Chapter 3. Mechanical Properties (Stress & Strain) and Mechanical Properties (Mechanical failure)

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PROPERTIES OF MATERIALS

- Different biomaterials possess different properties in varying degree and therefore behave in different ways under given conditions.
- These properties includes Mechanical properties, Electrical properties, Thermal properties, Chemical properties, and Physical properties.
- The performance of an implant material depends upon both bulk properties/ mechanical and surface properties.

- **1- Mechanical properties**

The mechanical properties of a biomaterial can best be described by its modulus of elasticity, ultimate tensile strength, elongation to failure, and fracture toughness.

- Modulus of elasticity describes the stiffness of the material and is usually obtained from the slope of a stress-strain diagram.
- Ultimate tensile strength describes the ability of the material to withstand a load before it fails.
- Elongation to failure describes how much strain the material can bear before it fails.

Mechanical properties

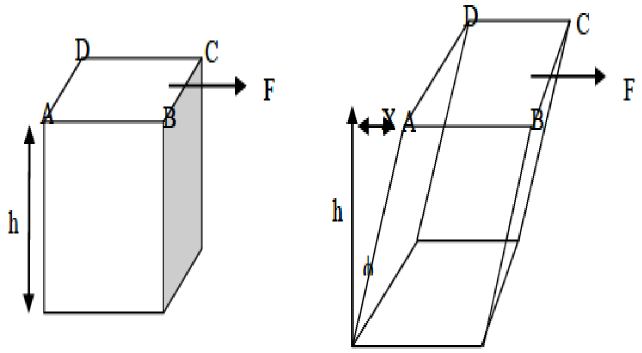
- Fracture toughness is an important measurement of the material's resistance to crack propagation
- Biomaterial design engineer is interested in the behavior of materials under load which is mechanical in nature.
- Any implant subjected to a load either deforms, yield, or break, depending upon the magnitude of the load.
- We are basically interested in knowing as to how a particular material will behave under applied load i.e. in knowing the mechanical properties.

Stress – Strain

The internal resistance of the material to the applied load is called stress, and the deformation as strain.

There are three types of stresses:

- Tensile stress: force acts to pull materials apart;
- Compressive stress: the force squeezes material;
- Shear stress: the force causes one part to slide on another part.

