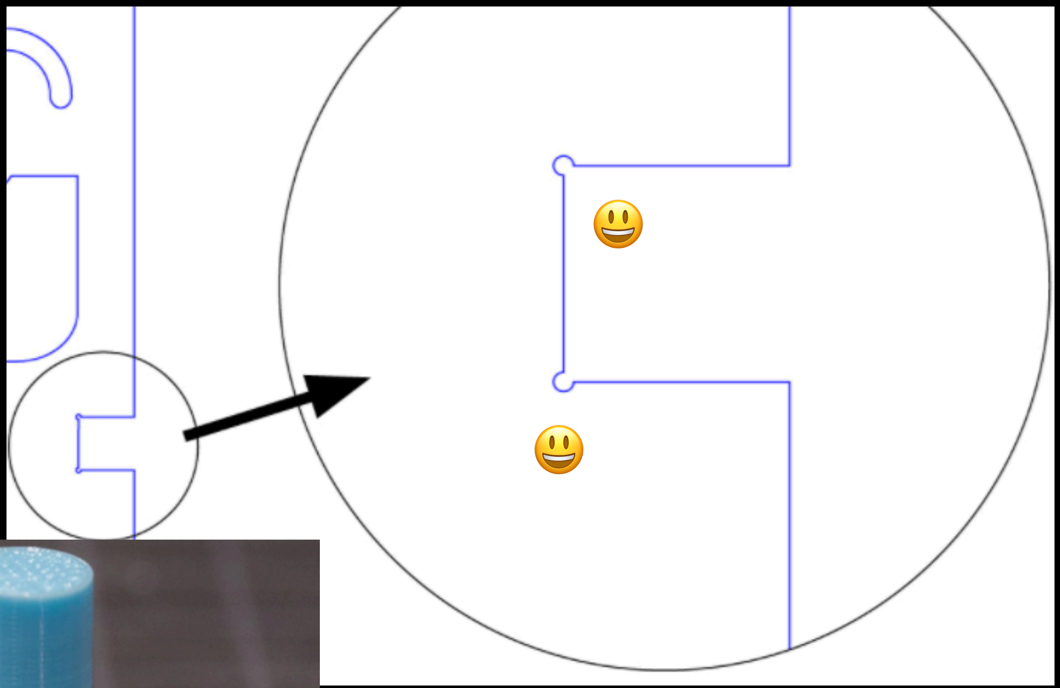
STRESS CONCENTRATION

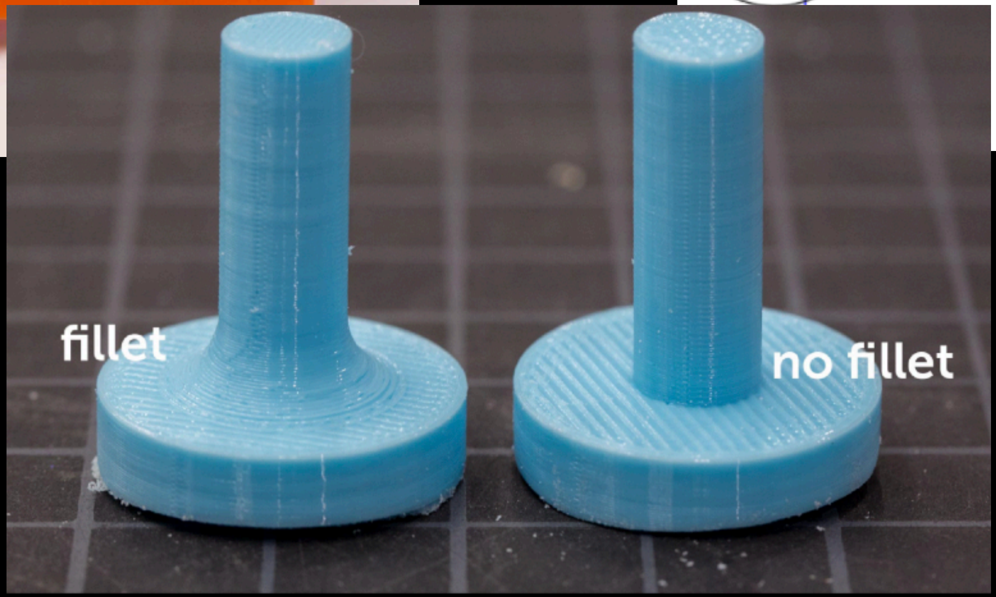


STRESS CONCENTRATION

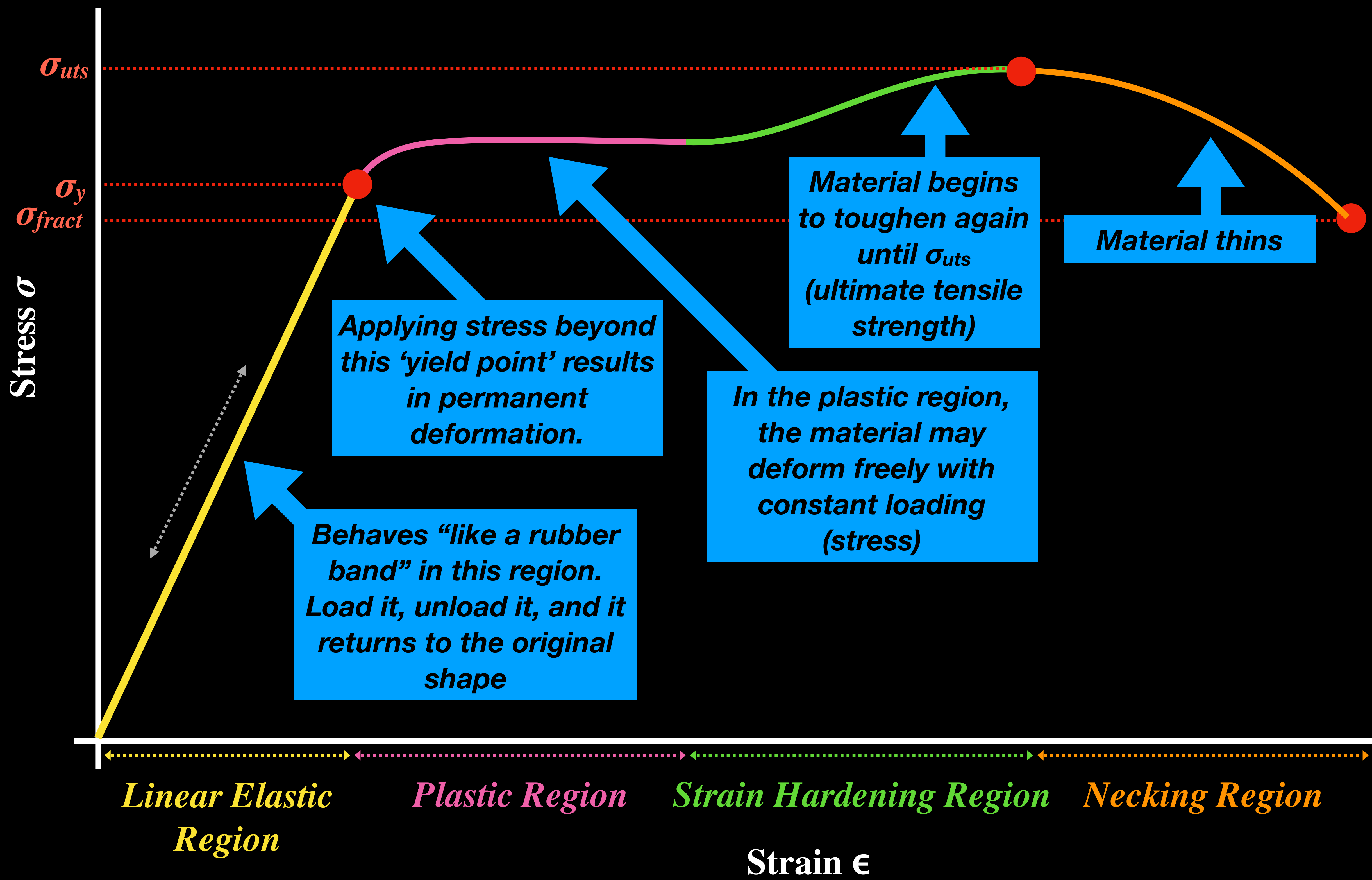
- When laser cutting, reduce stress concentration by avoiding abrupt angular changes.
- Add fillets when 3D printing to more evenly distribute stresses







