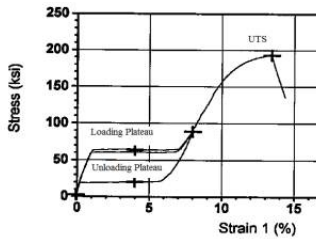
Class 4: Mechanical Properties



http://www.memry.com/nitinolfaq/nitinolfaq.html#superelasticity

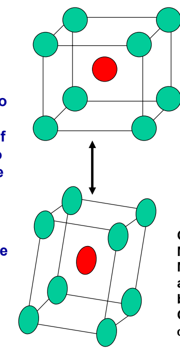
PRIME Modules
Project-based Resources for Introduction to Materials Engineering

Shape memory alloys change phase due to temperature or stress changes

Shape memory alloys such as NiTi convert from an austenite (CsCl like structure) to monoclinic

This phase change occurs due to temperature. That is, at higher temperatures it is austenite but if it is cooled quickly it converts to martensite. It then returns to the austenite shape when it is reheated.

The phase change from austenite to martensite can also be stress induced (applying a stress causes austenite to change to martensite)



Crystal Structure of NiTi
Austenite Phase
Simple Cubic
a = 3.105 Angstroms

Crystal Structure of NiTi
Martensite Phase
Monoclinic
a = 2.889 Angstroms
b= 4.12 Angstroms
C = 4.62 Angstroms
$\alpha=\gamma=90°$; $\beta=96.8°$

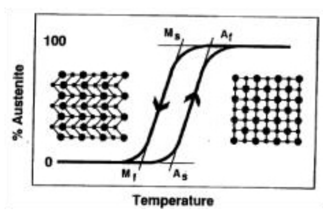
The SMA phase change causes change in shape and mechanical properties

There are 2 phenomena that make SMA's useful.

Shape Memory: At high temperatures, the product can be shaped into a certain form. At this point, it has an austenite crystal structure.

When it is cooled quickly, it becomes martensite. It can be mechanical deformed.

When it is reheated to austenite, it will resume the sample shape it had in the austenite form.



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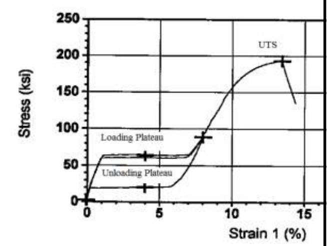
The stress strain for a super elastic material has a plateau

Super-elastic: In the martensite phase, the sample can undergo large changes in strain under a constant applied stress.

Typical metals have less than 1% strain!

This appears as a plateau on the stress strain diagram.

In an application like a stent, this allows the device to change size drastically (from closed to open).



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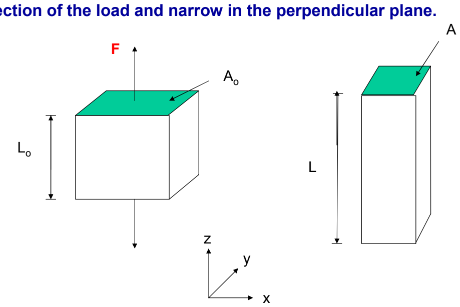
Stress strain behavior of a material describe how the sample shape changes when a load is applied.

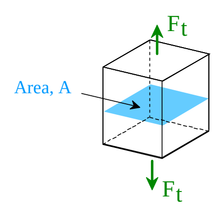
When a tensile load is applied, most materials stretch in the direction of the load and narrow in the perpendicular plane.



Stress is the applied force over a cross sectional area

An *engineering* stress-strain diagram plots the stress (force applied in tension normalized for the *original* cross sectional area)

Stress has units:
N/m2 or lb/in2



$$\sigma = \frac{F_t}{A_o}$$

original area before loading

Figure from Callister

Definition of stress, strain, Young's modulus, and Poisson's ratio are independent of the material type

Engineering Tensile Stress

$$\sigma = \frac{F}{A_o}\left[Pa = \frac{N}{m^2}\right]$$

Engineering Tensile Strain

$$\varepsilon = \frac{L - L_o}{L_o}[\text{unitless}]$$

Hooke's Law

$\sigma_z = \varepsilon_z E$ [Pa]

