MECHANICAL PROPERTIES
Static Mechanical Property Theory

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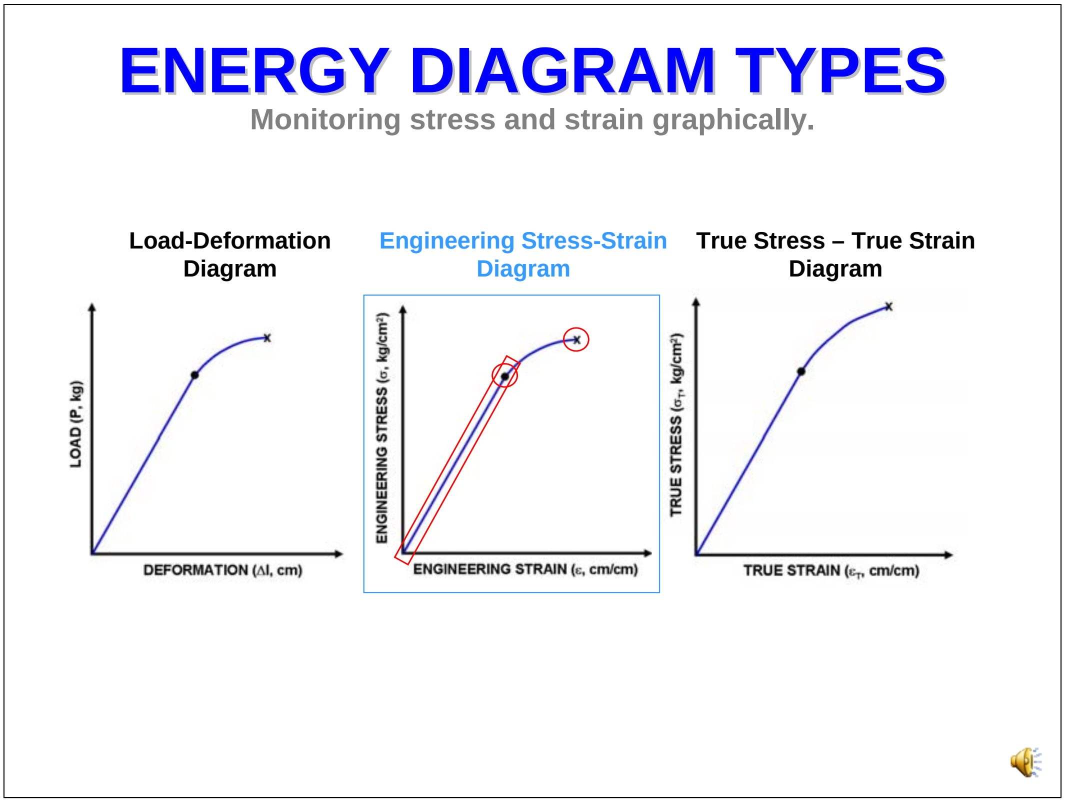
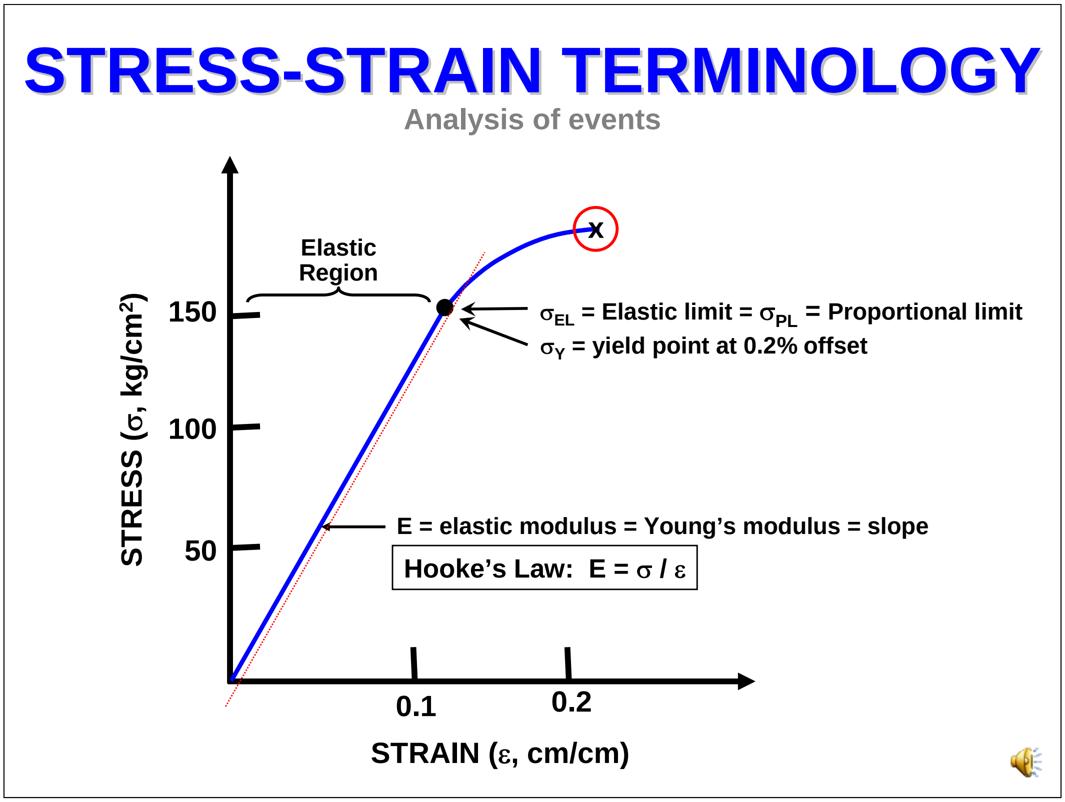
Now let’s see if we can connet the concepts of STRESS and STRAIN.