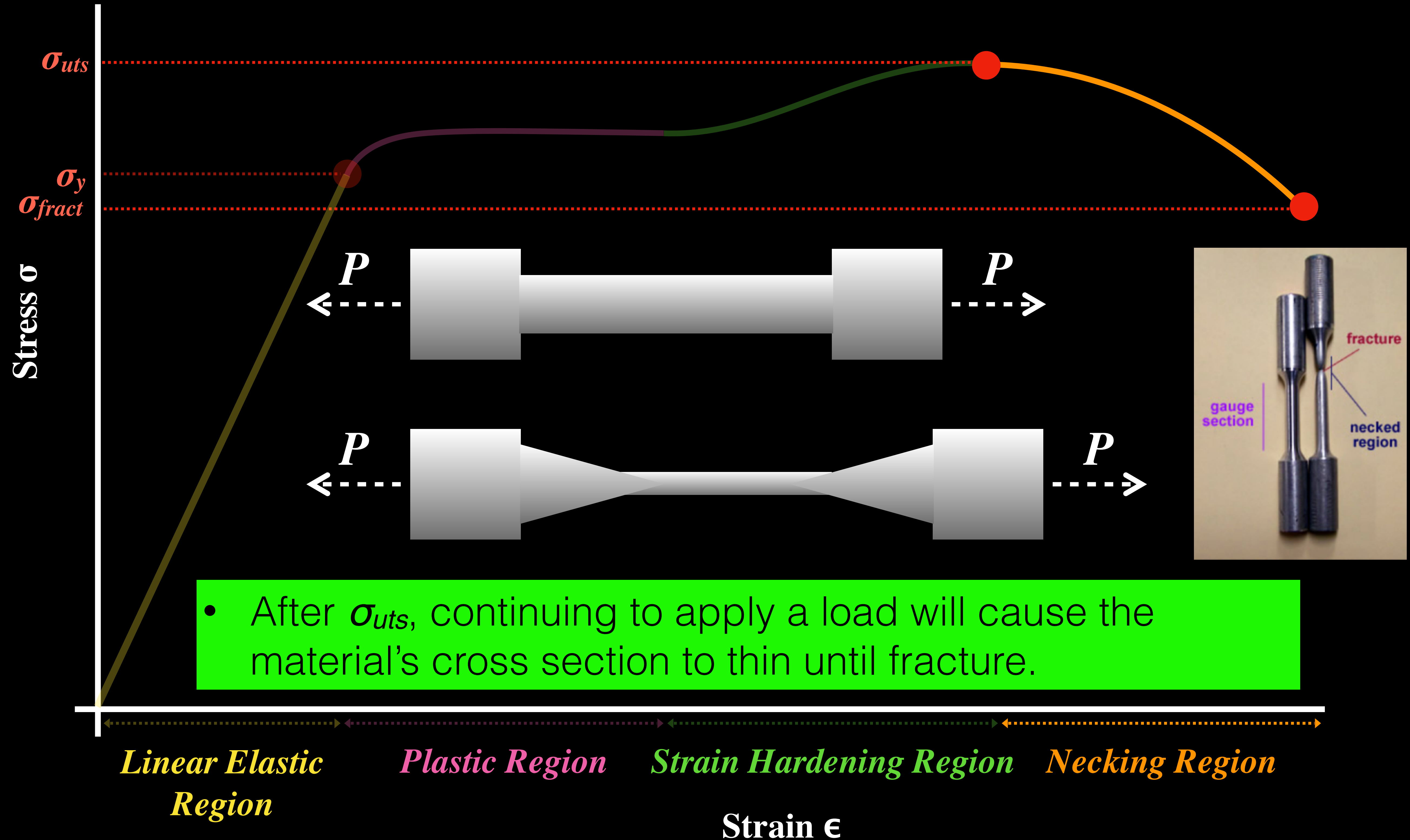
STRESS-STRAIN DIAGRAM



A NOTE ABOUT UNITS

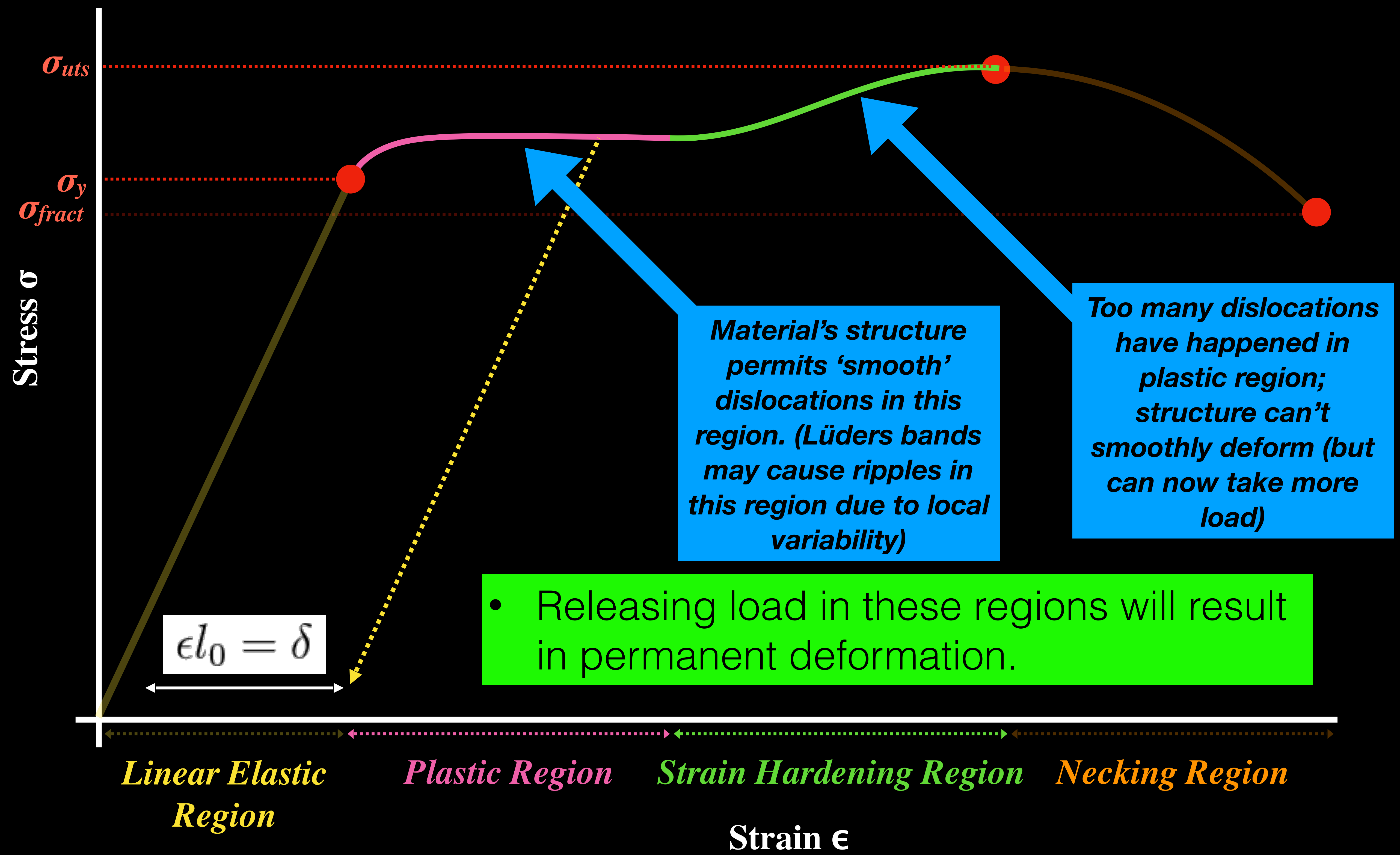
FORCE Unit: Newtons (N) 1 N = 1 kg · 1 m/s^2 (In engineering, we often use kN)	STRESS (σ, sigma) Unit: Pascal in SI (PSI in Imperial units) (Newtons per square metre: 1 N/m^2) MPa and GPa are common in mech. engineering.	STRAIN (ϵ, epsilon) Unit: dimensionless (ratio of two lengths), but you often see it as a ratio of lengths (e.g., m/m)

