Material Testing and Standards

Reference Books:

G. E. Dieter, Mechanical Metallurgy, McGraw Hill Book Company, 1987.

Testing of metallic materials by A.V.K Suryanarayana, PHI

ASTM standards

Syllabus

- **Unit-1**
- **Introduction: Importance of Material Testing.**
- Classification of various types of testing methods. Selection of testing methods.
- Importance of calibration of testing instruments.

- **Tensile test: Engineering stress –strain curve, true stress –strain curve, Instability in tension,**
- Stress distribution at neck, principle of stress and strain measurement, bend test measurement , compression test, yield stress and proof stress, universal tensile testing machine and tensometer.

Importance of Material Testing

- To assess numerically the fundamental mechanical properties of ductility, malleability, toughness etc.
- To determine data; i.e. force-deformation (or stress) values to draw up sets of specifications upon which the engineer can base his design.
- To determine the surface or sub-surface defects in raw material or processed parts.
- To check chemical composition.
- To determine suitability of a material for a particular application.

Classification of material testing

- Destructive Testing: After being destructively tested, the component or specimen either breaks or no longer remains useful for the future.
- Non-Destructive Testing: A component does not break in non-destructive testing & even after being tested, so it can be used for the purpose for which it was made.

CONT,

- Process Inspection/Tests: The name of the process inspection is derived form the type of manufacture where it is performed. The location often affects the name of the inspection viz. in receiving or incoming inspection, stores or stock inspection etc.
- Examples:
- Checking percentage composition of a melt in a foundry before pouring the molten metal in moulds.
- X-ray radiography of a welded pressure vessel

Cont,

- Ultrasonic testing of a welded assembly.
- Tensile or bend test of a welded specimen.
- Hardness test of a cast structure.
- Leak or tightness test of a welded pressure vessel.
- Magnetic particle inspection to detect cracks in welded or cast steel objects.

SELECTION OF MATERIAL TESTING

- Customer's requirement.
- Development Strategies.
- Testing objectives.
- System Environment.
- Mandated Methodologies.
- Adhering to a standard

Calibration: Importance

- Calibration defines the accuracy and quality of measurements recorded using a piece of equipment.
- Over time there is a tendency for results and accuracy to drift ,particularly when technologies or measuring parameters such as temperature and humidity.
- To be confident in the results being measured, there is an ongoing need to service and maintain the calibration of equipment throughout its lifetime for reliable, accurate and repeatable measurements .

Purpose of calibration

- To ensure readings from an instruments are consistent with other measurements.
- To determine the accuracy of the instruments readings.
- To establish the reliability of the instrument

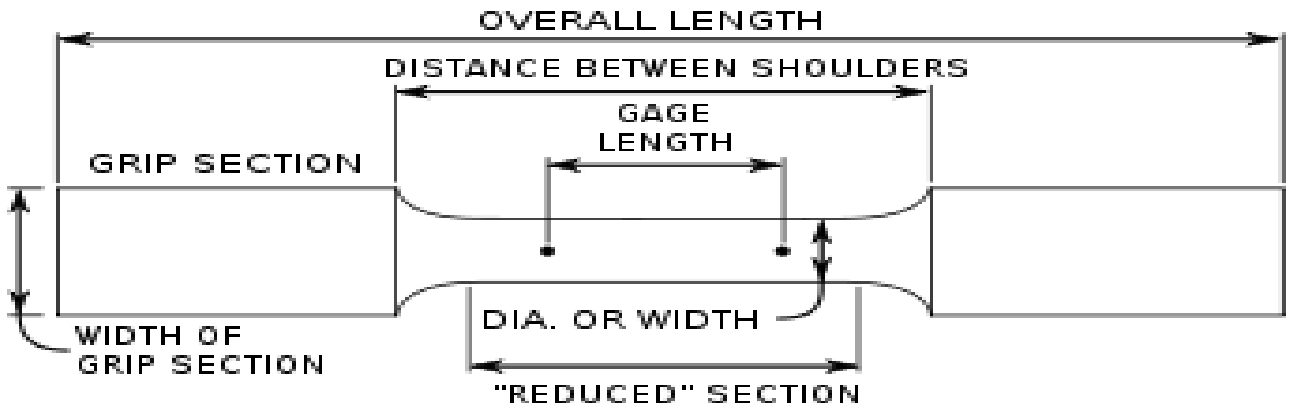
Calibration: Definition and goals

- Calibration: It is defined as an association between measurements- one of a scale or accuracy made or set with a piece of equipment and another measurement made in a similar way as possible with the second piece of equipment.
- The piece of equipment or device with the known or assigned accuracy is called 'Standard'.
- The goal of calibration is to minimize any measurement uncertainty by ensuring the accuracy of test equipment.
- Calibration quantifies and controls errors or uncertainties within measurement process to an acceptable level.

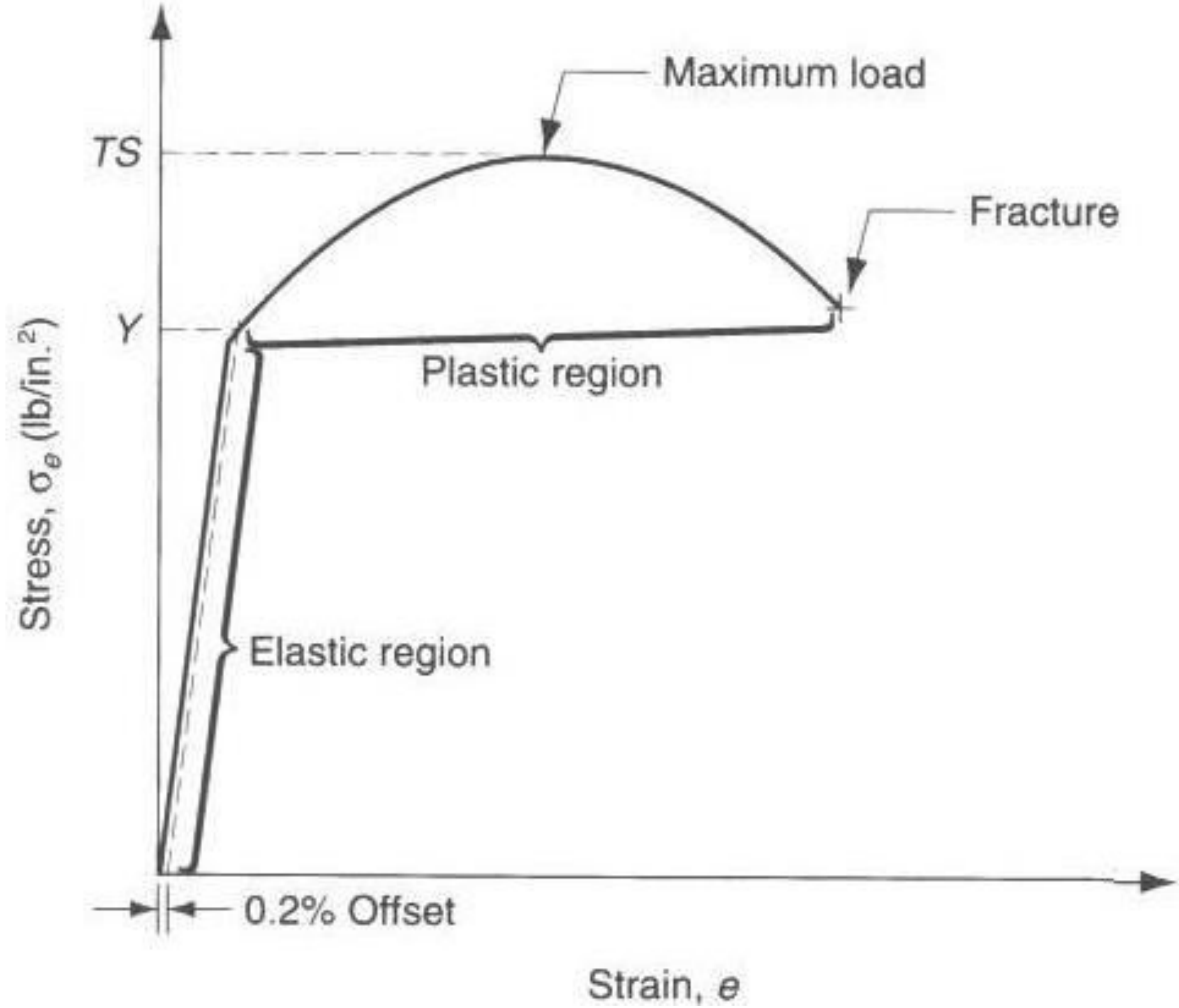
Tensile testing: Testing method.

- It is one of the most widely used mechanical test.

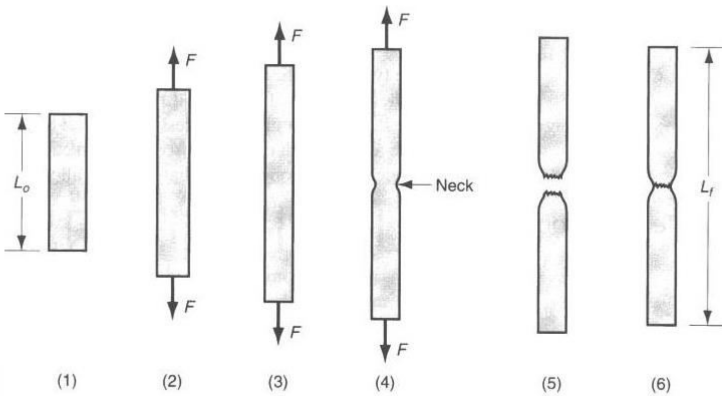
- A tensile test helps determining tensile properties such as tensile strength , yield strength or yield point, % elongation, % reduction in area and modulus of elasticity.