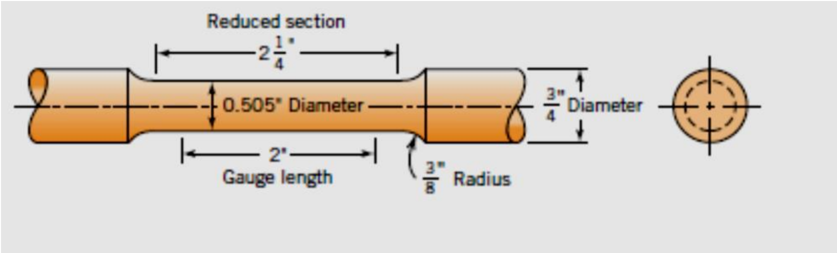


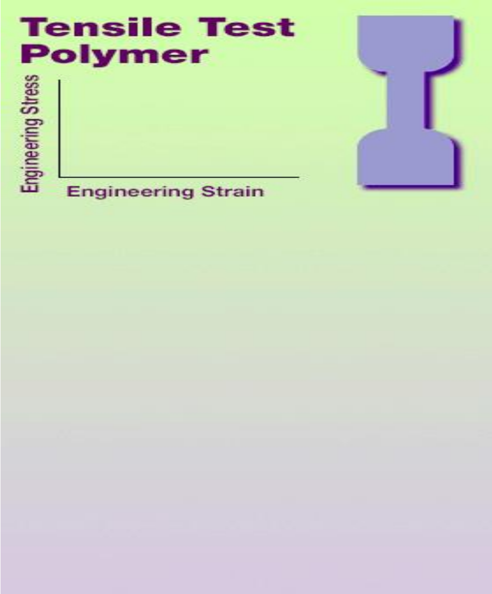
Stress – Strain

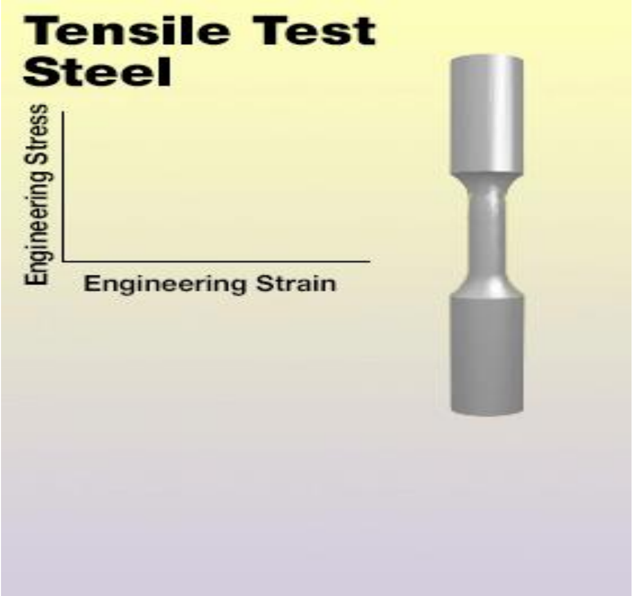
- The relationship between stress and strain in a material is determined by subjecting a material specimen to a tension or compression test.
- In this test, a steadily increasing axial force is applied to a test specimen, and the deflection is measured as the load is increased.
- These values can be plotted as a load-deflection curve.
- The deflection in the test specimen is dependent on both the material's elastic modulus as well as the geometry of the specimen (area and length).
- Since we are interested material behavior without regard to geometry, it is useful to generalize the data to remove the effect of geometry.
- This is done by converting the load values to stress values and converting the deflection values to strain values:

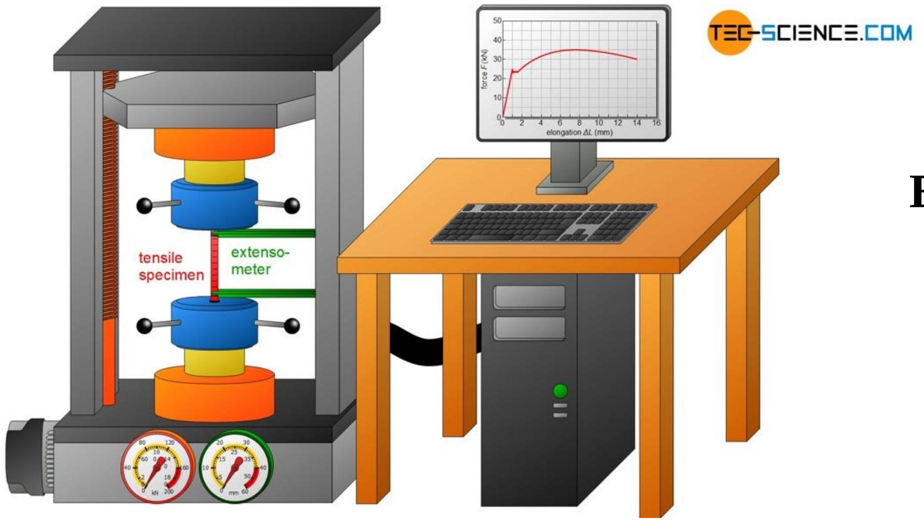
Engineering testing of materials

This dog bone‖ specimen









Engineering stress and Strain

Stress:

$\sigma = P / Ao$

Strain:

$\varepsilon = L - Lo / L0$

True Stress and Strain

$$\sigma_T = \frac{F}{A_i}$$

$$\epsilon_T = \ln \frac{l_i}{l_0}$$

instantaneous cross-sectional area

Conversion of engineering stress to true stress

$$\sigma_T = \sigma(1 + \epsilon)$$

Conversion of engineering strain to true strain

$$\epsilon_T = \ln(1 + \epsilon)$$

P is the load and Ao is the original cross-sectional area of the test specimen.
In the equation for strain, L is the current length of the specimen and Lo is the original length.