In the last module, we introduced the process of normalizing load-deformation events to stress-strain events. Now let's look at graphically analyzing them. There are actually 3 diagrams – **[CLICK]** (1) un-normalized load-deformation, **[CLICK]** (2) engineering stress-strain, and **[CLICK]** (3) true stress – true strain. We will be working now on almost exclusively with engineering stress-strain.

What do we mean by engineering stress-strain. We defined stress as load per unit area. We defined strain as change in length per unit length. If you normalize things to the original dimensions of an object, you ignore the fact that the dimensions may have changed in response to the stress. This simplification is called "engineering stress-strain." True stress – true strain is calculated on the instantaneous dimensions of the object. In most cases, this simplification causes very little perturbation of the graphical analysis. Unless otherwise note, **[CLICK]** always assume that we are considering engineering stress-strain.

You will notice that the general characteristics of all the diagrams are the same. The first portion is linear. **[CLICK]** There is a point at which the straight line becomes a curved one and begins to tilt toward the right. **[CLICK]** At some point, the curve ends, representing failure or fracture of the material. **[CLICK]**

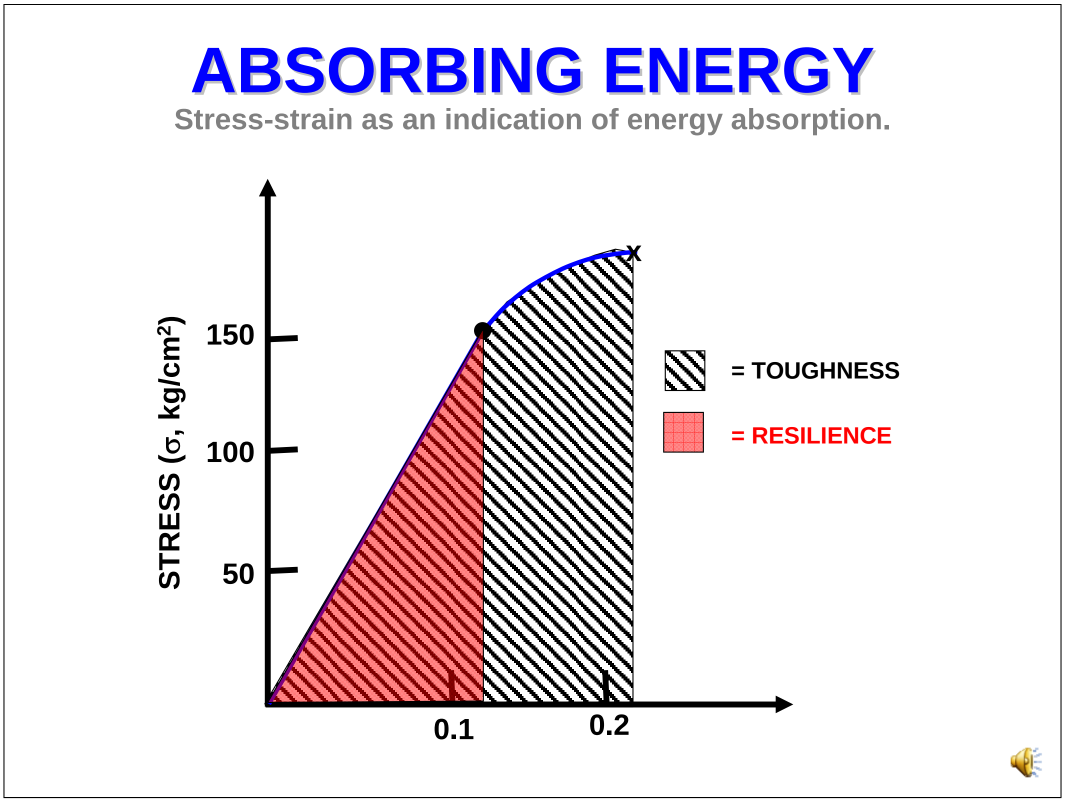


Now lets look at the diagram as though we were actually applying a load to an object and observing its deformation. Start at stress = 0 and strain = 0. As stress increases, there is a proportional response in deformation or strain – generating the straight line above. The slope is constant. Another word for the term constant is MODULUS. **[CLICK]** The strain in this region is totally elastic and so this slope is called the elastic modulus. **[CLICK]** If you double the stress, you double the strain. If you remove the stress, the strain goes back to zero. The slope or elastic modulus is abbreviated as "E." **[CLICK]** The slope is the change in the y-axis divided by the change in the x-axis. In other words, E = stress / strain = σ / ε -- and this relationship is called HOOKE's LAW after the first person to define the relationship. The moduls is also called the STIFFNESS.

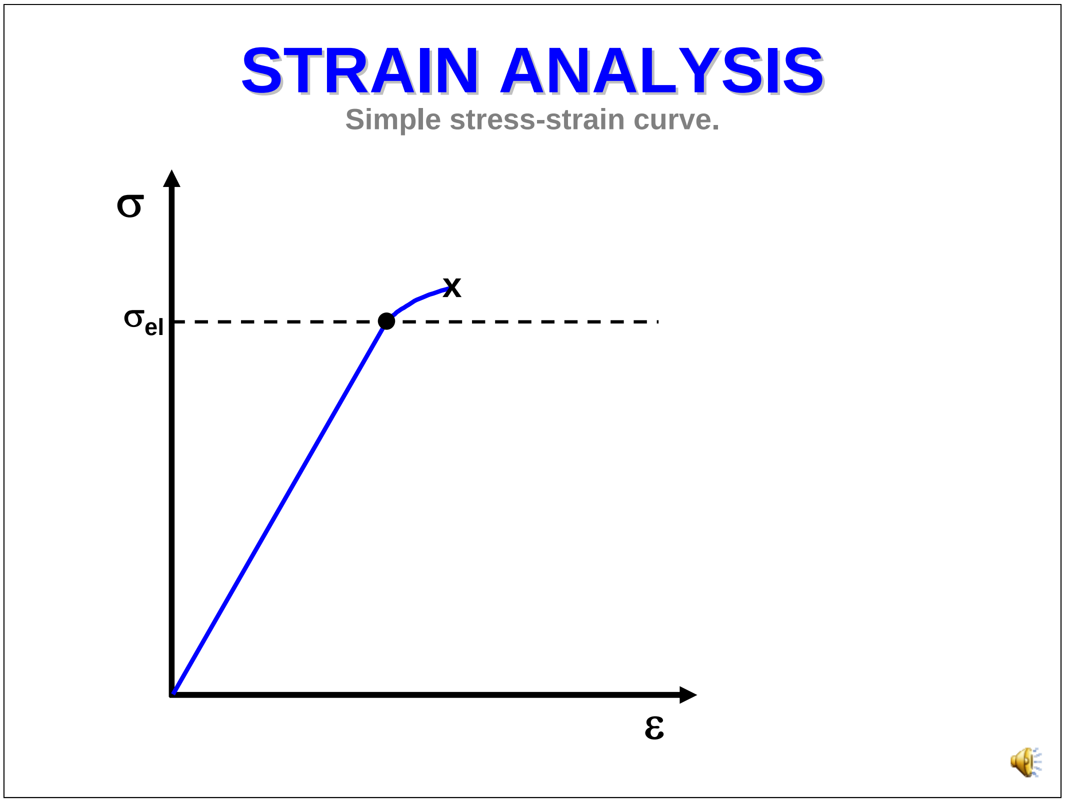
At high values for stress, a point is encountered in which plastic strain begins to occur. Instead of the material behaving totally elastically, it now shows some elastic behavior but also some plastic behavior. **[CLICK]** This point is called the ELASTIC LIMIT. Other names are the ELASTIC LIMIT or PROPORTIONAL LIMIT. For all practical terms these words can be used interchangeably, but we will try to always call this the elastic limit.