NECKING REGION



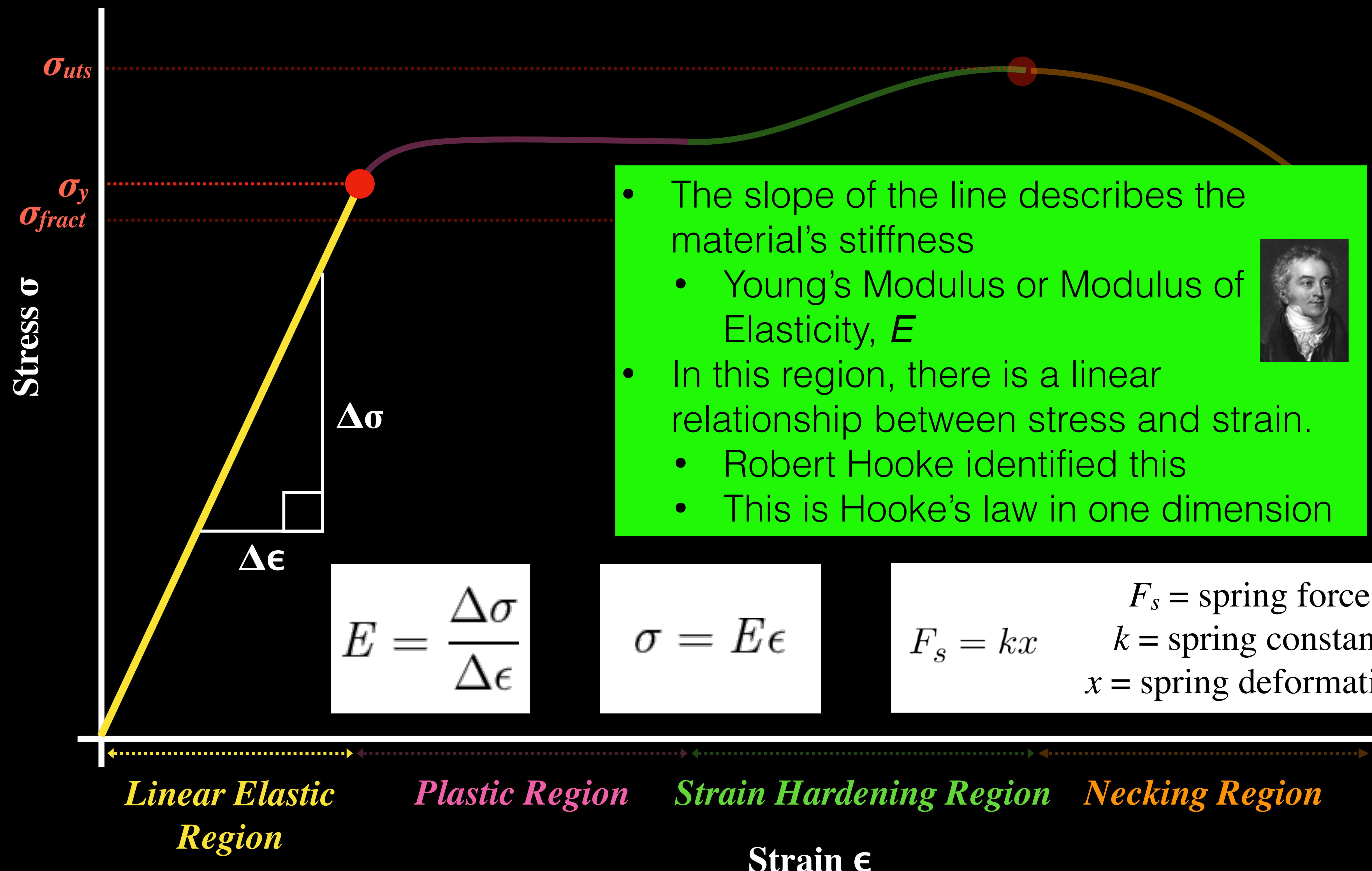
- After σ_{uts}, continuing to apply a load will cause the material's cross section to thin until fracture.

PLASTIC & STRAIN HARDENING REGIONS



- Releasing load in these regions will result in permanent deformation.

LINEAR ELASTIC REGION



- The slope of the line describes the material's stiffness
  - Young's Modulus or Modulus of Elasticity, *E*

- In this region, there is a linear relationship between stress and strain.
  - Robert Hooke identified this
  - This is Hooke's law in one dimension

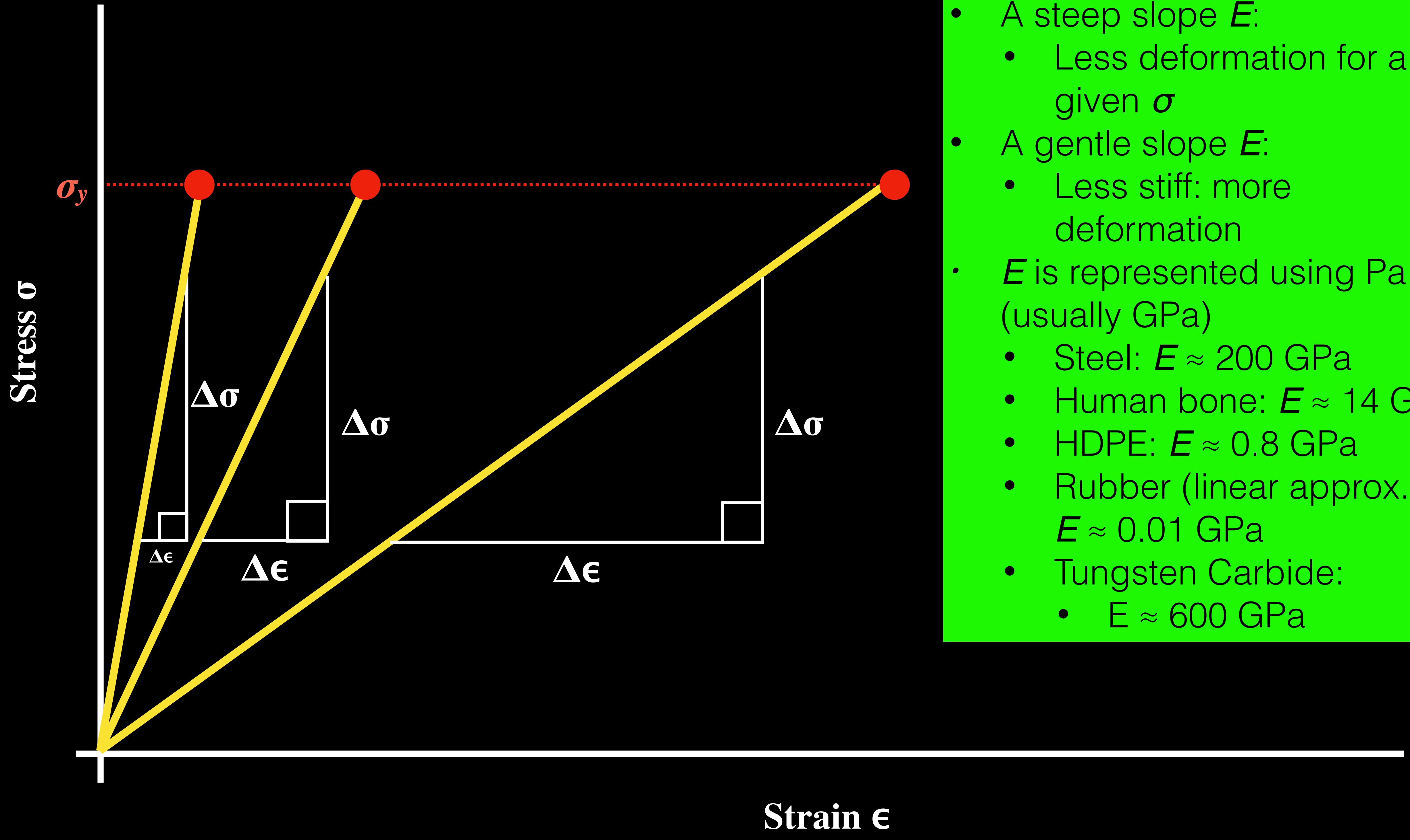
$$E = \frac{\Delta\sigma}{\Delta\epsilon}$$

