# MODULE 2

# Subject:- Materials, Testing & Evaluation

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# What is material Engineering ????

- New materials have been among the greatest achievements of every age and they have been central to the growth, prosperity, security, and quality of life of humans since the beginning of history. It is always new materials that open the door to new technologies, whether they are in civil, chemical, construction, nuclear, aeronautical, agricultural, mechanical, biomedical or electrical engineering.
- The definition of the academic field of Materials Science & Engineering is :- It is the properties of the material that give its value.
- A material may be chosen for its strength, its electrical properties, resistance to heat or corrosion, or a host of other reasons; but they all relate to properties.
- Experience shows that all of the useful properties of a material are intimately related to its structure, at all levels, including which atoms are present, how the atoms are joined, and how groups of atoms are arranged throughout the material. Most importantly, we learn how this structure, and the resulting properties, are controlled by the processing of the material.

- Materials can be characterized in terms of :-
  - ❖State of matter: solid, liquid, gas, plasma etc.
  - ❖Physical properties like density, melting point etc.
  - ❖ Mechanical properties like hardness, strength, brittleness or ductility etc.
  - ❖ Electrical properties like conductivity
  - ❖ Magnetic properties like ferro, para, and dia magnetism
  - ❖ Optical properties like transparent, opaque, translucent etc. I have answered in general terms as I am not clear the purpose of your question.

# ELASTICITY AND PLASTICITY

- **Elasticity** is the property of the solid material by virtue of which it tends to regain its shape after the removal of external load. Elasticity is the way a material initially responds when it is subjected to stresses. Elasticity refers to the material's ability to deform in a non-permanent way, meaning that when the stress load is removed from the material it will recover its original form.
- A material will continue to deform elastically as the stress upon it increases until the elastic limit is reached. The elastic limit can be found on stress-strain diagrams for all materials, and the limit varies by the material. For instance, steel experiences far less stress before reaching the elastic limit than rubber does.

LINK:-https://www.youtube.com/watch?v=frGL1jTnDsg

- **Elastic Constants:** Stress produces a strain, but how much strain is produced depends on the solid itself. The solid is then characterised by anelastic modulus that relates strain to stress

$$\frac{Stress}{Strain} = Elastic\ Modulus = \frac{\sigma}{\varepsilon}$$

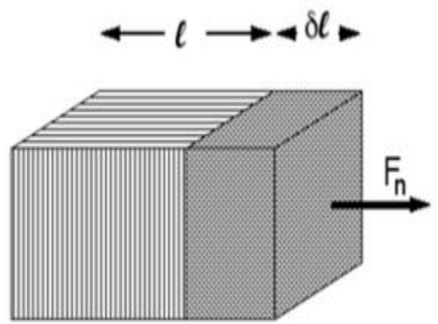
Different types of stresses and their corresponding strains within elastic limit are related which are referred to as elastic constants. The three types of elastic constants (moduli) are:

- ❑ Modulus of elasticity or Young’s modulus *(E)*
- ❑ Bulk modulus (*K*)
- ❑ and Modulus of rigidity or Shear Modulus (G)

## Young’s modulus

$$\frac{\text{normal stress}}{\text{normal strain}} = \text{Young's Modulus}$$

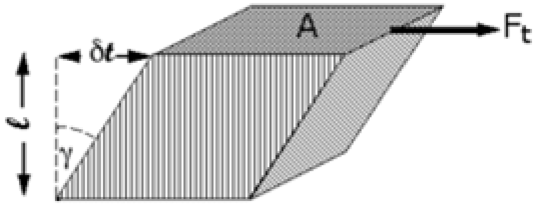
$$E = \frac{\sigma_n}{\varepsilon_n} = \frac{F_n / A}{\delta l / l} = \frac{F_n \bullet l}{\delta l \bullet A}$$




## Rigidity modulus

$$\frac{\text{shear stress}}{\text{shear strain}} = \text{hear Modulus}$$

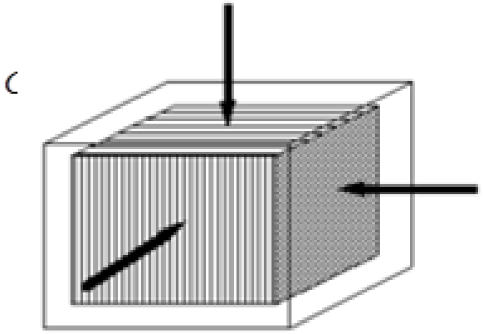
$$G = \frac{\sigma_s}{\varepsilon_s} = \frac{F_t / \mathrm{A}}{\delta t / f} = \frac{F_t}{A \bullet \gamma}$$