The elastic limit represents the onset of some plastic deformation. As the component of elastic behavior decreases, the curves bends to the right. At some point, when elastic behavior ceases, and only plastic deformation is occurring, the curve reaches its maximum value, and the material begins to fail. It is common to mark the maximum or end of the curve with an "x" to indicate the failure. **[CLICK]** Occasionally, the curve goes through a maximum and starts to decrease but that is an artificiality of the engineering stress versus true stress approach.

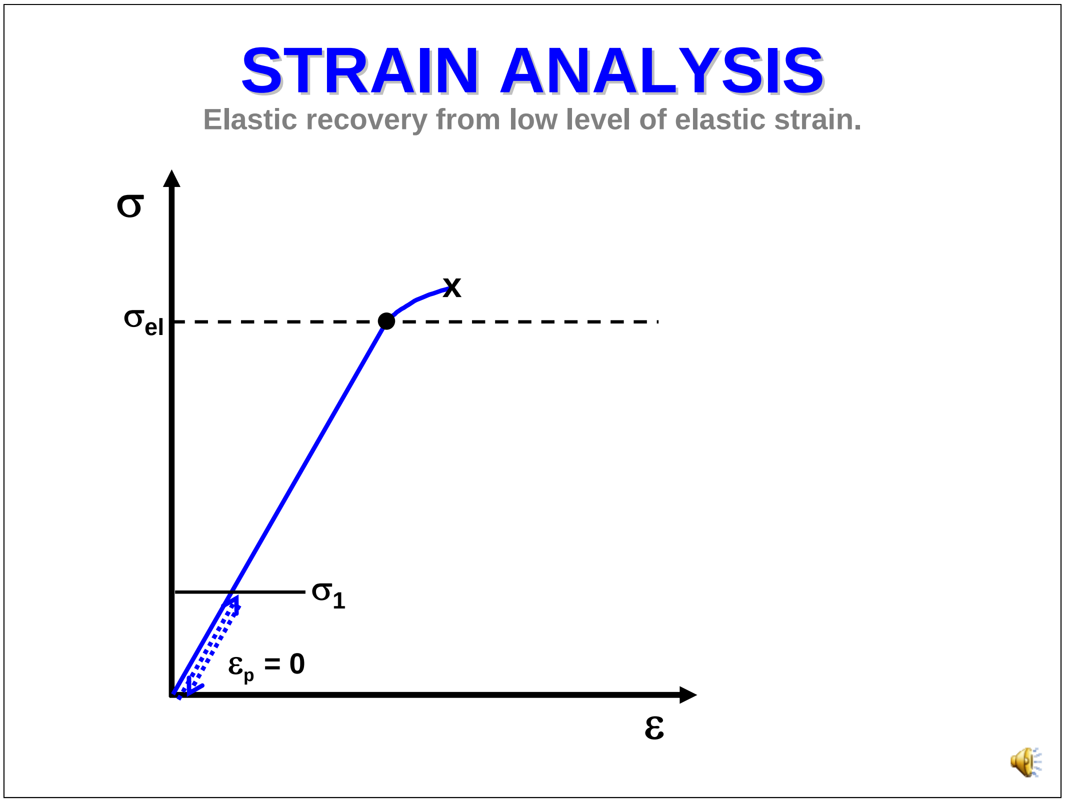
Occasionally, the end of the straight line portion of the curve is difficult to identify and so we use a graphical means to define it. If you imagine laying a ruler parallel to the major part of the straight line, **[CLICK]** and drawing a line that is offset by 0.2% strain (a very small amount), you can use the place that it crosses the curve as an estimate of the elastic limit. **[CLICK]** It is called the yield point at 0.2% offset. It is an estimate of the elastic limit.