$$\sigma = E\epsilon$$

$$F_s = kx$$

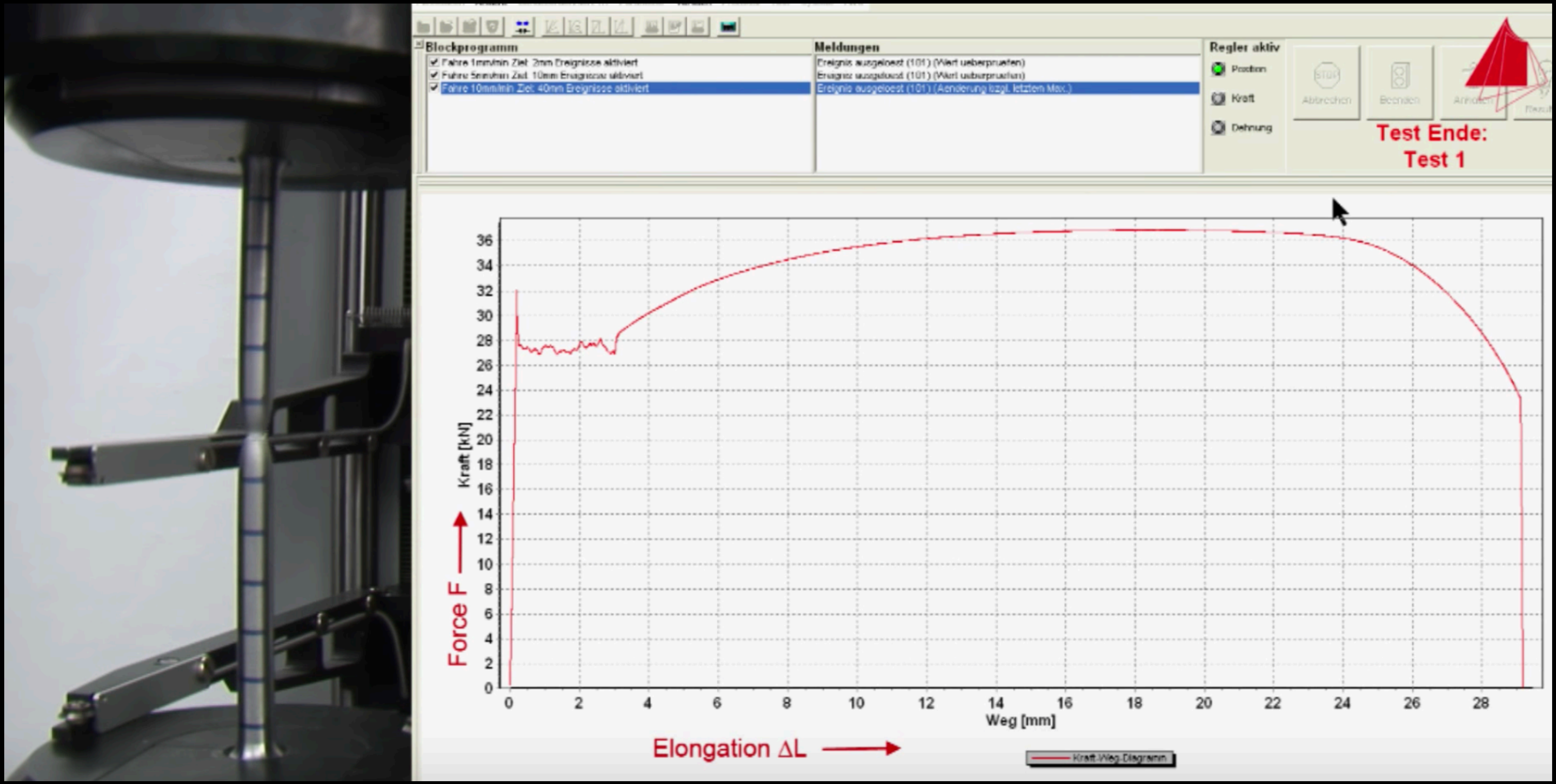
F_s = spring force
k = spring constant
x = spring deformation

MODULUS OF ELASTICITY



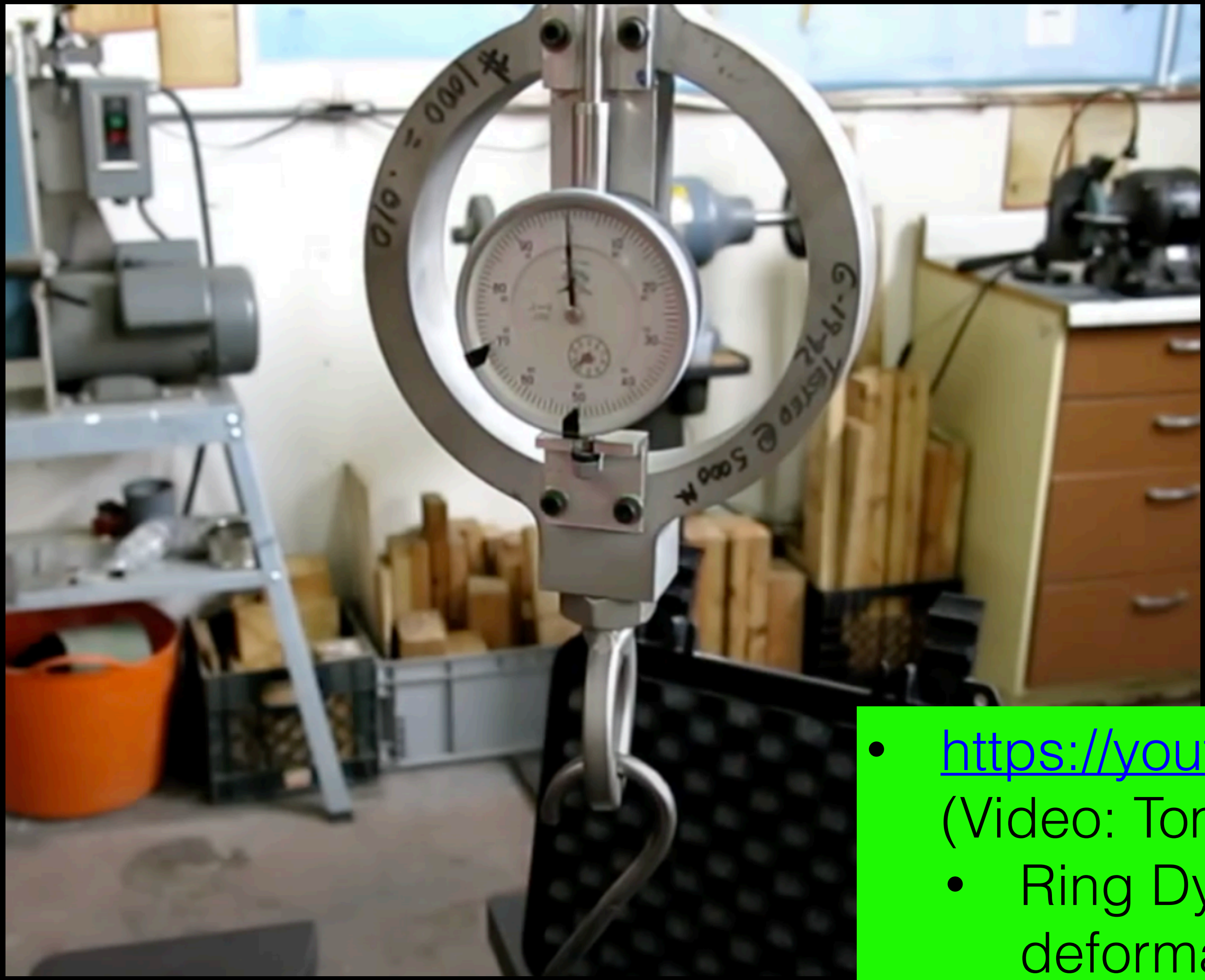
- A steep slope *E*:
  - Less deformation for a given σ
- A gentle slope *E*:
  - Less stiff: more deformation
- *E* is represented using Pa (usually GPa)
  - Steel: $E \approx 200$ GPa
  - Human bone: $E \approx 14$ GPa
  - HDPE: $E \approx 0.8$ GPa
  - Rubber (linear approx.): $E \approx 0.01$ GPa
  - Tungsten Carbide:
    - E ≈ 600 GPa