Stress-Strain Curve

- *The values of stress and strain determined from the tensile test can be plotted as a stress-strain curve, as shown below.*

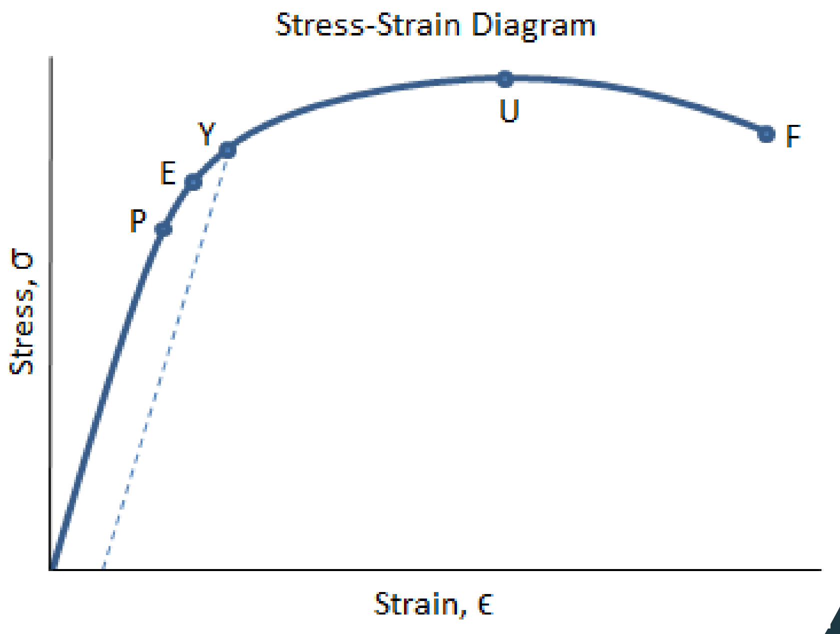
There are several points of interest in the diagram above:
P: This is the proportionality limit, which represents the maximum value of stress at which the stress-strain curve is linear.

E: This is represents the maximum value of stress at which there is no permanent sets the elastic limit, which. Even though the curve is not linear between the proportionality limit and the elastic limit, the material is still elastic in this region and if the load is removed at or below this point the specimen will return to its original length.

Y: This is the yield point, which represents the value of stress above which the strain will begin to increase rapidly.

U: This point corresponds to the ultimate strength, which is the maximum value of stress on the stress-strain diagram. The ultimate strength is also referred to as the tensile strength.

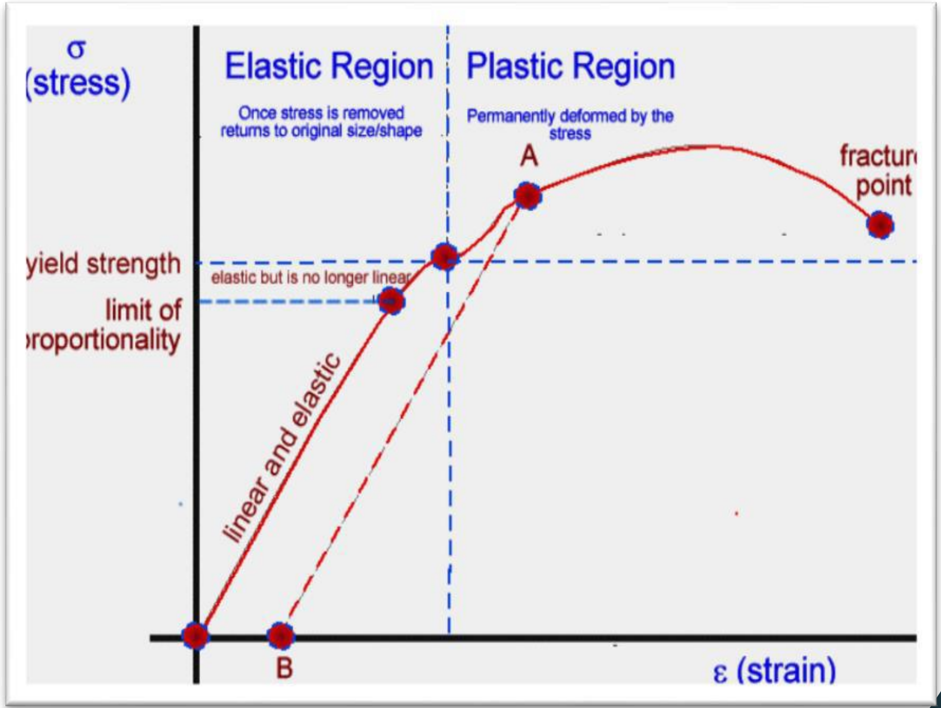
F: This is the fracture point or the break point, which is the point at which the material fails and separates into two pieces.