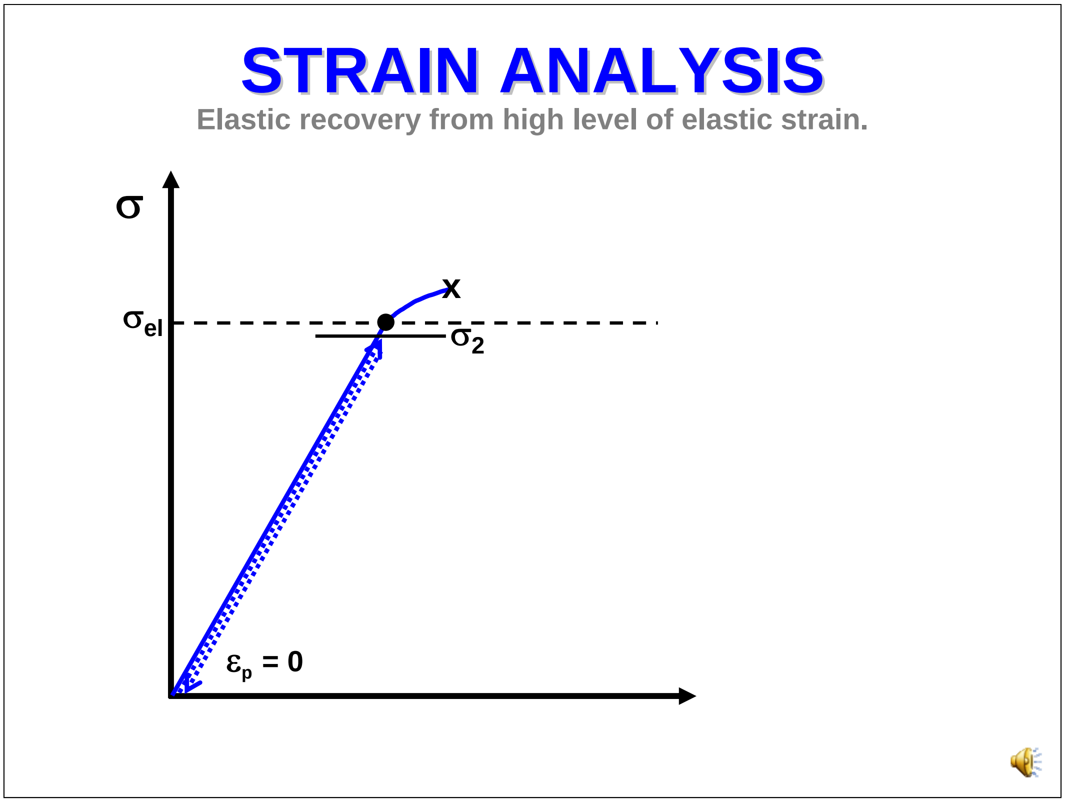
As you continue to apply load and observe deformation, you can think of the process as mapping the ability of the material to absorb energy. A material that is good at energy absorption is called TOUGH. **[CLICK]** The area under the stress-strain curve up to the point of fracture is called the TOUGHNESS. **[CLICK]** If you are only interested in the ability of the material to absorb energy totally elastically with no plastic deformation, then you consider the area under the curve up to the elastic limit and call that the RESILIENCE or the MODULUS OF RESILIENCE.