VIDEO: TENSION TEST



https://youtu.be/D8U4G5kcpcM?t=86

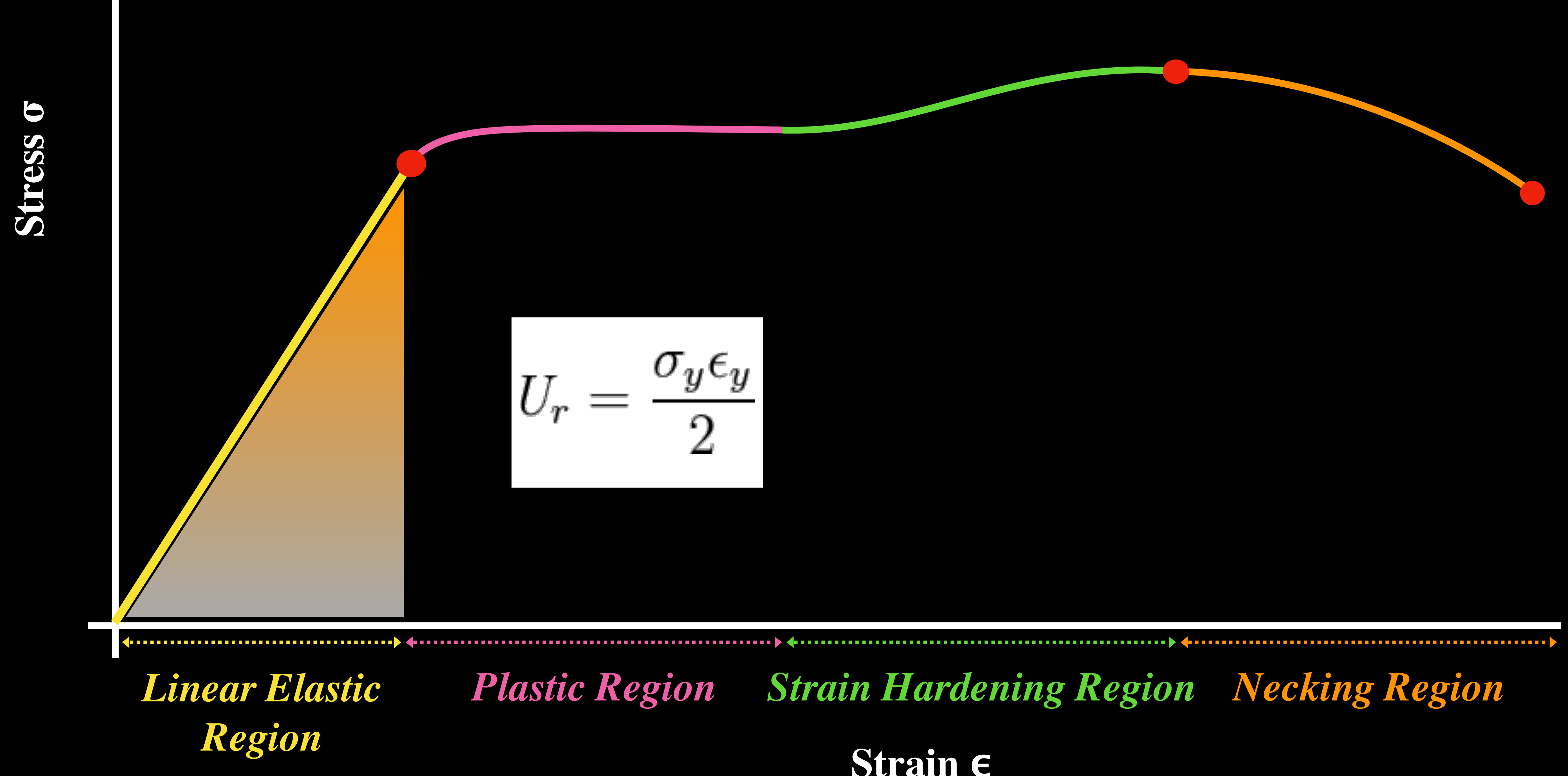
OBSERVING MATERIAL YIELD



- https://youtu.be/kvkFWEuFxck?t=440 (Video: Tom Lipton)
  - Ring Dynamometer - elastic deformation in aluminium ring is measured with a dial indicator.
  - Hook is loaded (stressed), and permanent deformation is induced.

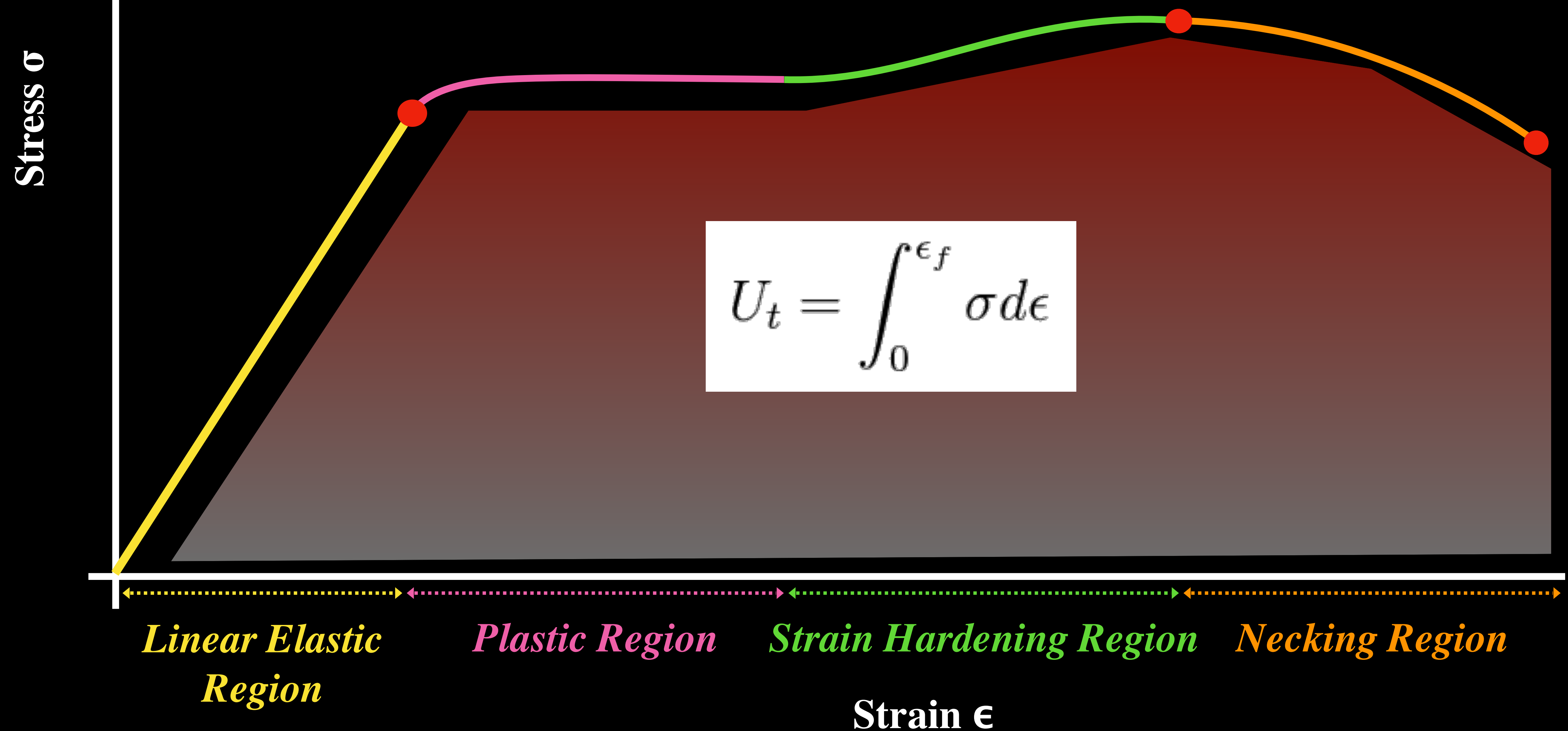
RESILIENCE

- The amount of energy required to arrive at different points in a material's stress/strain curve can be determined by finding the area under different parts of the curve.
- Area under Linear Elastic Region: amount of energy required to make the material yield.
  - This is called the Modulus of Resilience (*U_r*, sometimes *u_r*), with units of J*m^{-3}
- Given the same σ_y, a stiffer material will have a lower *U_r* than a less stiff material.