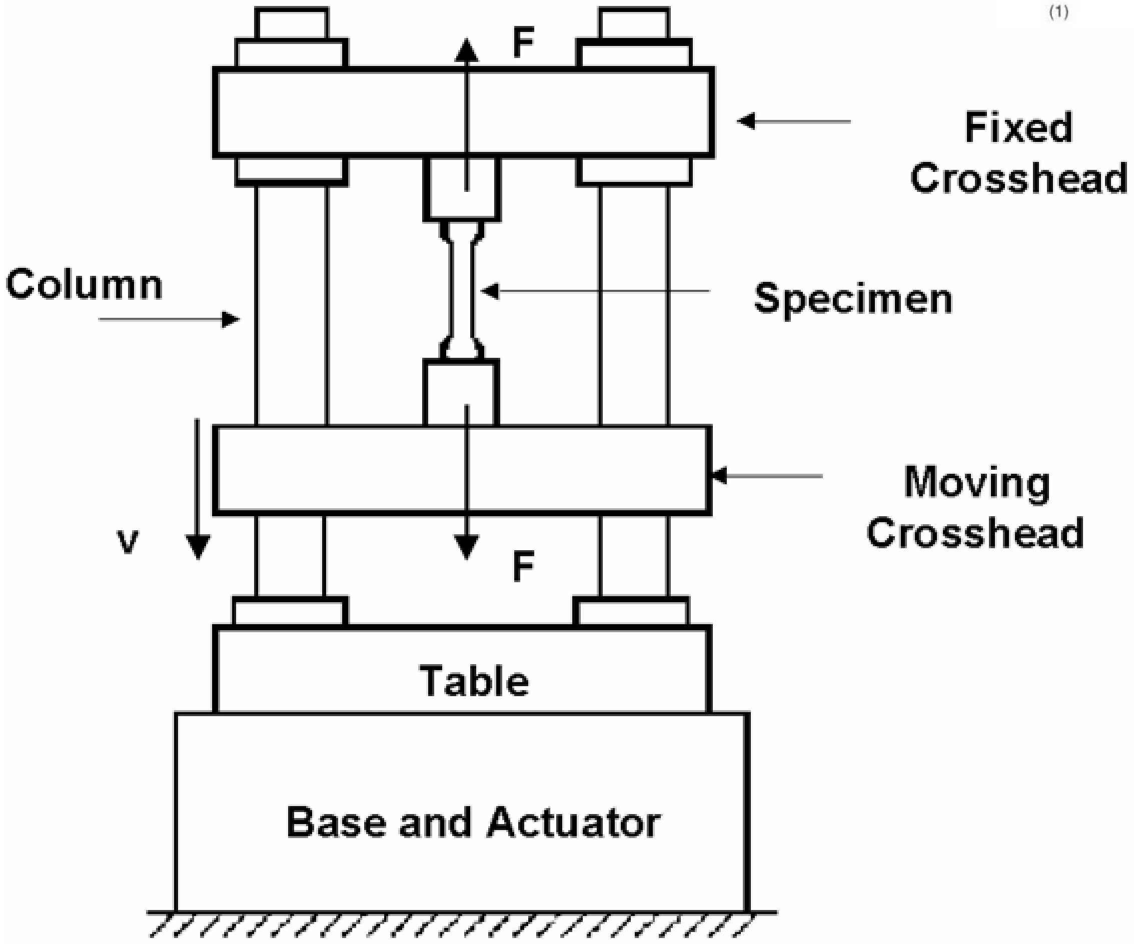
- Figure shows a specimen for tensile test. Since mechanical properties to some extent are influenced by the size and shape of the test specimen, it is customary to use standard specimen.
- Tensile test is carried out by gripping the ends of the specimen in a tensile testing machine and applying increasing pull on the specimen till it fractures.
- During the test, the tensile load as well as the elongation of a previously marked gauge length in the specimen is measured with the help of load dial of the machine and extensometer respectively. These readings help plot the stress strain curve.



Maximum load
TS
Fracture
Y
Plastic region
Elastic region
Stress, σ_e (lb/in.²)
0.2% Offset
Strain, e



F
Lo
Neck
Lf
(1)
(2)
(3)
(4)
(5)
(6)



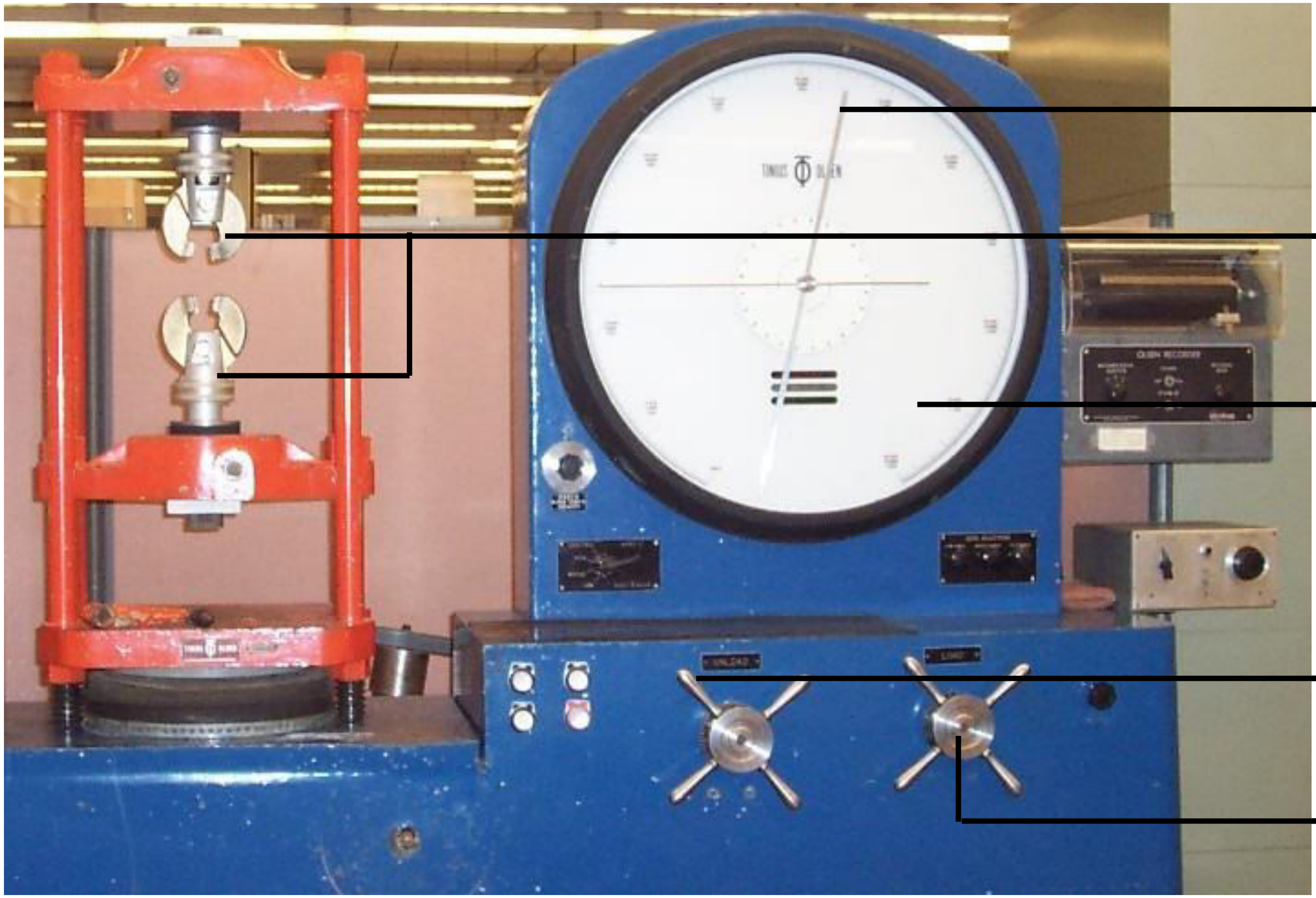
F
Fixed Crosshead
Column
Specimen
Moving Crosshead
V
F
Table
Base and Actuator

Steps

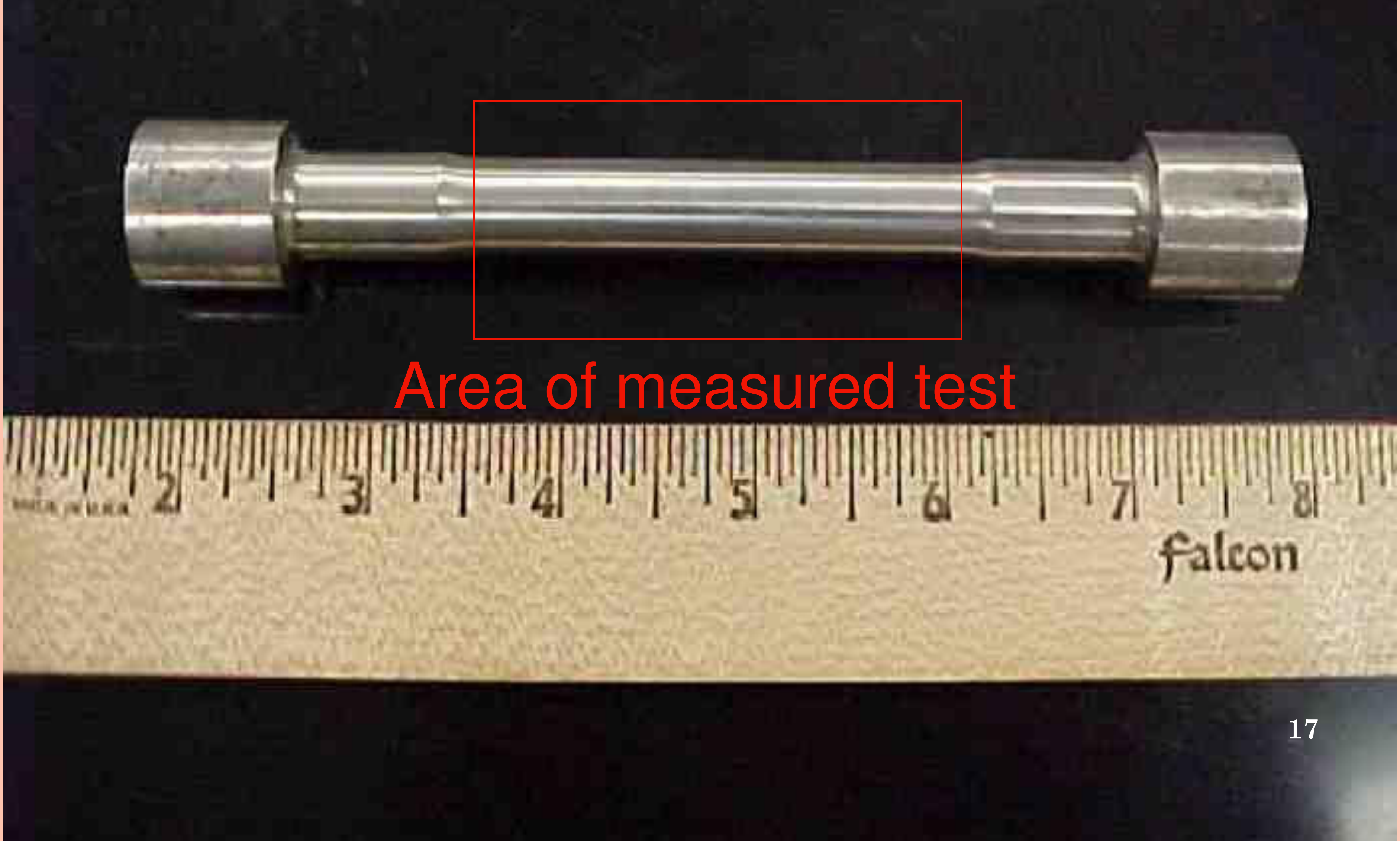
- Step 1: Original shape and size of the specimen with no load.
- Step 2: Specimen undergoing uniform elongation.
- Step 3: Point of maximum load and ultimate tensile strength.
- Step 4: The onset of necking (plastic instability).
- Step 5: Specimen fractures.
- Step 6: Final length.