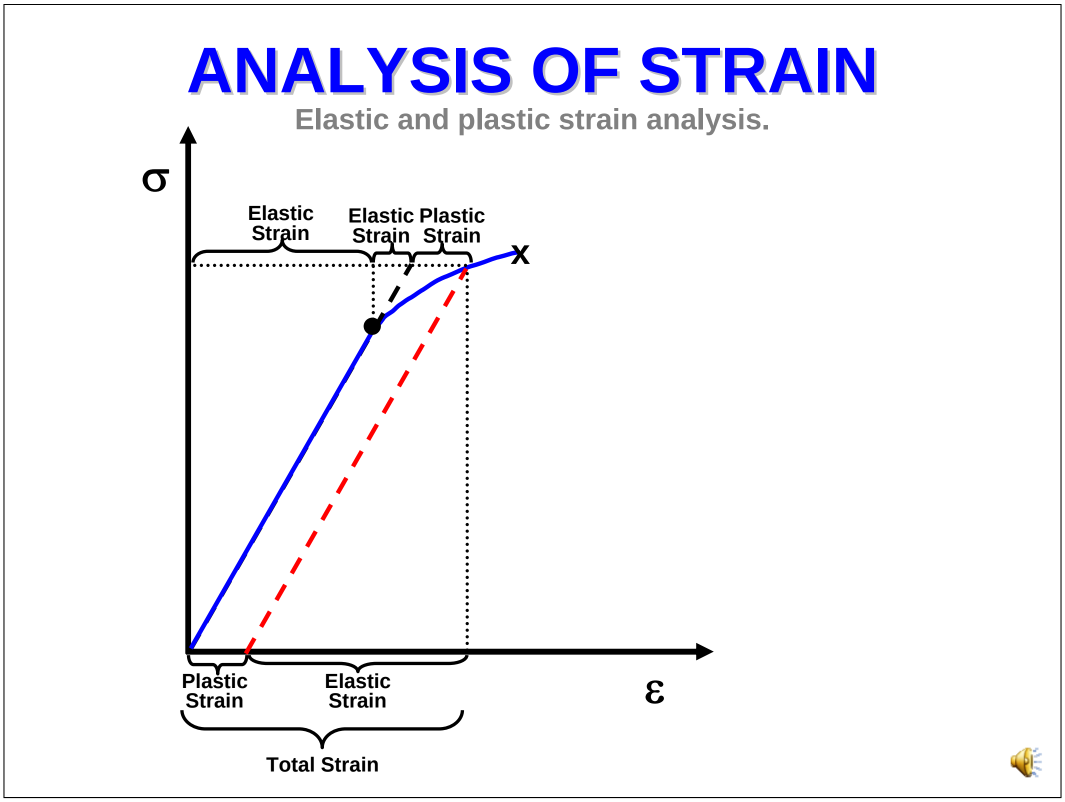
Now let’s look at an engineering stress-straing curve while examining what happens when you apply and remove stress at different levels. The elastic limit is demarcated with a dashed line.



When a low level of stress is applied, **[CLICK]** the strain is low and totally elastic. If you remove the stress, **[CLICK]** the strain is all elastic strain and it recovers. **[CLICK]** The plastic strain is zero.



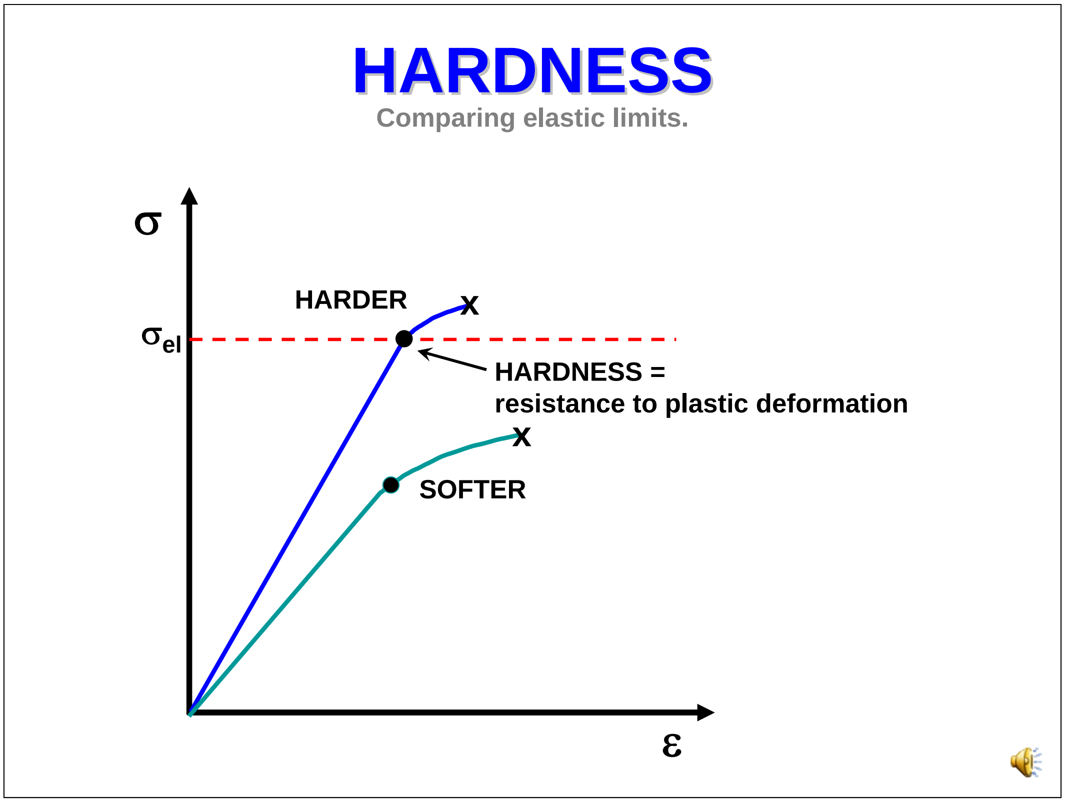
If you apply a much higher stress, **[CLICK]** appropaching the elastic limit, you still expect it to be totally elastic **[CLICK]** and totally recoverable. **[CLICK]** The plastic strain is zero.