Stress-Strain Curve

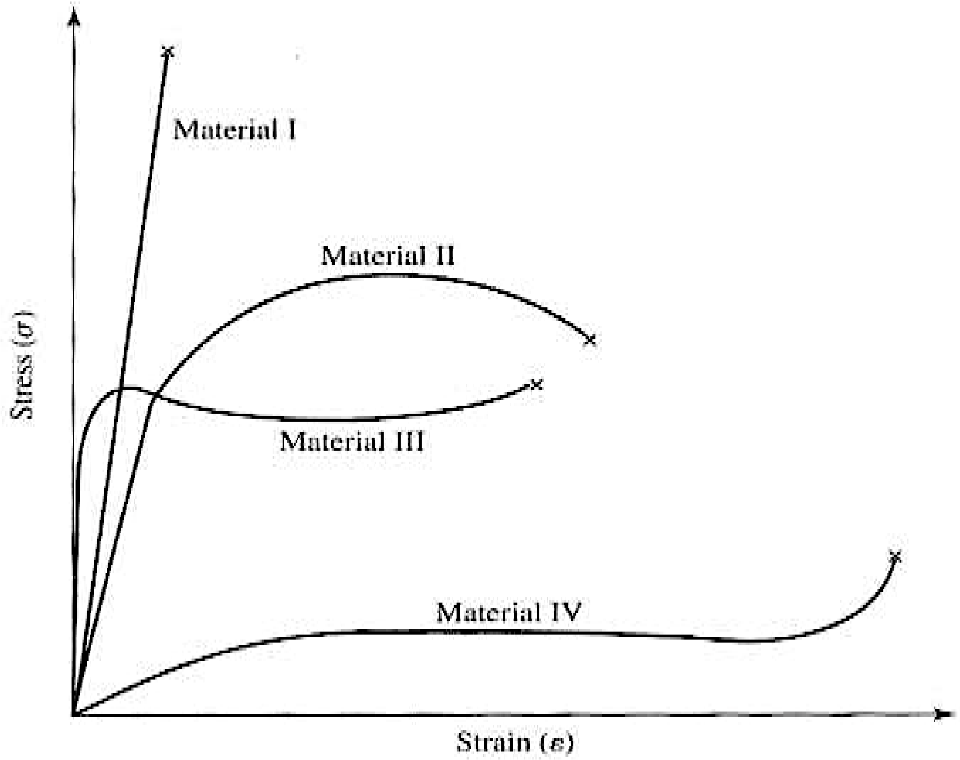
Elastic strain : It is the change in dimensions of a body when some load is applied to it . It is a reversible strain, it disappears after removal of stress or applied load . It is proportional to the applied stress . In this strain , after the removal of load , same atomic neighbors without any displacement are retained.

- Plastic strain : It is the deformation or change in dimensions of a body which remain in it after the release of load .It is a result of the permanent displacement of the atoms inside the material.



Stress-Strain Curve

- The wide variations possible on the stress-strain curve depending on the tested material.
- Ceramics (brittle)- Material I
- Metals - Material II
- Polymers –fall into wide range of categories
  - **Brittle –Material I**
  - **Plastic deformation– Material III**
  - **Highly elastic – Material IV**



PRINCIPAL MECHANICAL PROPERTIES

The most important and useful mechanical properties are:

1- Strength

It is the resistance offered by a material when subjected to external loading. So, stronger the material the greater the load it can withstand.

Depending upon the type of load applied the strength can be tensile, compressive, shear or torsional.

The maximum stress that any material will withstand before destruction is called its ultimate strength.

2- Elasticity

Elasticity of a material is its power of coming back to its original position after deformation when the stress or load is removed. Elasticity is a tensile property of its material.

The greatest stress that a material can endure without taking up some permanent set is called elastic limit .

3- Stiffness (Rigidity)

The resistance of a material to deflection is called stiffness or rigidity. Steel is stiffer or more rigid than aluminum.

Stiffness is measured by Young's modulus E.

The higher the value of the Young's modulus, the stiffer the material.

E is the ratio of stress over strain and is given by the slope of line .

PRINCIPAL MECHANICAL PROPERTIES

4- Plasticity

The plasticity of a material is its ability to undergo some degree of permanent deformation without failure. Plastic deformation will take place only after the elastic range has been exceeded, beyond point b.