Tensile Test

Tensile testing machine:



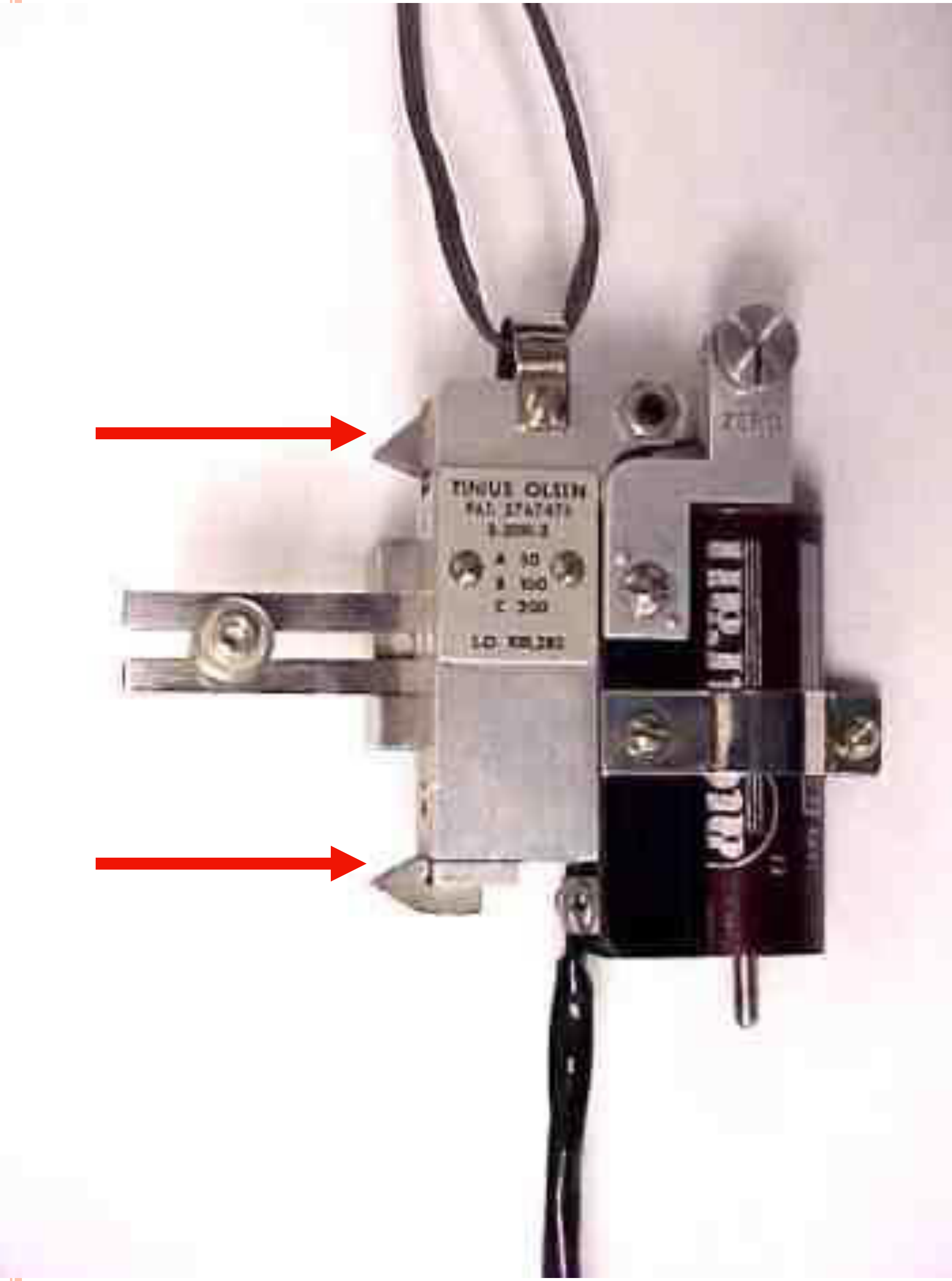
THE SAMPLE



Marking the sample:

A precision punch with two points exactly 2.000" apart is used to mark the sample in the tested region.