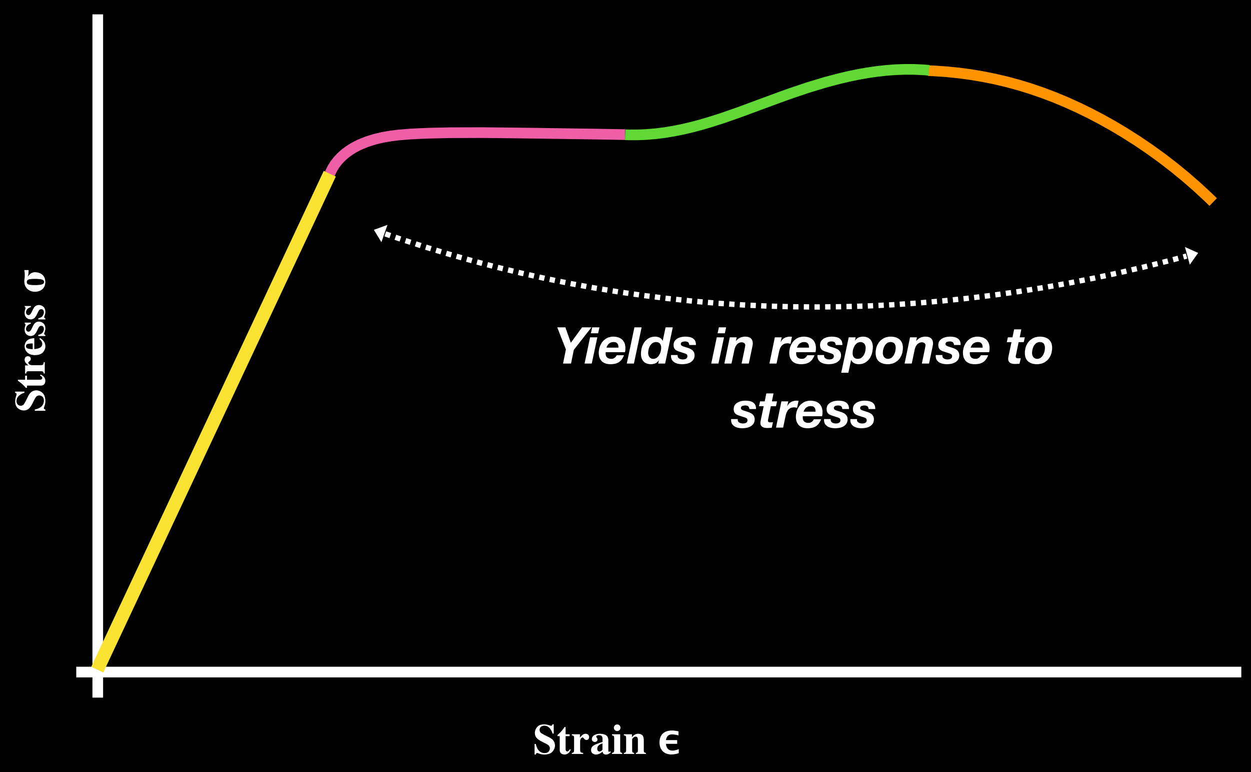
TOUGHNESS

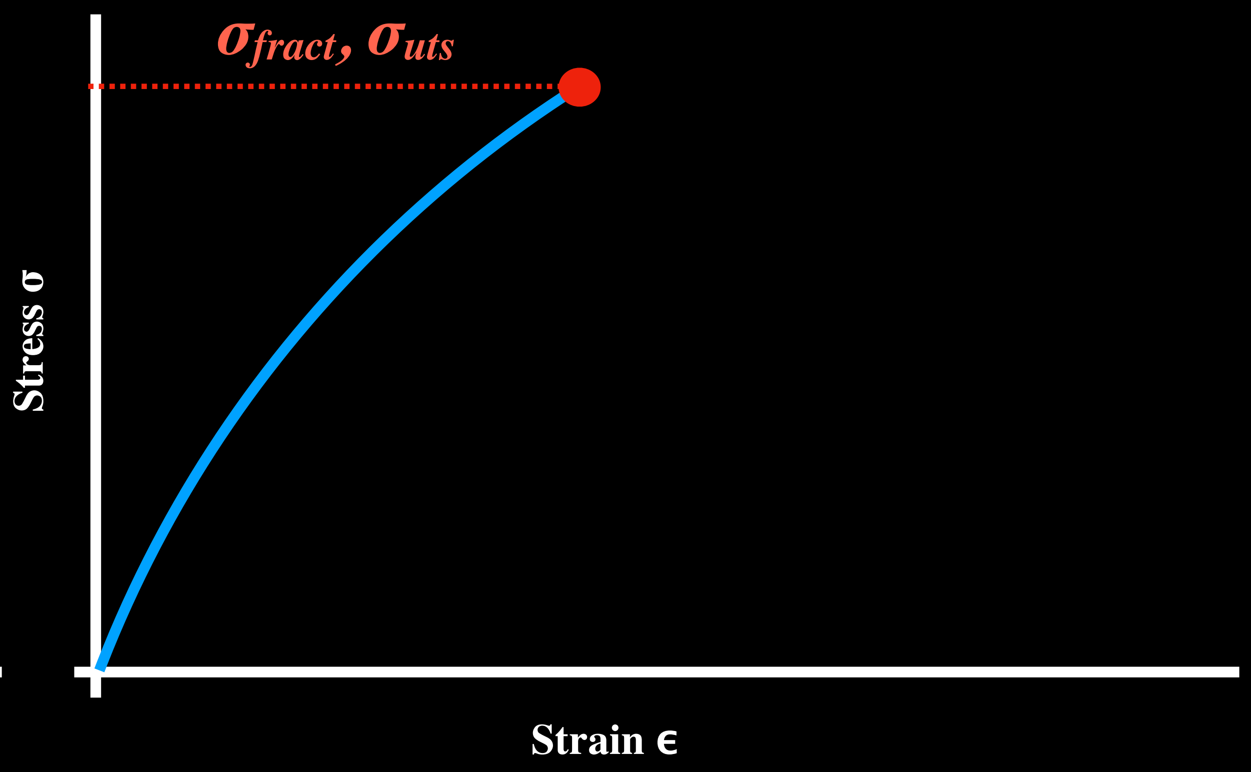
- The amount of energy required to reach the point of fracture can be determined by finding the area under the entire stress-strain diagram.
  - This value is known as the modulus of toughness, U_t
  - Unlike the linear modulus of resilience, this is usually found using numerical integration approximations, graphical approaches, etc.
- For most structural mechatronic engineering situations, we focus more on U_r