In general, plasticity increases with increasing temperature and is a favorable property of material for secondary forming processes.

Due to this properties various metal can be transformed into different products of required shape and size.

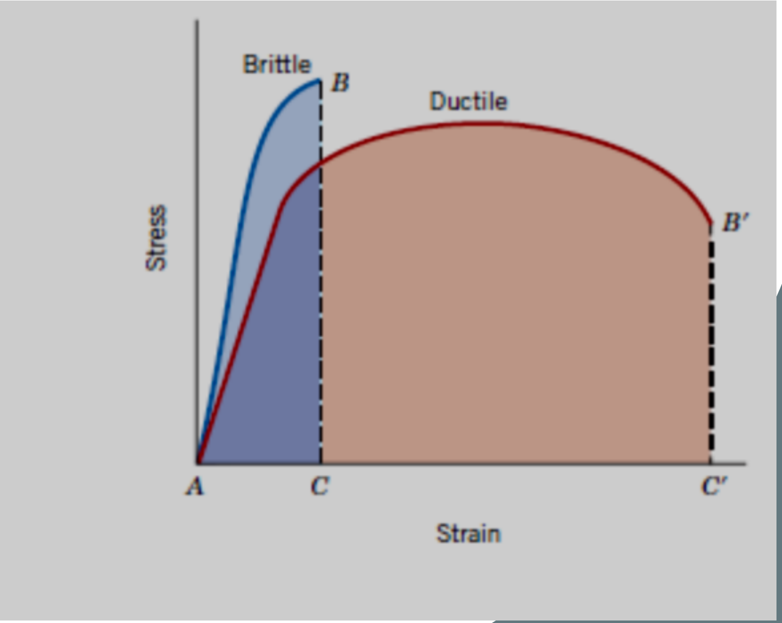
This conversion into desired shape and size is effected either by the application of pressure, heat or both.

5- Ductility

Ductility of a material enables it to draw out into thin wire on application of the load.

The ductility decreases with increase of temperature.

The percent elongation and the reduction in area in tension is often used as empirical measures of ductility.



6- Malleability

Malleability of a material is its ability to be flattened into thin sheets without cracking by hot or cold working.

Ductility is a tensile property, whereas malleability is a compressive property.

Malleability increases with increase of temperature.

PRINCIPAL MECHANICAL PROPERTIES

7- Brittleness

The brittleness of a material is the property of breaking without much permanent distortion.
There are many materials, which break or fail before much deformation take place.
Therefore, a non-ductile material is said to be a brittle material.

Usually the tensile strength of brittle materials is only a fraction of their compressive strength.

8- Toughness

The toughness of a material is its ability to withstand both plastic and elastic deformations.

It is a highly desirable quality for structural and machine parts to withstand shock and vibration.
For Ex: If a load is suddenly applied to a piece of mild steel and then to a piece of glass the mild steel will absorb much more energy before failure occurs. Thus, mild steel is said to be much tougher than a glass.

Toughness is a measure of the amount of energy a material can absorb before actual fracture or failure takes place. “The work or energy a material absorbs is called modulus of toughness”

Toughness is also resistance to shock loading. It is measured by a special test on Impact Testing Machine.

PRINCIPAL MECHANICAL PROPERTIES

9- Hardness

Hardness is closely related to strength. It is the ability of a material to resist scratching, abrasion, indentation, or penetration.

It is directly proportional to strength and is measured on special hardness testing machines by measuring the resistance of the material against penetration of an indenter of special shape and material under a given load.

Type of hardness test

The different scales of hardness are Brinell hardness, Rockwell hardness, Vicker’s hardness, etc.

10- Impact Strength

It can be defined as the resistance of the material to fracture under impact loading, i.e., under quickly applied dynamic loads.

Two standard tests are normally used to determine this property.