This establishes the original length.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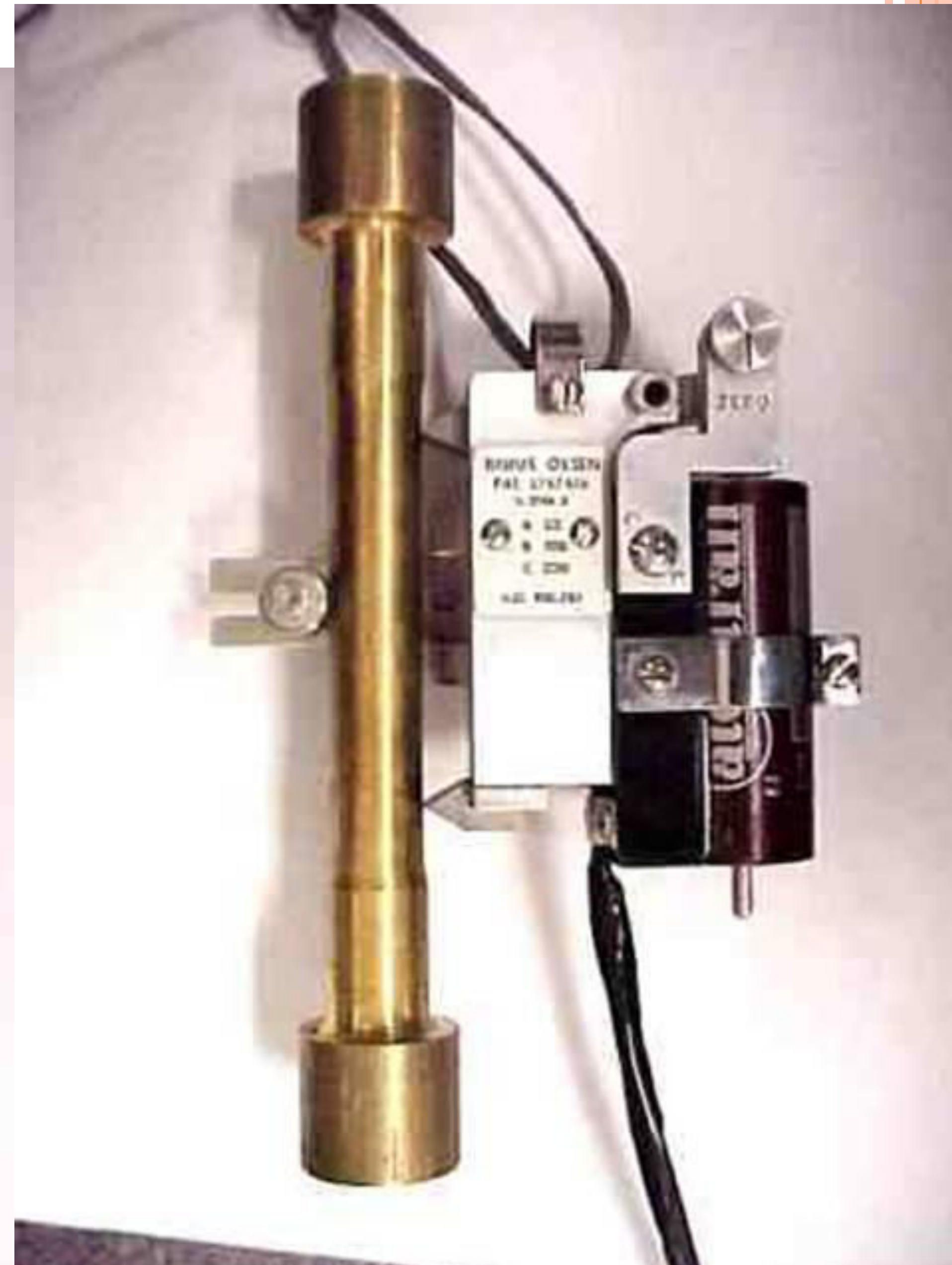
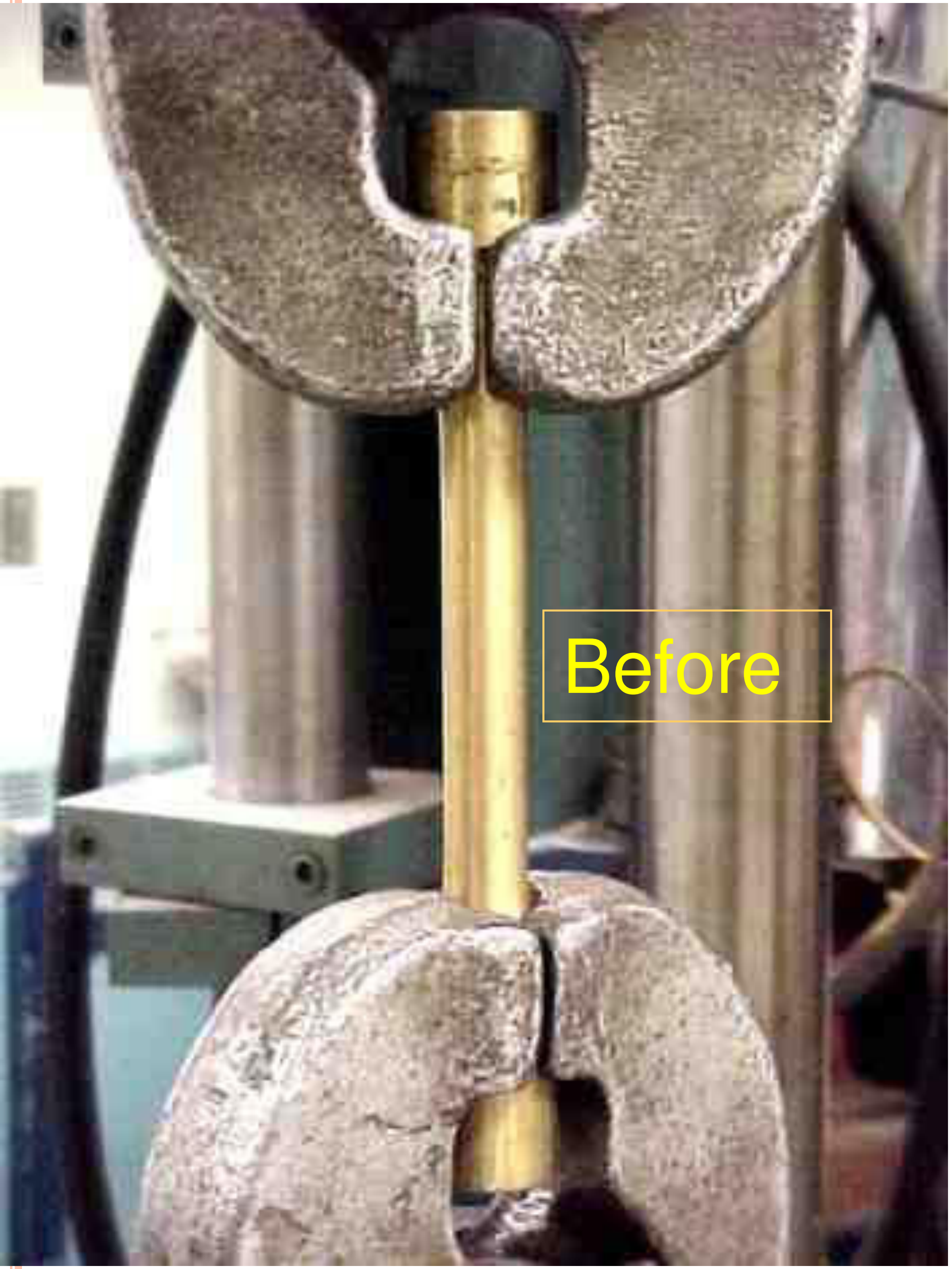
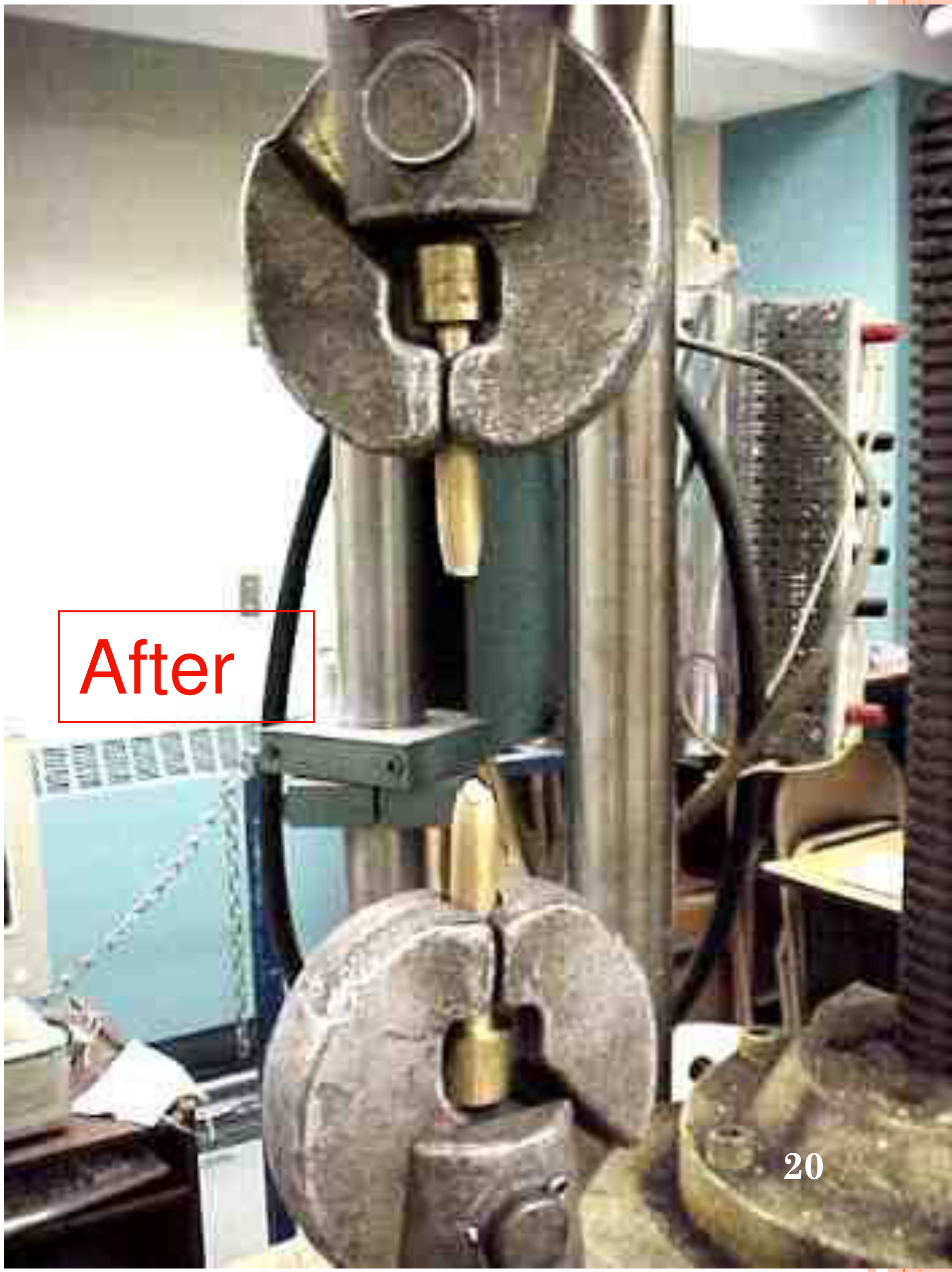
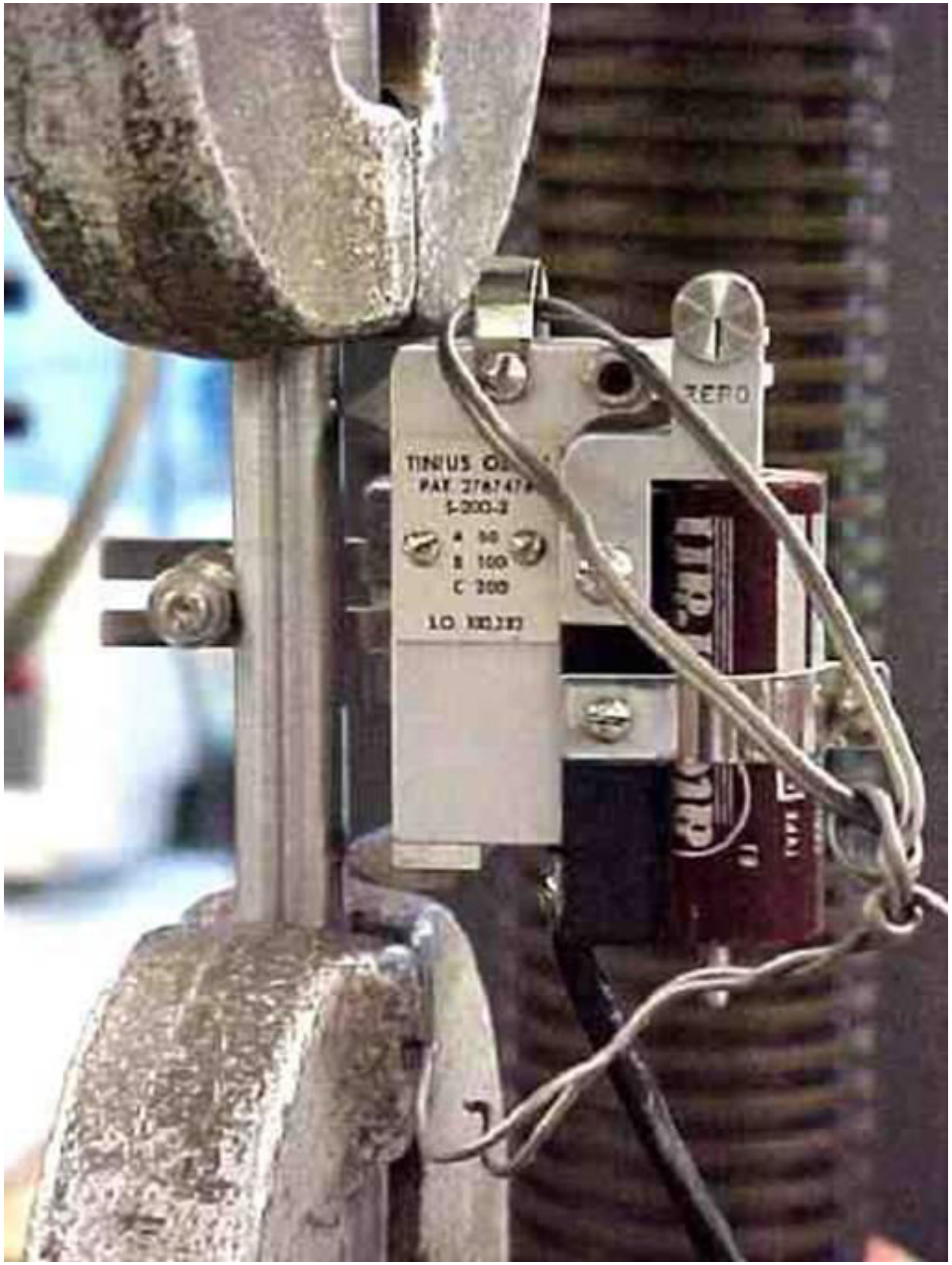
ZERO