$$U_t = \int_0^{\epsilon_f} \sigma \, d\epsilon$$

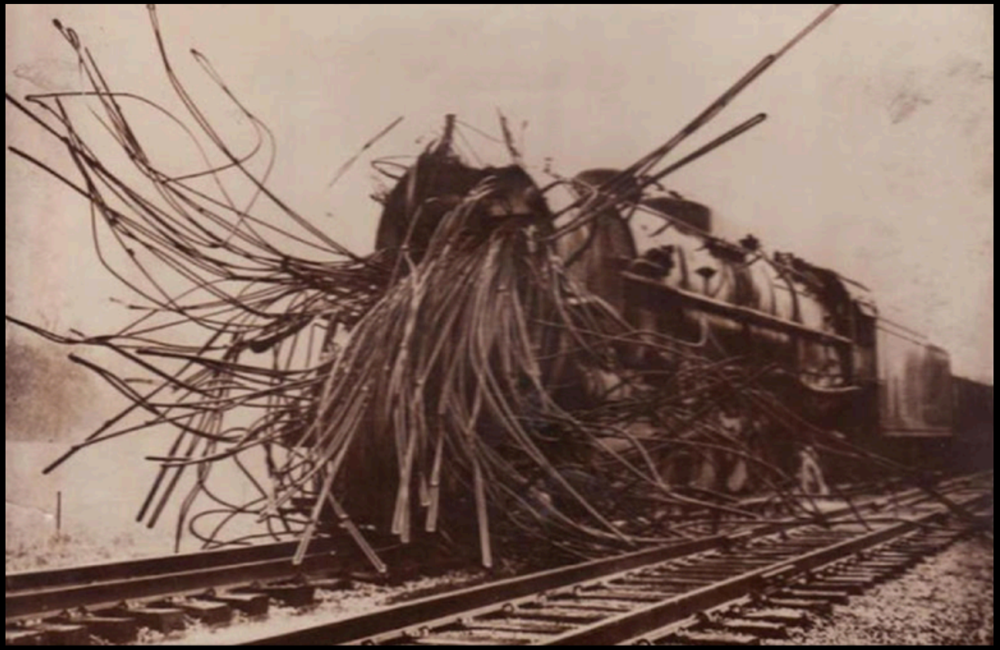
DUCTILE/BRITTLE

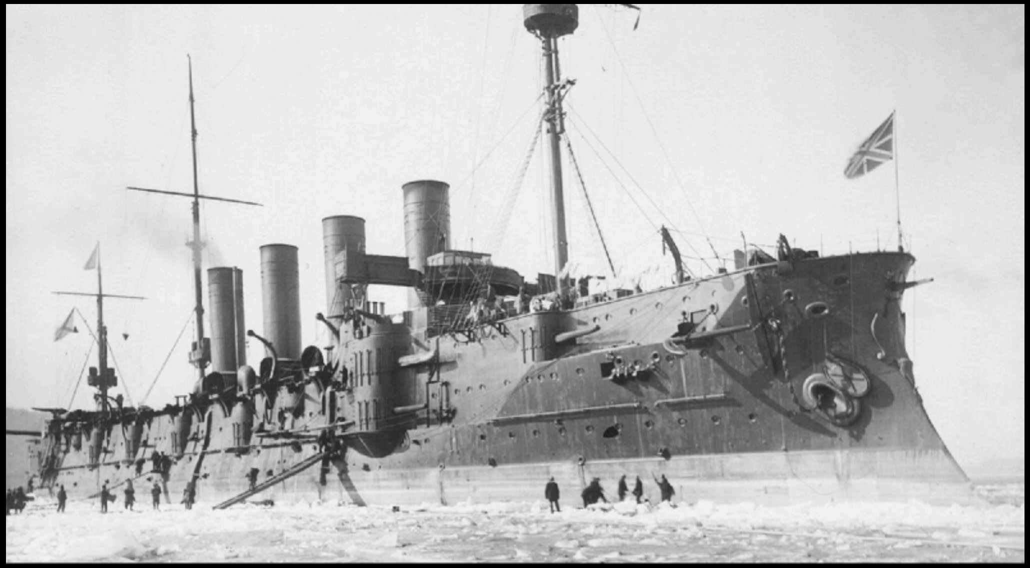


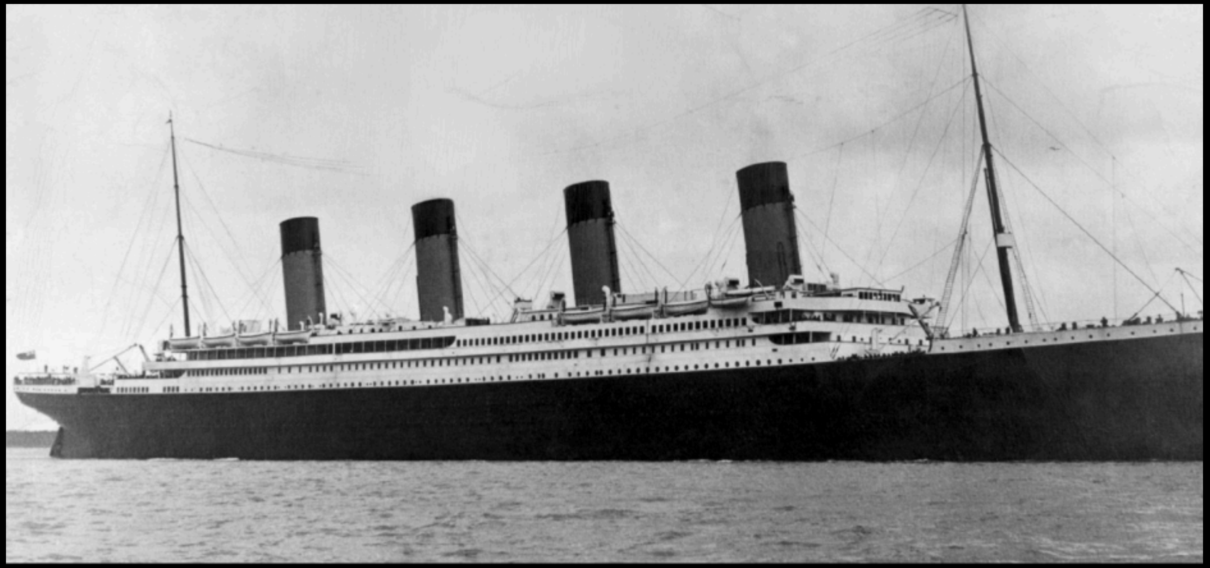


- Ductile materials exhibit yielding in response to stress.
  - Silver (Ag): very ductile
- A non-ductile material has the same point of ultimate tensile strength as its fracture point.
  - Failure occurs in the elastic region.
    - E.g., Glass: flex then break, no plastic deformation

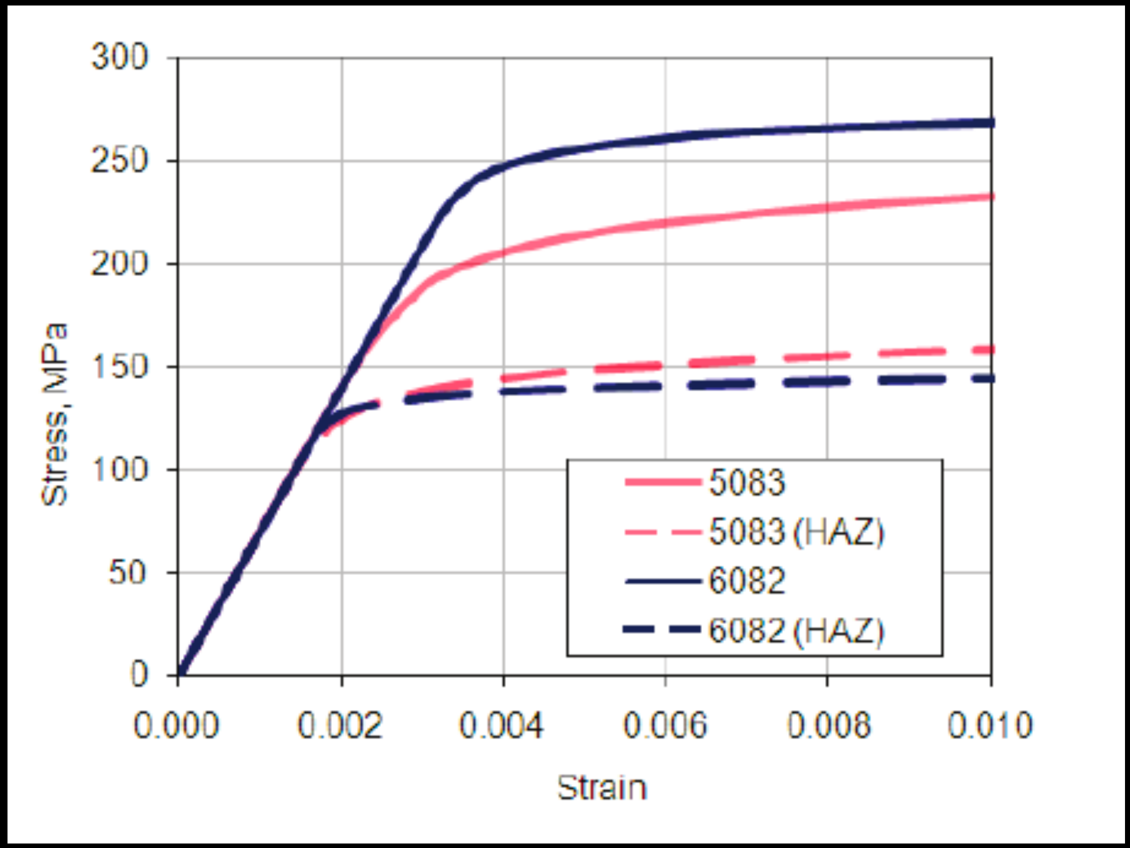
DUCTILE/BRITTLE







EXAMPLE STRESS-STRAIN CURVE



https://www.researchgate.net/figure/Material-stress-strain-curves-for-aluminium-alloys-5083-H116-and-6082-T6-in-the-parent_fig2_233118591