Let's dissect the events on going to a stress above the ELASTIC LIMIT. **[CLICK]** Everything up to the elastic limit is only elastic strain. **[CLICK]** Past the elastic limit there is still some elastic strain but more and more components of plastic strain. **[CLICK]** You can tell how much elastic strain by just extending the modulus portion of the curve. **[CLICK]** The remainder is the plastic strain.

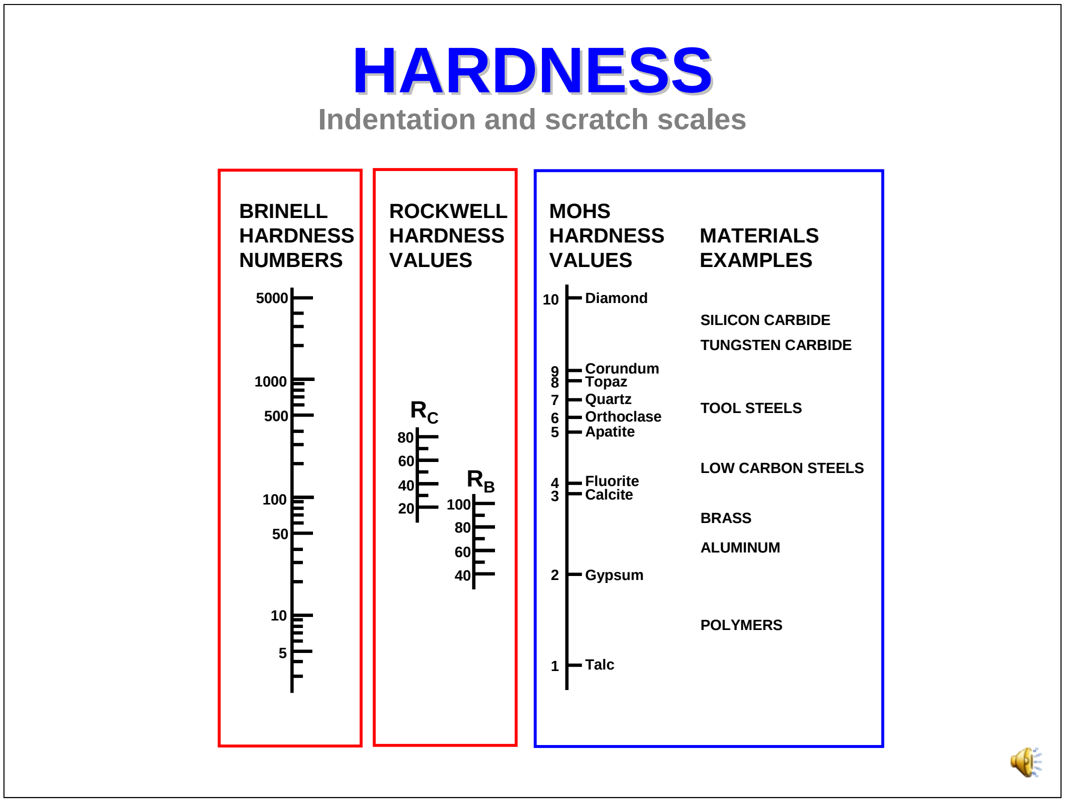
A much more practical way to determine the elastic and plastic components of the total strain **[CLICK]** is to remove the stress and see what recovers. **[CLICK]** The remaining strain is the plastic strain. **[CLICK]**

A common error in the analysis of strain is to think that you can drop straight down from the curve and read the elastic and plastic strain. You must follow the paths of elastic recovery.