Before


After

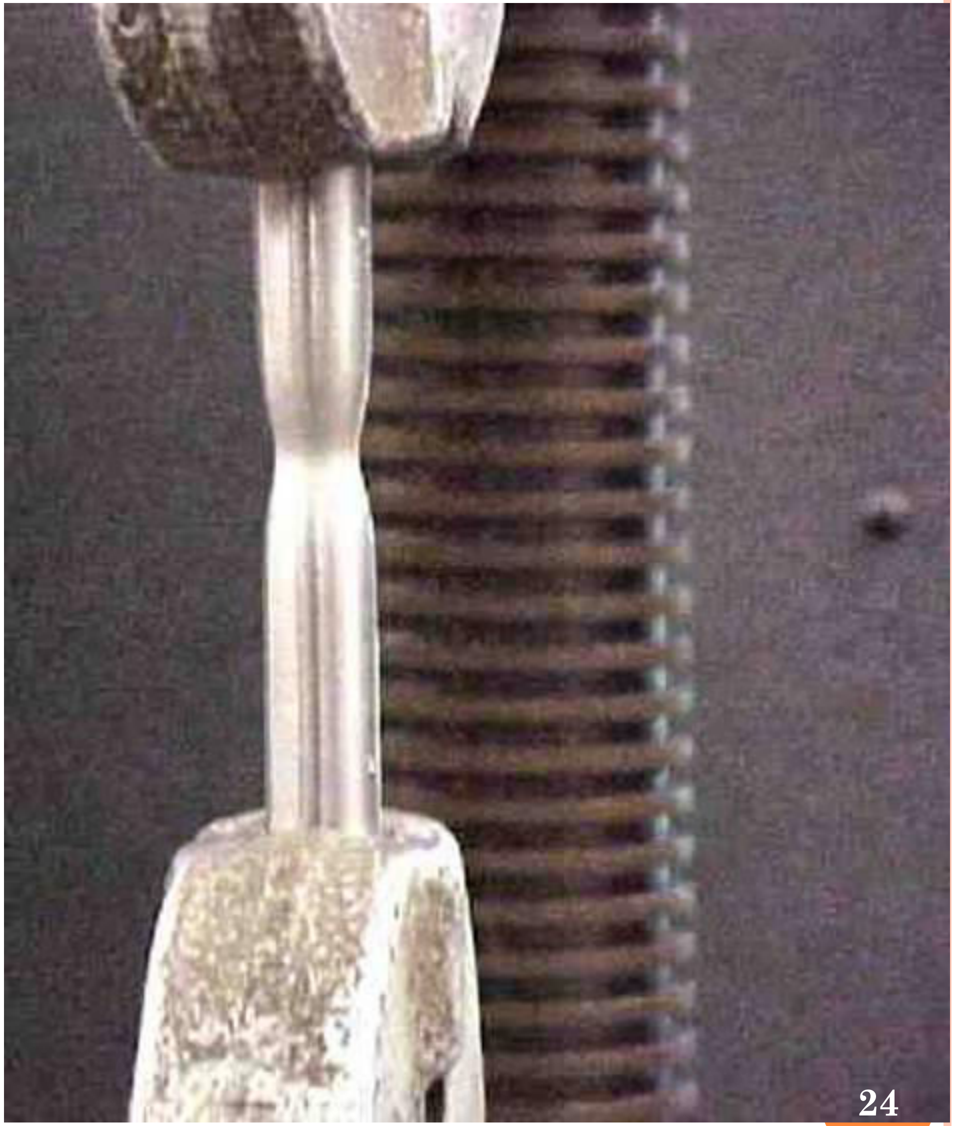

ZERO

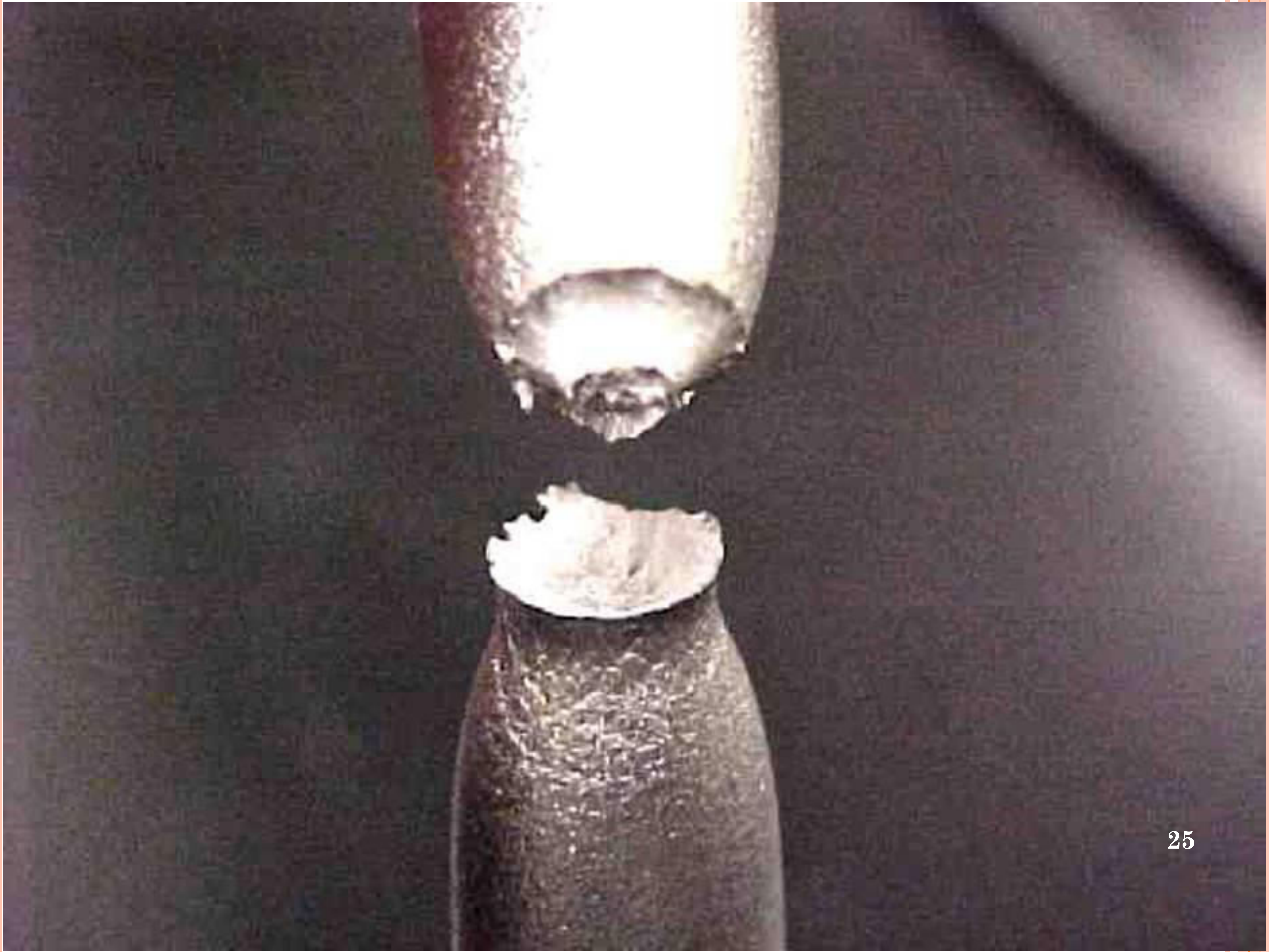

TINIUS OL
PAT. 2767
S-200-2
A 50
B 100
C 200
S.O. 100,2


TINIUS OLSE
PAT. 2767476
S-200-2
A 50

NECKING

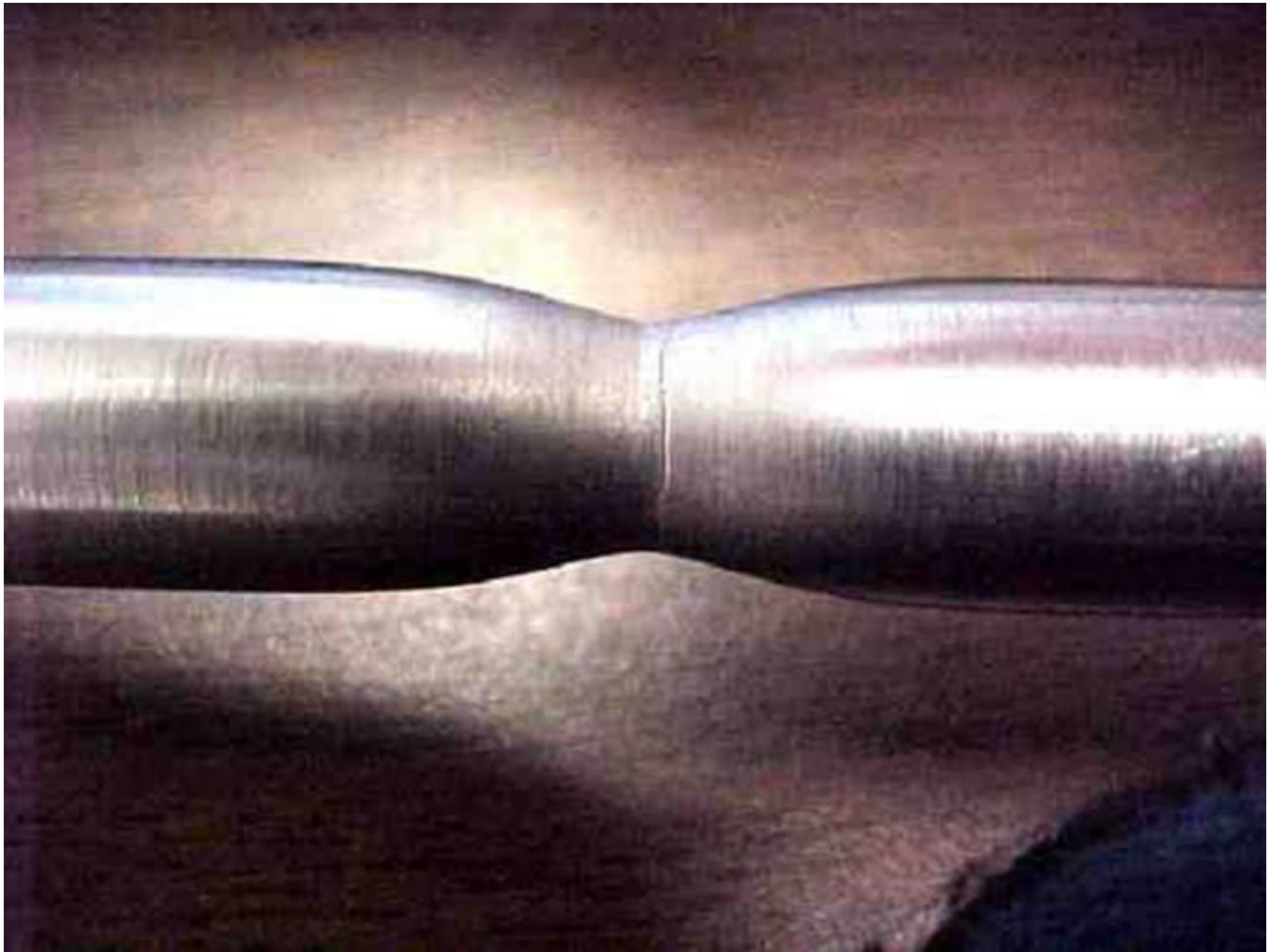
"Necking" occurs as the sample leaves the elastic deformation region and begins to deform plastically.