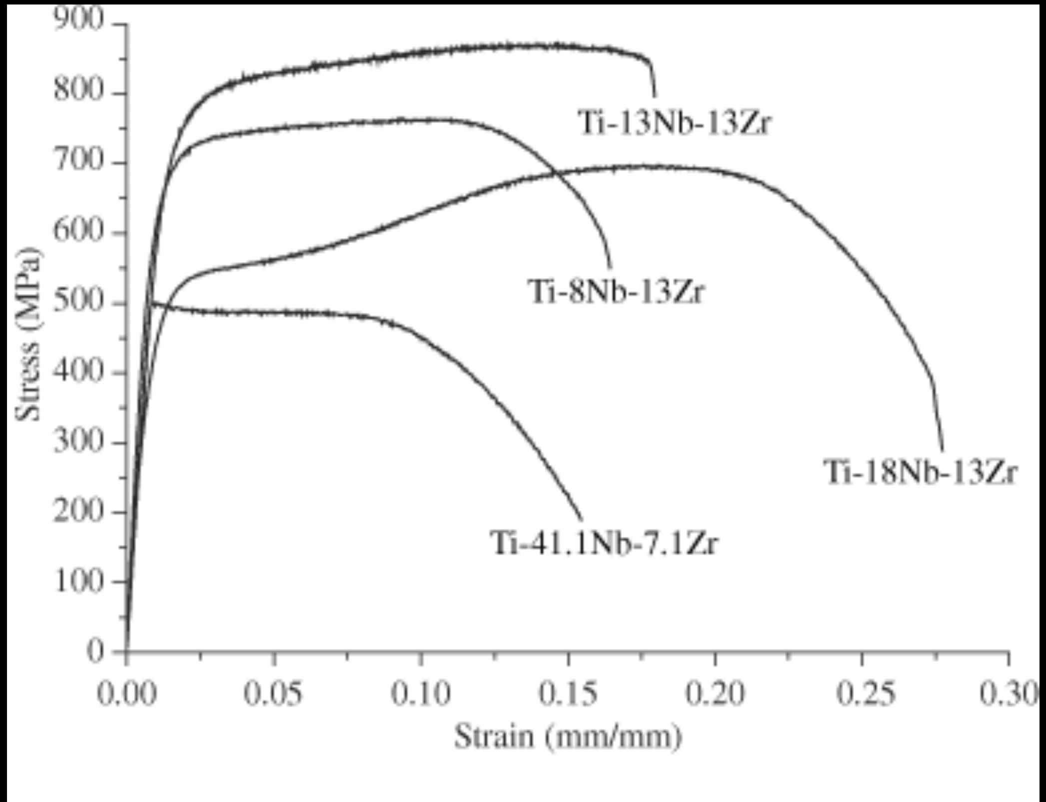


Figure 2. Full stress-strain curves for Ti-Nb-Zr alloys.

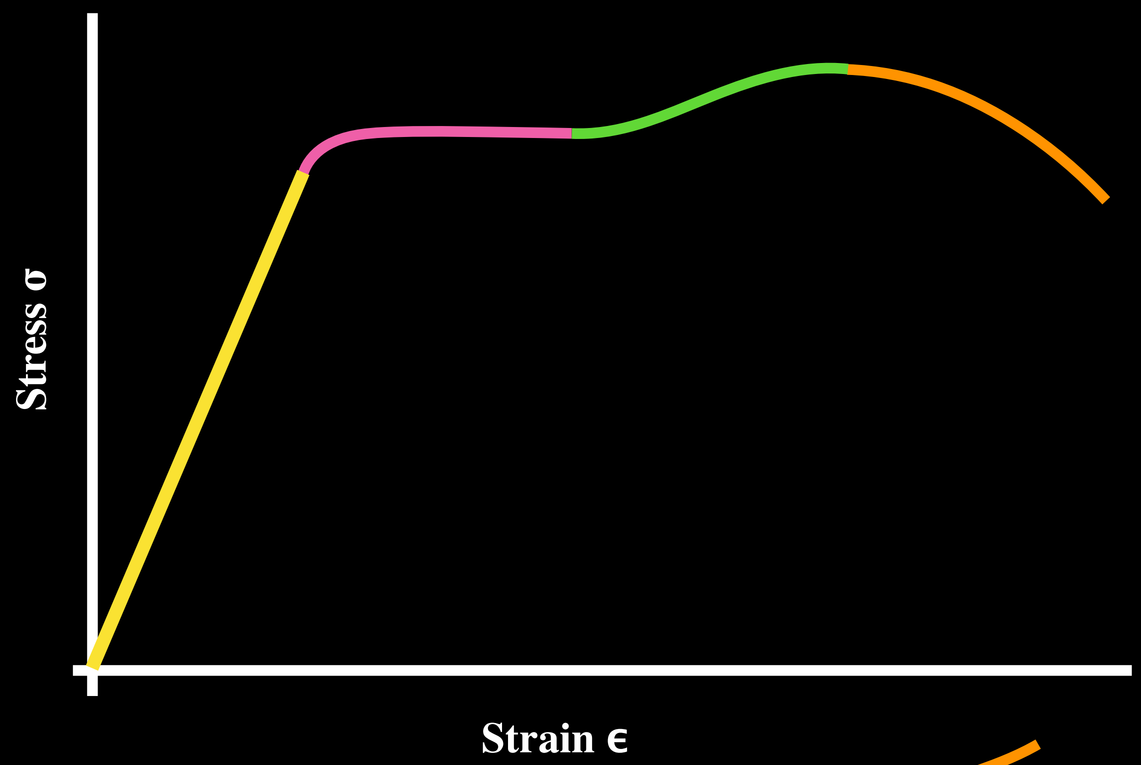
http://www.scielo.br/scielo.php?script=sci_arttext&pid=S1516-14392005000400013

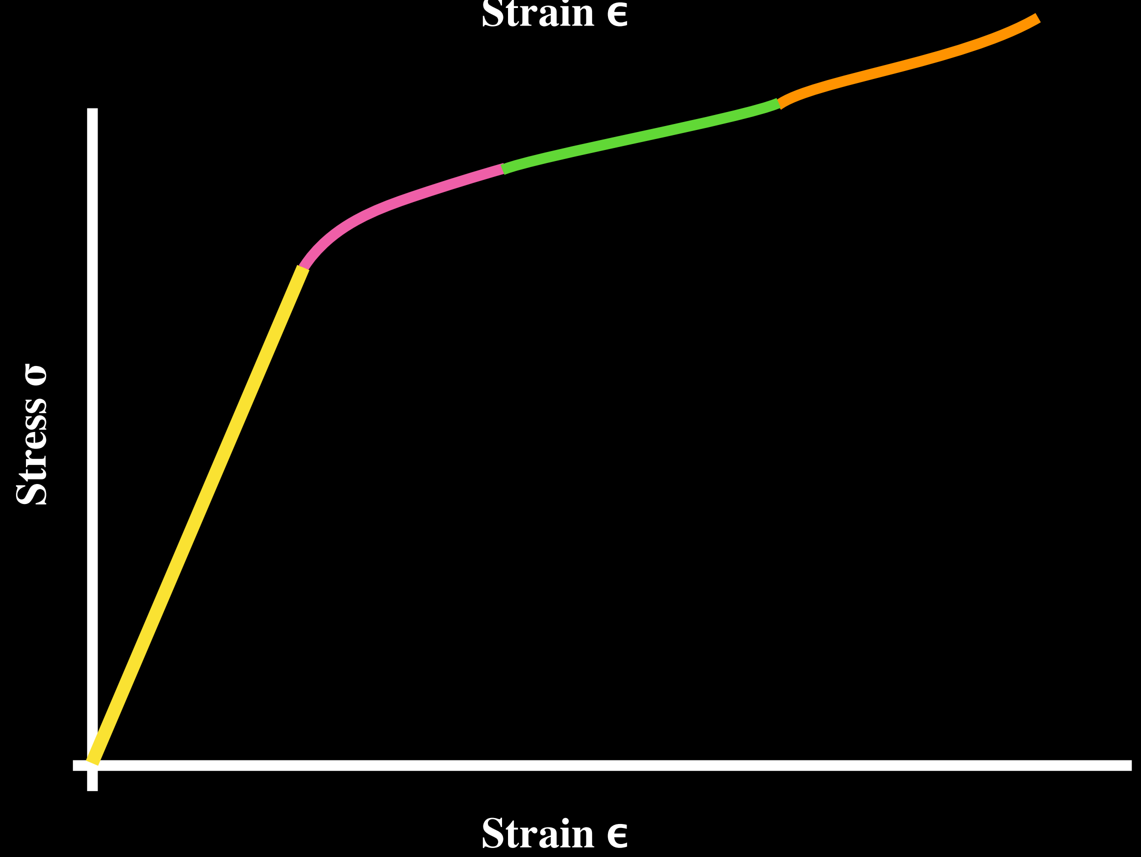
Linear elastic region, affected by "Heat Affected Zones" in different aluminium alloys

Stress-strain curves for various Titanium alloys. Tradeoff between cost, ultimate tensile strength, machinabilty, etc.

TRUE VS. ENGINEERING STRESS-STRAIN

- Up to now, we have been assuming that the diameter of the sample doesn't change.
  - This assumption leads to apparent flat or decreasing slopes in stress-strain diagrams.
- As the sample is stressed, the diameter (and area) decreases.
  - If this decrease in area is taken into account, then the stress-strain diagram would show an upward slope until fracture.
    - Such a diagram is called a "true stress-strain diagram"





COLD WORKING

- There are many ways to work materials with *high temperatures*
  - *High temperatures*: temps. above recrystallisation temperature
  - These approaches tend to greatly affect the material's structure and, thus, its whole stress-strain curve.
- Working a material at normal temperatures ('cold working'):
  - Stress is applied to material into its plastic region.