E = modulus of elasticity or Young's Modulus

Poisson's Ratio: A measure of volume change

$$\upsilon = -\frac{\varepsilon_x}{\varepsilon_z} = -\frac{\varepsilon_y}{\varepsilon_z}[\text{unitless}]$$

metals: ν ~ 0.33
ceramics: ~0.25
polymers: ~0.40

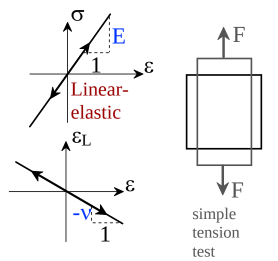


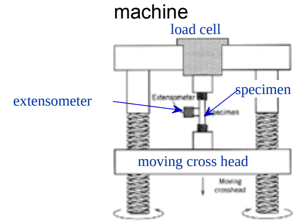
Figure adapted from Callister

Stress strain tests are set by ASTM standards

American Society for Testing and Materials (ASTM) sets standards for testing of materials which includes

- **sample size and shape**
- **pull rates**
- **instructions on loading samples**

Typical tensile test machine

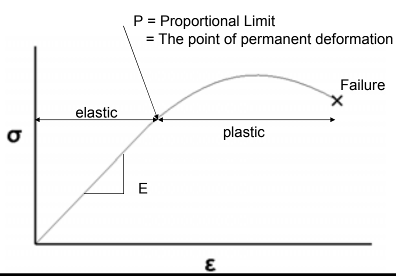


Adapted from Fig. 6.3, *Callister 6e.* (Fig. 6.3 is taken from H.W. Hayden, W.G. Moffatt, and J. Wulff, *The Structure and Properties of Materials*, Vol. III, *Mechanical Behavior*, p. 2, John Wiley and Sons, New York, 1965.)

In general, stress strain curves give information on elastic and plastic deformation regimes

In the elastic regime, deformation to an applied stress is temporary

In the plastic regime, an applied stress causes permanent deformation



Initially, elastic deformation takes place as the atomic bonds stretch

Initially, the force causes bonds to stretch. This is elastic deformation.

If the force is removed, the bonds will return to their original equilibrium spacing and the sample will regain its original shape and size.

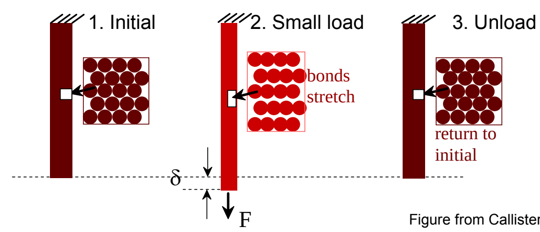


Figure from Callister

Dislocation motion causes permanent (plastic) deformation

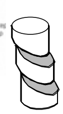
When a force is exerted on a sample, edge dislocation can break their atomic bond and form a new bond (move over one spot)

The required force depends on the atomic bond strength and spacing.

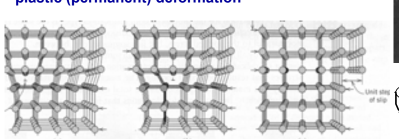
These incremental motions result in macroscopic, plastic (permanent) deformation

Plastically stretched zinc single crystal.

Adapted from Fig. 7.9, *Callister 6e.* (Fig. 7.9 is from C.F. Elam, *The Distortion of Metal Crystals*, Oxford University Press, London, 1935.)



Adapted from Fig. 7.8, *Callister 6e.*

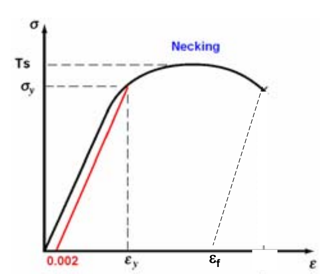


Adapted from Fig. 7.1, *Callister 6e.* (Fig. 7.1 is adapted from A.G. Guy, *Essentials of Materials Science*, McGraw-Hill Book Company, New York, 1976. p. 153.)

From a stress strain curve for a typical metal, tensile strength, 0.2% yield strength, and fracture strain can be defined

The main points on a stress strain curve for metals are

- **σ_y = yield stress = 0.2% offset yield**
- **ε_y = yield strain**
- **TS = Tensile Strength**
- **ε_f = fracture strain or ductility**
- **% elongation (ductility) = ε_f * 100**
- **Toughness = energy to fracture= area under curve**

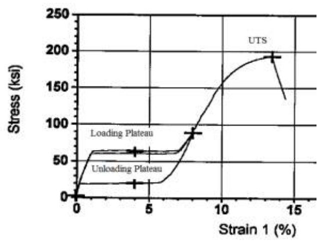


In summary, stress strain diagrams tell key components about the elastic and plastic deformation

SMA alloys have a shape change and mechanical properties change when they go from austenite to martensite

In elastic deformation, bonds stretch causing only temporary deformation.

Key components from a stress strain diagram include Young's modulus, yield stress, UTS, and ductility.



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