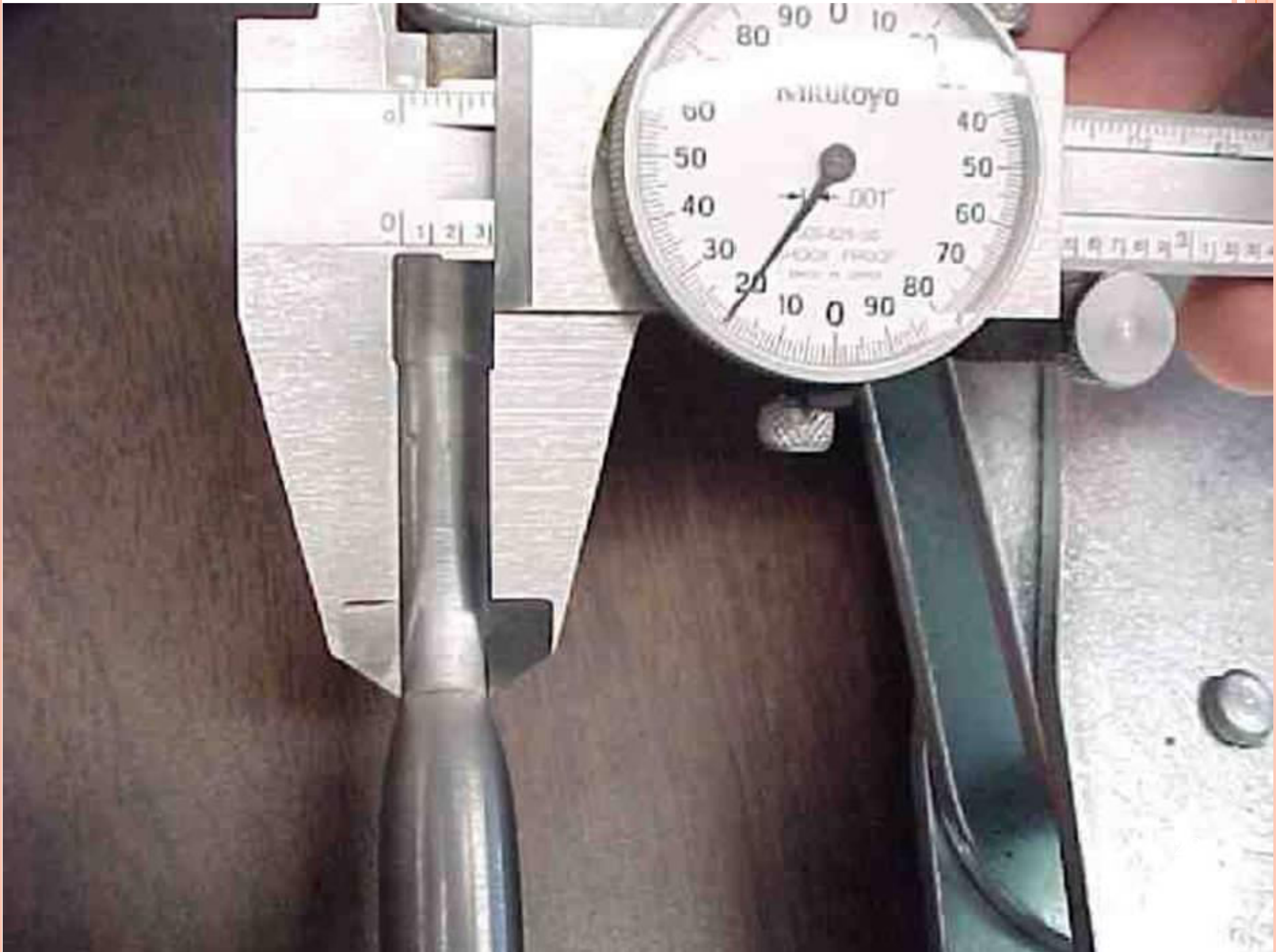


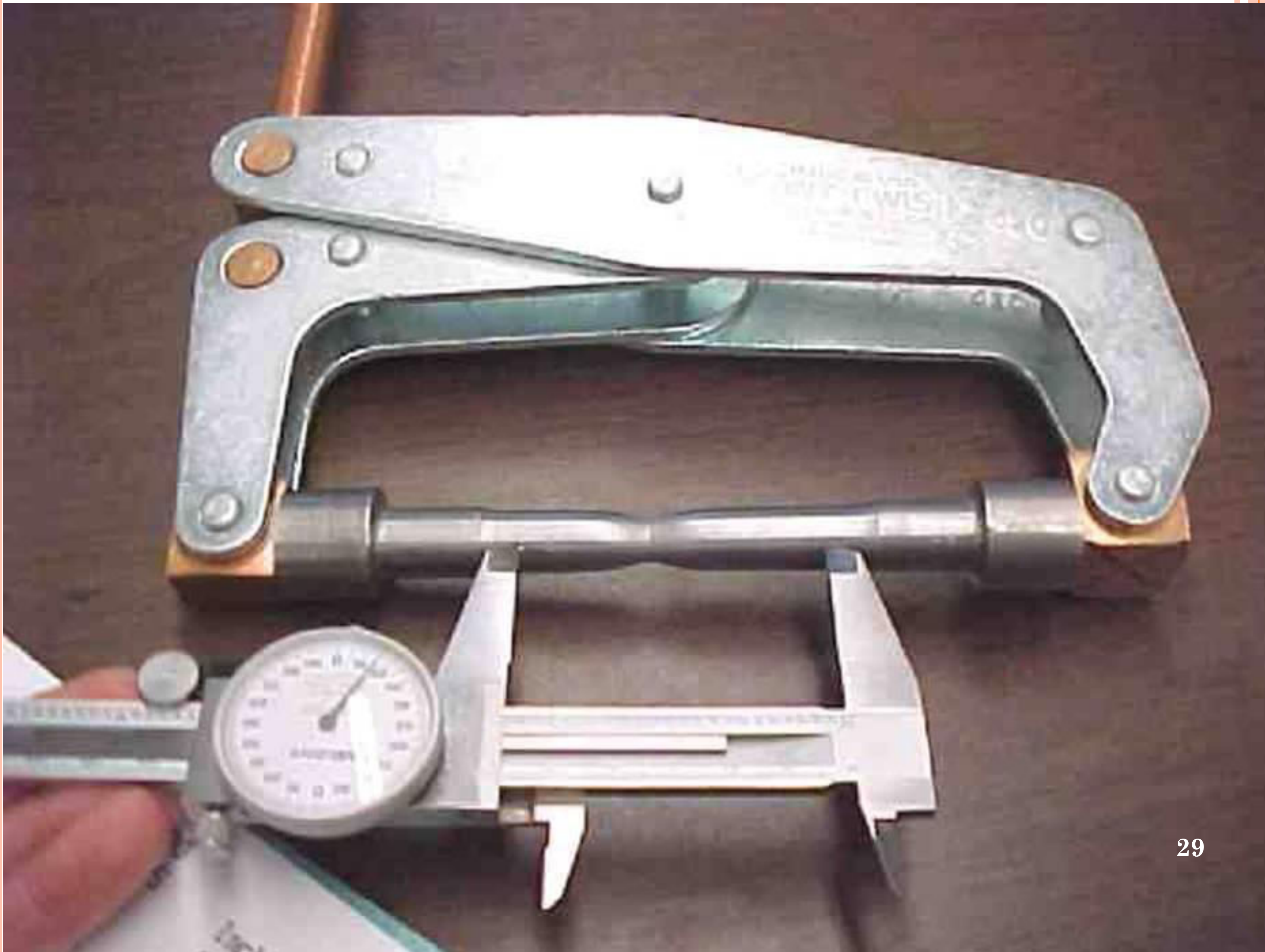


The classic cup & cone shape of a fairly ductile tensile fracture is visible here.

Upon completion of the test, the sample is reassembled and final measurements for total elongation and minimum diameter are made using a vernier caliper.




Mitutoyo
.001"



For maximum precision, the points of the vernier caliper must be placed exactly at the center of the marks made by the punch prior to the test.

Terminology

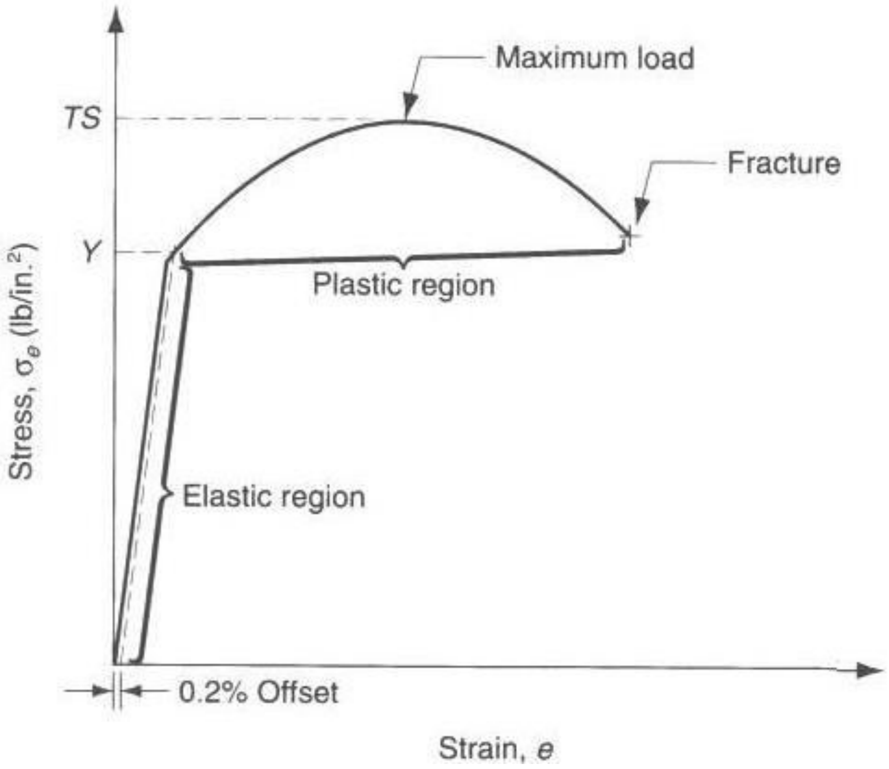
Engineering Stress and Strain:

- These quantities are defined relative to the original area and length of the specimen.
- The engineering stress (σ_e) at any point is defined as the ratio of the instantaneous load or force (F) and the original area (A_o).
- The engineering strain (e) is defined as the ratio of the change in length ($L-L_o$) and the original length (L_o)

$$\sigma_e = \frac{F}{A_o} \qquad e = \frac{L - L_0}{L_0}$$

TERMINOLOGY

Engineering Stress Strain Curve:



- The engineering stress-strain curve (σ_e- e) is obtained from the load-elongation curve.
- The yield point, called the yield strength (Y), signifies the start of the plastic region.

TERMINOLOGY

- It is very difficult to find the actual yield strength experimentally. Instead, we use a 0.2% offset yield strength.
- 0.2% offset yield strength is the point on the curve which is offset by a strain of 0.2% (0.002) [the intersection of the curve with a line parallel to the linear elastic line and is offset by a strain of 0.002]
- The stress at maximum (F_{max}/A_o) is referred to as the Ultimate Tensile Strength (TS) and signifies:
  - the end of uniform elongation.
  - the start of localized necking i.e. plastic instability.

Terminology

Ductility:

- Ductility can be defined as the amount of deformation or strain that the material can withstand before failure. For metal forming processes, increasing the ductility increases the material formability .
- In general, the ductility of the specimen is defined in terms of the elongation (EL) or the area reduction (AR) before fracture, i.e.:

$$EL = \frac{L_f - L_0}{L_0} \qquad AR = \frac{A_0 - A_f}{A_0}$$

Terminology

True Stress and Strain:

- The true stress (σ) uses the instantaneous or actual area of the specimen at any given point, as opposed to the original area used in the engineering values.

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

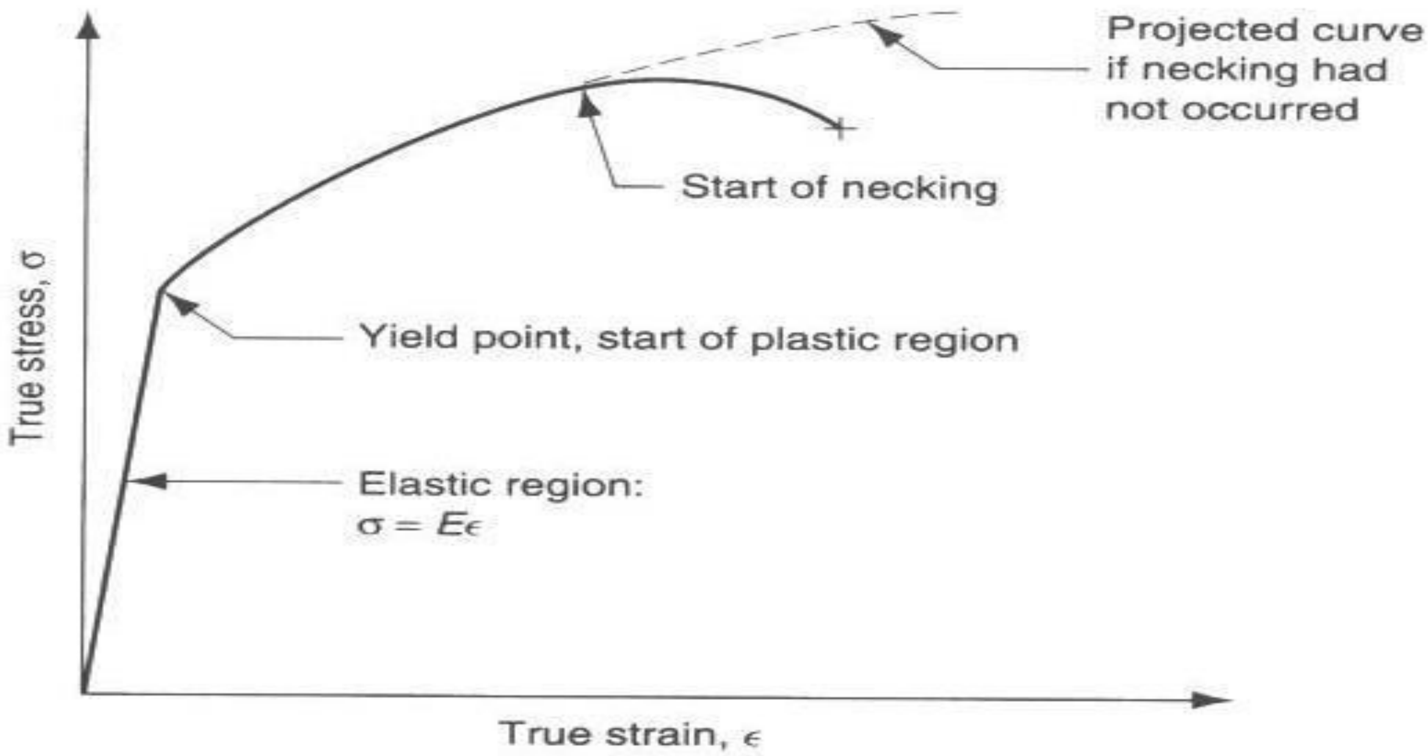
- The true strain (ε) is defined as the instantaneous elongation per unit length of the specimen.

$$\varepsilon = \int_{L_o}^{L} \frac{dL}{L} = \ln \frac{L}{L_o}$$

- The relationship between the true and engineering values is given by:

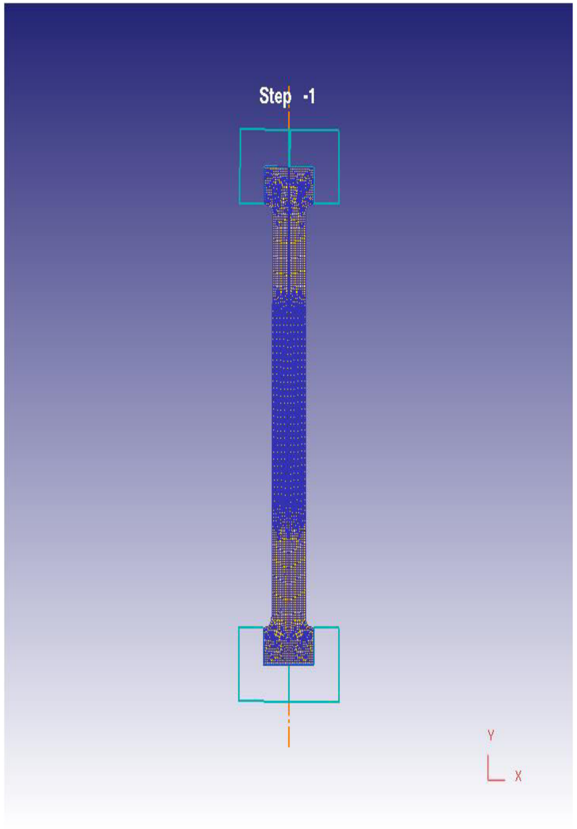
$$\sigma = \sigma_e(1+e) \qquad \varepsilon = \ln(1+e)$$