For real materials in service (such as a crown or bridge or composite), it is important to avoid any plastic deformation. You always want to stay below the elastic limit. Remember that the elastic limit represents the limit of totally elastic behavior. Another way to say the same thing is to define the elastic limit as the "onset of plastic deformation.' The resistance to plastic deformation is defined as the HARDNESS. **[CLICK]** So, in essence, the elastic limit may also be called the hardness.

Now let's make some better sense out of all of this. If a material is HARD, it resists being indented, or scratched, or permanently deformed in any way. **[CLICK]** A simple test of whether one material is harder than another is to try to scratch one with the other and see which one scratches first. **[CLICK]** The softer material scratches. The harder material does not. This is a very simple way of detecting the relative elastic limits of materials.



A wide range of scales have developed that rely on producing indentations or scratches on materials to rank their relative hardnesses. Generally scales are only useful for a narrow range of materials properties, so you find that scales or tests are good for metals (eg, BRINELL or ROCKWELL) **[CLICK]** but not for polymers.

One of the broadest and simplest scales is the Mohs Hardness Scale. **[CLICK]** It is a scratch test with a very soft reference material (TALC) valued as 1.0 and the hardest material of all (DIAMOND) valued at 10.

HARDNESS

Dental materials examples.

Reference Material	*Mohs Hardness Value (1-10)*	*Dental Material*
Diamond, C	**10**	Cutting diamonds (10)
		Yttria-stabilized zirconia (9-10)
Corundum, Al_2O_3	**9**	Alumina (99)
Topaz, $Al_2SiO_4(OH^-,F^-)_2$	**8**	
		Cobalt-chromium alloys (7-8)
Quartz, SiO_2	**7**	Quartz Polishing Particles (7)
		CAD-CAM Ceramics (6-7) Dental Porcelain (6-7)
Feldspar (Orthoclase), $KAlSi_3O_8$	**6**	
		Composite (5-7) Glass Ionomer (5-7) Glass Fillers (5-6) **DENTAL ENAMEL (5-6)**
Apatite, $Ca_5(PO_4)_3(OH^-,Cl^-,F^-)$	**5**	
		Dental Amalgam (4-5)
Fluorite, CaF_2	**4**	
		Hard Gold Alloys (3-4) **DENTINE (3-4)**
Calcite, $CaCO_3$	**3**	
		Pure Gold (2-3) Denture Acrylic (2-3) **CEMENTUM (2-3)**
Gypsum, $CaSO_4 \cdot 2H_2O$	**2**	
		Diatomaceous earth (1-1.5) Nylon toothbrush bristles (1-2)
Talc, $Mg_3Si_4O_{10}(OH)_2$	**1**	

Examine the table of reference materials, ranges for Moh's hardness, and dental materials that fall into those ranges. **[CLICK]** Hydroxyapatite is a Moh's hardness of 5-6. To avoid scratching it during finishing and polishing operations, one should use a material that has a lower hardness value. Polishing tooth surfaces with TALC (Moh's =1) will prevent scratches. **[CLICK]** Will nylon toothbrush bristles harm enamel? **[CLICK]** No, because their hardness is only 1-2. What type of dental instruments would be needed to cut or polish zirconia? **[CLICK]** You are right – you need to use diamond instruments.

QUICK REVIEW

Review of uniaxial analysis, normalization, and stress-strain.

- **Which energy diagram type is normally used for stress-strain?**
  ENGINEERING
- **What is HOOKE's LAW?**
  E = σ / ε OR Elastic Modulus = Stress/Strain
- **What names are used for the limit of totally elastic behavior?**
  ELASTIC LIMIT, PROPORTIONAL LIMIT, YIELD AT 0.2% OFFSET, HARDNESS
- **How do you determine the elastic strain associated with stress?**
  RELEASE THE STRESS. Subtract the plastic from total strain.
- **What is a name for the total area under the stress-strain curve?**
  TOUGHNESS

Here is a quick review of the concepts from this module.

[CLICK] (1) Which engineering diagram type is normally used for stress-strain analysis?

[CLICK]

[CLICK] (2) What is HOOKE's LAW?

[CLICK]

[CLICK] (3) What names are used for the limit of totally elastic behavior?

[CLICK]

[CLICK] (4) How do you determine the elastic strain associated with stress?

[CLICK]

[CLICK] (5) What is the name for the total area under the stress-strain curve?

[CLICK]

THANK YOU

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