1. The IZOD impact test.
2. The CHARPY test.

11- Fatigue And Fatigue Test

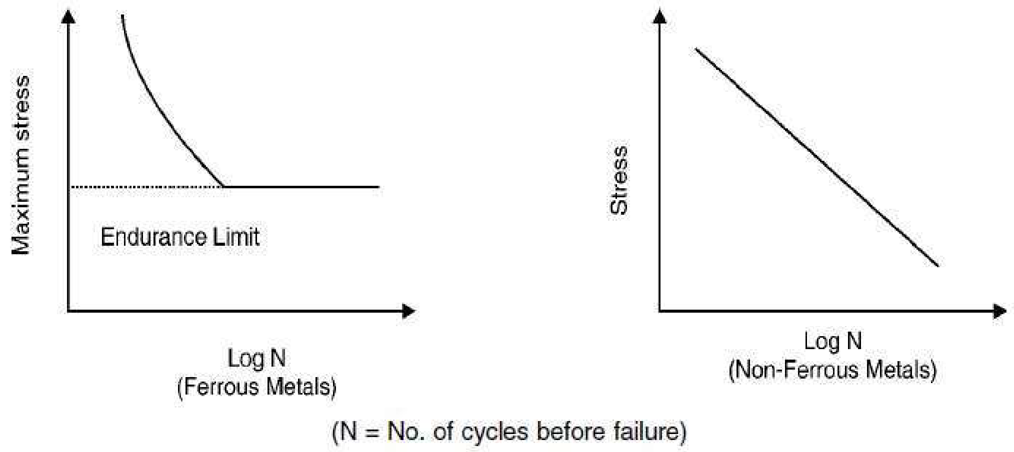
The fatigue strength of a material is the maximum stress at which failure may occur after a certain number of cyclic load applications.

The fatigue strength of material is used in the design of parts subjected to repeated alternating stresses over an extended period of time

Specimens are tested to failure using different loads.

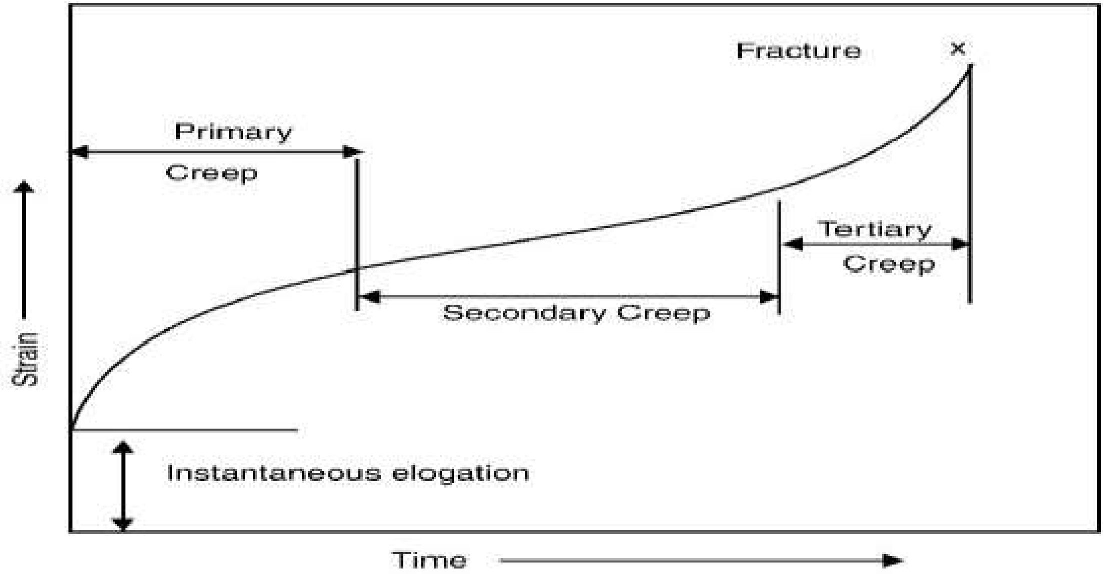
The number of cycles is noted for each load. The results of such tests are plotted as graphs of applied stress against the logarithm of the number of cycles of failure.

The curve is known as S-N curve. The tests are carried out on special fatigue testing machines.



12- Creep And Creep Testing

The slow and continuous elongation of a material with time at constant stress and high temperature below elastic limit is called creep.
At high temperatures, stresses even below the elastic limit can cause some permanent deformation on stress-strain diagram.
There are three stages of creep.
In the first stage the material elongates rapidly but at a decreasing rate.
In the second stage, the rate of elongation is constant.
In third stage, the rate of elongation increases rapidly until the material fails.
The stress for a specified rate of strain at a constant temperature is called creep strength.



Creep Test Curve

Thank you for your Kind Attention