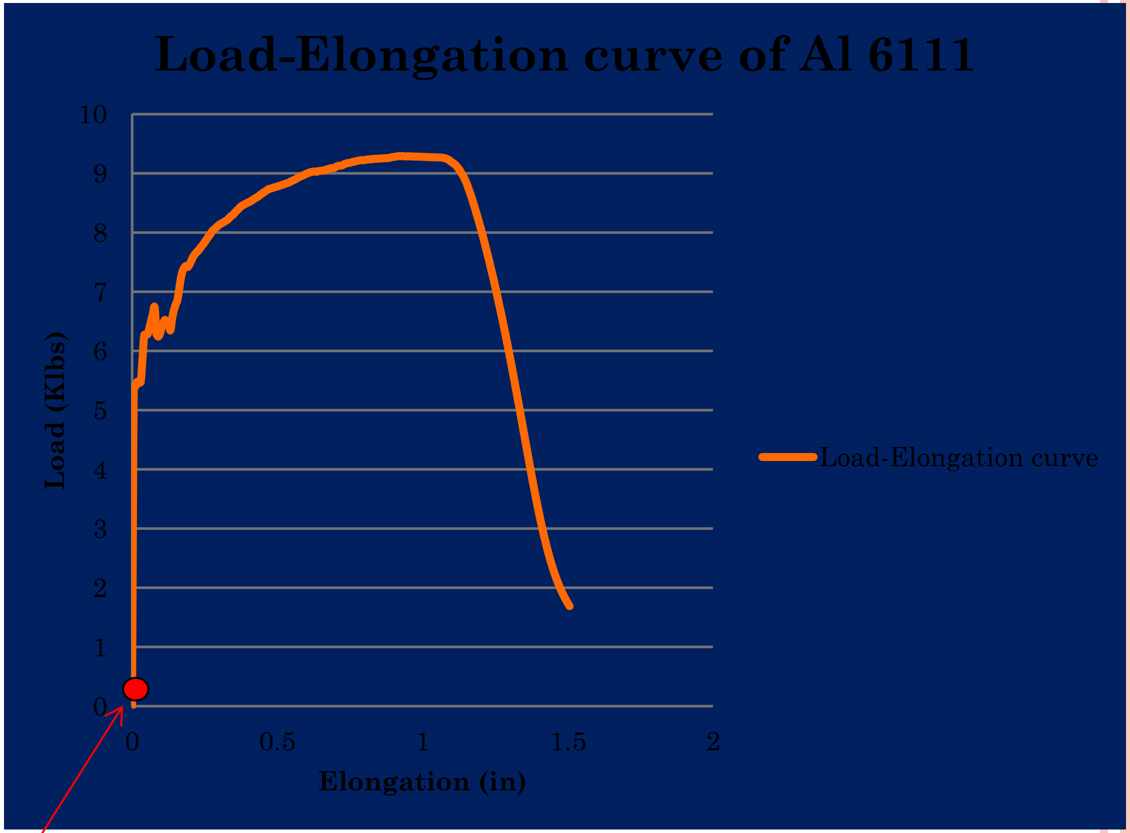
Terminology: True Stress and Strain:



Note: For a given value of the load and elongation, the true stress is higher than the Eng. Stress, while the true strain is smaller than the Eng. Strain.

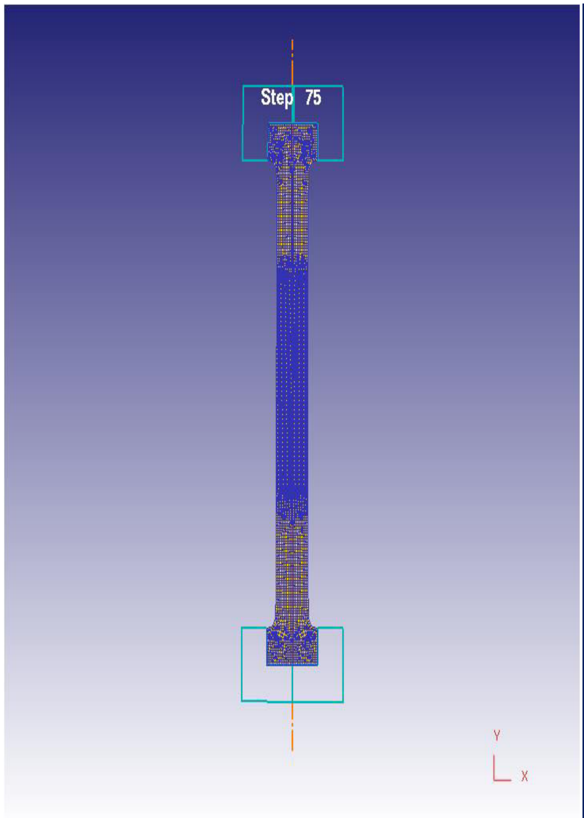
Tensile Testing Simulation

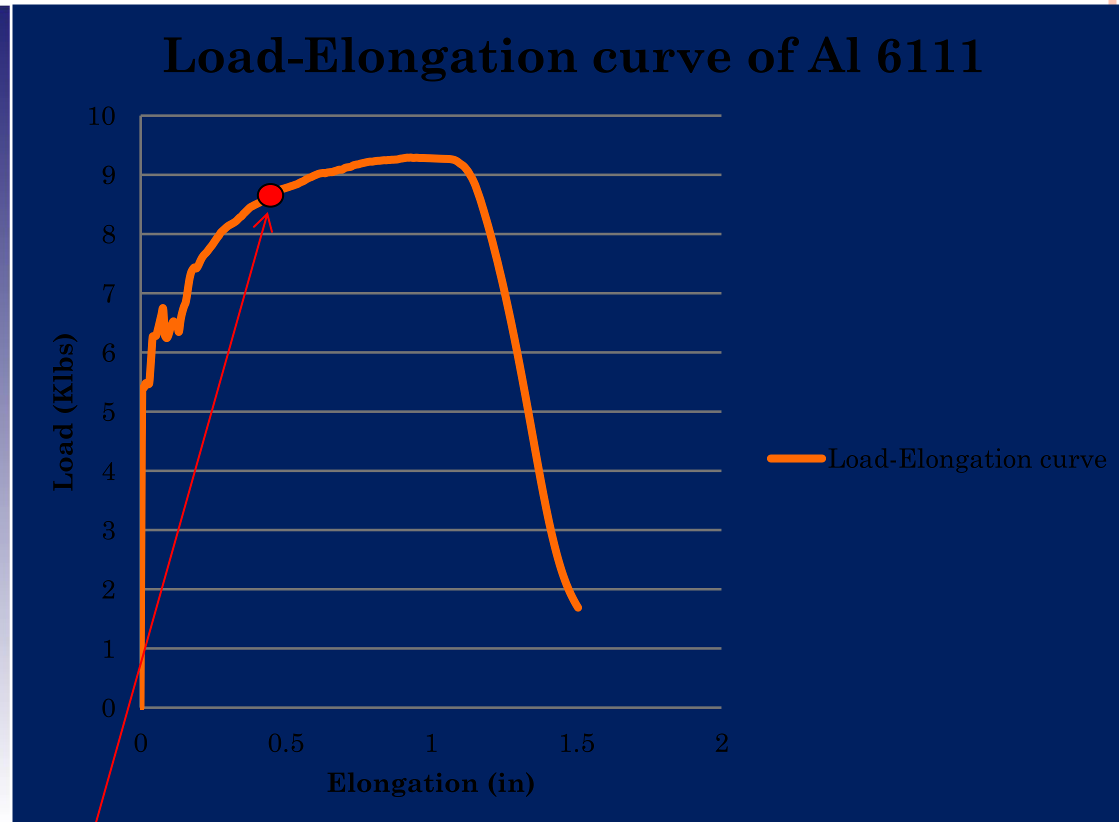




Before the test

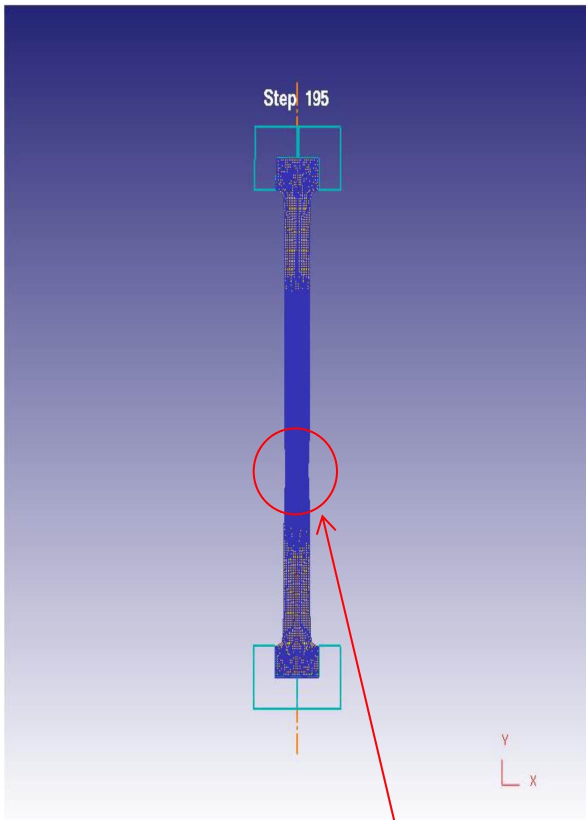
Tensile Testing Simulation

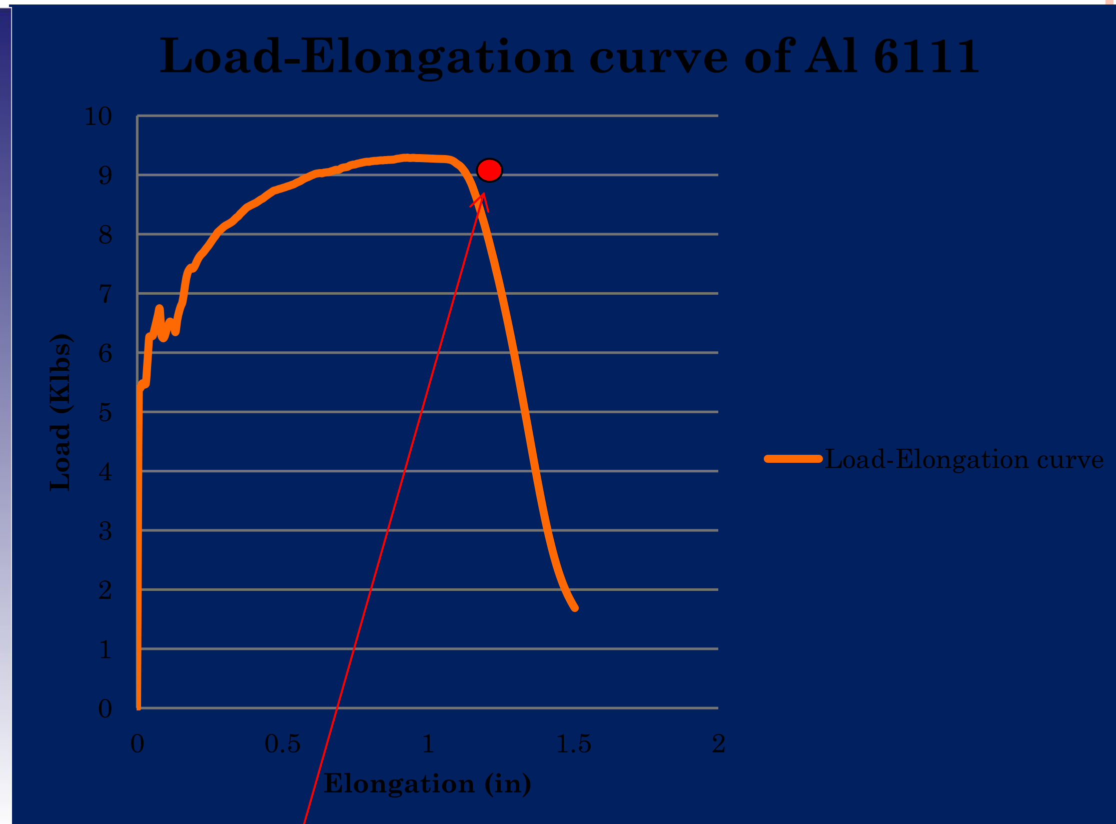




Uniform elongation

Tensile Testing Simulation

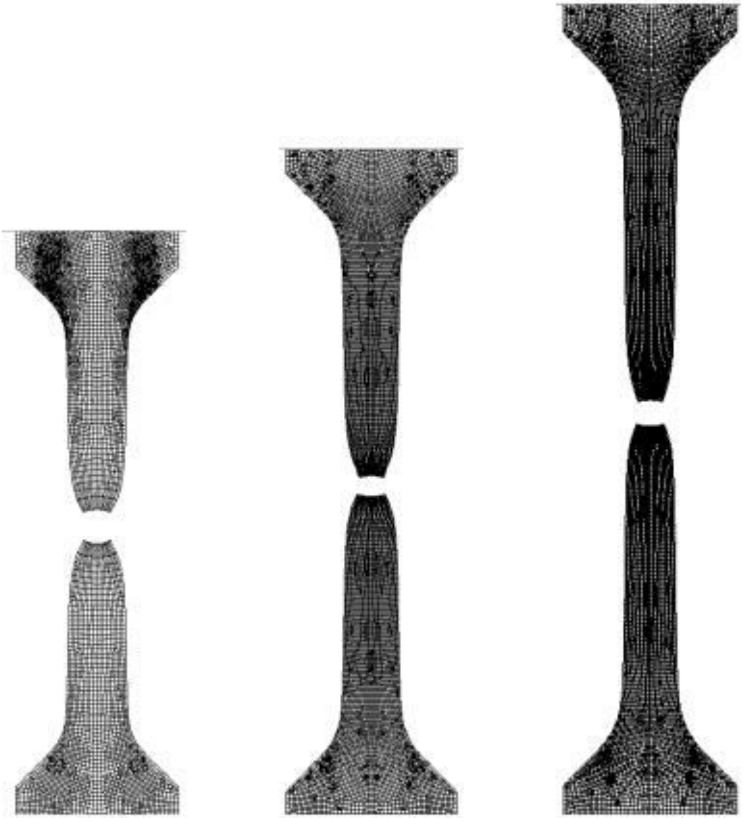




Neck formation

Instability started

Simulation results- Fracture



(a) (b) (c)

INSTABILITY IN TENSION

- Necking generally begins at maximum load during he tensile deformation of a ductile metal.
- An ideal plastic material in which no strain hardening occurs would become unstable in tension and begin to neck just as soon as yielding takes place.
- However a metal(non-ideal) undergoes strain hardening which tends to increase the load carrying capacity of the specimen as deformation increases

- This effect is opposed by the gradual decrease in the cross-sectional area.

- Necking or localised deformation begins at maximum load where the increase in stress due to decrease in the cross-sectional area of the specimen becomes greater than the increase in the load-carrying ability of the metal due to strain hardening.

- Ideal Plastic Material: Undergoes necking after yielding with no strain hardening.

- Most Metal: Necking begins at maximum load with strain hardening, as strain hardening increases-→ load capacity increases.

- Necking or localised deformation starts at the maximum load which is opposed by a decrease in cross-sectional area of the specimen as it elongates

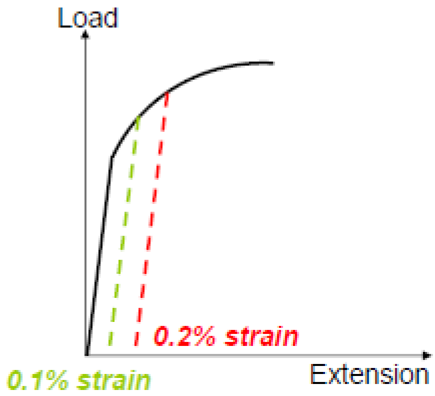
- Instability occurs when:
- An increase in stress due to reduced cross-section area is greater than the increase in load carrying capability due to strain hardening.

Yielding

- True elastic limit: based on microstrain measurement at strains on order of 2 x 10^{-6}. Very low value and is related to the motion of a few hundred dislocations.
- Proportional limit: the highest stress at which stress is directly proportional to strain.
- Elastic limit: is the greatest stress the material can withstand without any measurable permanent strain after unloading. Elastic limit > proportional limit.
- Yield strength is the stress required to produce a small specific amount of deformation.

- The offset yield strength can be determined by the stress corresponding to the intersection of the stress-strain curve and a line parallel to the elastic line offset by a strain of 0.2 or 0.1%. (e = 0.002 or 0.001)
- Used for design and specification purposes to avoid the practical difficulties of measuring the elastic limit or proportional limit.

$$s_o = \frac{P_{(strain\ offset=0.002)}}{A_o}$$



Ductility measurement

- Measured elongation in tension specimen depends on the gauge length or cross-sectional area.

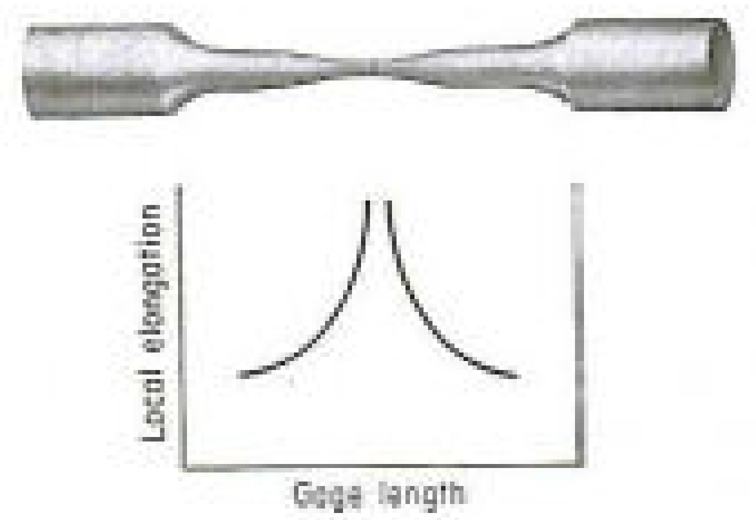
Total extension

- Uniform extension up to necking

  Depends on
  Metallurgical condition of the material
  Specimen size and shape on the development of necking

- Localised extension once necking begins

- The shorter the gauge length, the greater the effect of localised deformation at necking on total elongation.



Variation of local elongation with position along gauge length of tensile specimen

Compression test

- Like tensile test, compression test is also carried out on a UTM.
- In compression test, the piece of material is subjected to end loading which produces crushing action, whereas in a tension test the piece elongated in a direction parallel to the applied load but in a compression test it shortens.
- Compression specimens or test pieces are limited to such a length that bending due to column action does not takes place.

- For uniform stressing of the compression specimen, a circular cross section is to be preferred over other shapes. The rectangular and square shapes are also used.
- In order to avoid bending of a specimen a height-diameter ratio of 10 is suggested as a practical upper limit. The ends of specimen to which load is applied should be flat and perpendicular to the axis of the specimen.
- In compression testing, great care must be exercised to obtain accurate centering and alignment of specimen and bearing blocks in the testing machine.

- The compression test specimen “Say 25mm dia and 25mm long cylindrical” is loaded between the fixed and movable cross-heads, compressive load is read from the scale a breakage/crushing of the specimen.
- Depending upon the size of the specimen, extensometer may be fitted upon it as in tensile testing.
- *Check Slide Notes.*

Bend Test

- A bend test is preferred for brittle materials such as cast iron, in which case it may also serves as a simpler substitute for the tension test (Why?)
- A bend test may well be used as a good shop test for acceptance purposes, but not for research purposes.
- A bend test is also carried out on other materials such as cast steel and welded joints in order to ascertain the degree of ductility or to test the bond between materials.

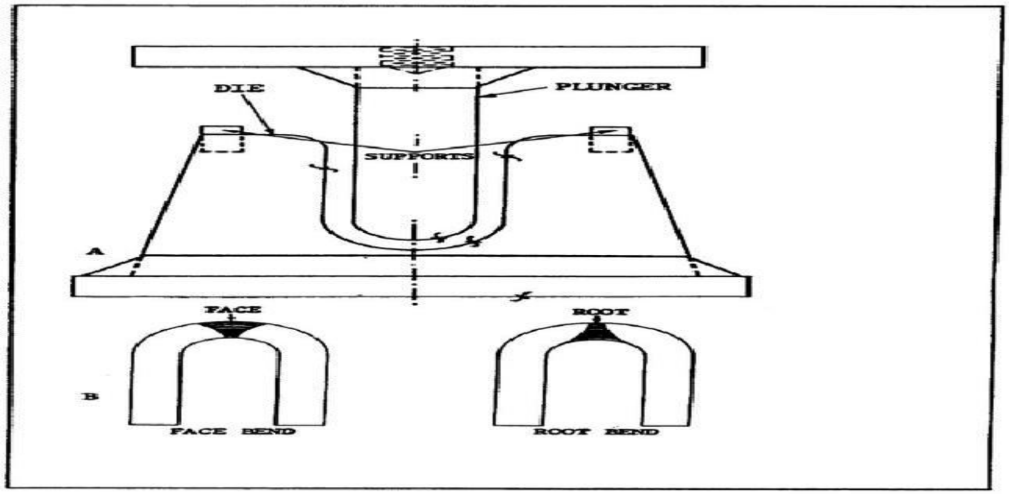
- There are two types of bend test., viz Free bend test and guided bend test.
- Free bend test:
- A free bend test may be conducted on a tensile testing machine or a vice capable of exerting a sufficiently large compressive force.
- For bend test the test specimen are cut from the plate so as to include the weld as shown in the figure. The top of the weld is ground or machined so that It becomes in sync with the base metal surface

- The specimen may be bent initially by using a device as shown in figure

- After giving an initial bend on to the specimen, it is placed in another fixture. The bending is continued until a crack or open defect in any direction appears on the convex surface of the specimen shall be bent double.
- The percent of elongation is obtained as follows:
  - % Elongation = (Z-B/B)*100
  - Where,
  - B is the original distance between gauge lines.
  - Z is the distance between gauge lines after the bend.

GUIDED BEND TEST

- A guided bend test shows surface imperfections near and in the weld bead.
- A guided bend test is performed on the specially designed jig.



- The specimen to be tested is first ground smooth so that all weld reinforcement is removed.
- The specimen is then placed across the die supports and bent by depressing the plunger until it forms the shape of U