## Bulk modulus

$$\frac{\text{bulk stress}}{\text{bulk strain}} = \text{Bulk Modulus}$$

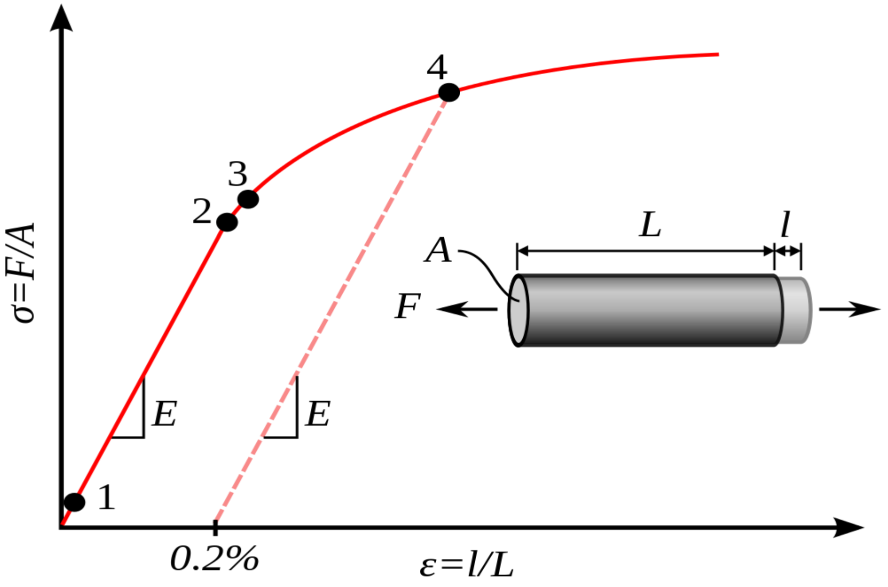
$$K = \frac{\sigma_b}{\varepsilon_b} = \frac{P}{-\delta V / V} = -\frac{PV}{\delta V}$$



Normal inward forces compress the solid

- **Plasticity** is the property of the solid material by virtue of which it tends to retain its deformed shape even after the removal of external load.

In the other words, plasticity, also known as plastic deformation, is the ability of a solid material to undergo permanent deformation, a non-reversible change of shape in response to applied forces.




llustration of offset yield point. Key: 1: True elastic limit 2: Proportionality limit 3: Elastic limit 4: Offset yield strength, usually defined at e=0.2% σ: Engineering stress ε: Engineering strain A: Undeformed cross-sectional area F: Uniaxial load L: Undeformed length

# TENSILE TEST

- Tensile testing, also known as tension testing, is a fundamental materials science and engineering test in which a sample is subjected to a controlled tension until failure.
- Properties that are directly measured via a tensile test are ultimate tensile strength, breaking strength, maximum elongation and reduction in area. From these measurements the following properties can also be determined: Young's modulus, Poisson's ratio, yield strength, and strain-hardening characteristics.

Uniaxial tensile testing is the most commonly used for obtaining the mechanical characteristics of isotropic materials.

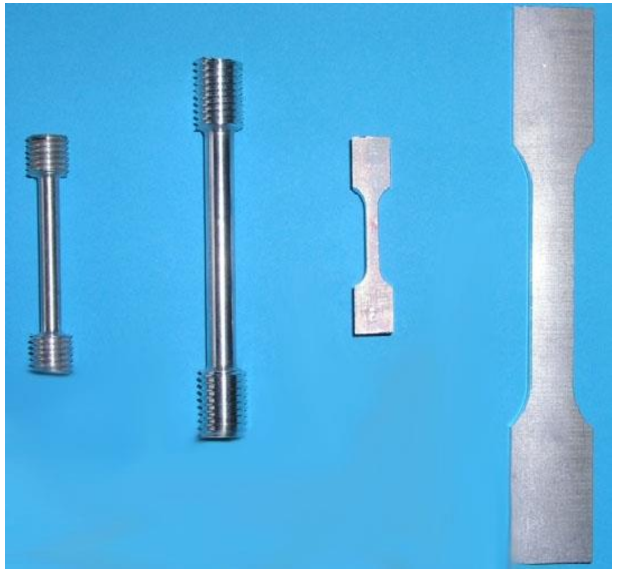
- Tensile testing might have a variety of purposes, such as:
- Select a material or item for an application
- Predict how a material will perform in use: normal and extreme forces.
- Determine if, or verify that, the requirements of a specification, regulation, or contract are met

- Decide if a new product development program is on track
- Demonstrate proof of concept
- Demonstrate the utility of a proposed patent
- Provide standard data for other scientific, engineering, and quality assurance functions
- Provide a basis for Technical communication
- Provide a technical means of comparison of several options
- Provide evidence in legal proceedings
- **Tensile specimen**:-
- The preparation of test specimens depends on the purposes of testing and on the governing test method or specification. A tensile specimens is usually a standardized sample cross-section. It has two shoulders and a gage (section) in between. The shoulders are large so they can be readily gripped, whereas the gauge section has a smaller cross-section so that the deformation and failure can occur in this area

- Equipment :-

The most common testing machine used in tensile testing is the **universal testing machine.** This type of machine has two *crossheads*; one is adjusted for the length of the specimen and the other is driven to apply tension to the test specimen. There are two types:-

1. hydraulic powered
2. electromagnetically powered machines.



Tensile specimens made from an aluminum alloy. The left two specimens have a round cross-section and threaded shoulders. The right two are flat specimens designed to be used with serrated grips.

The machine must have the proper capabilities for the test specimen being tested. There are four main parameters: force capacity, speed, precision and accuracy. Force capacity refers to the fact that the machine must be able to generate enough force to fracture the specimen.

- The machine must be able to apply the force quickly or slowly enough to properly mimic the actual application. Finally, the machine must be able to accurately and precisely measure the gauge length and forces applied; for instance, a large machine that is designed to measure long elongations may not work with a brittle material that experiences short elongations prior to fracturing.
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- Alignment of the test specimen in the testing machine is critical, because if the specimen is misaligned, either at an angle or offset to one side, the machine will exert a bending force on the specimen. This is especially bad for brittle materials, because it will dramatically skew the results.

- If the initial portion of the stress–strain curve is curved and not linear, it indicates the specimen is misaligned in the testing machine

The strain measurements are most commonly measured with an extensometer, but strain gauges are also frequently used on small test specimen or when Poisson's ratio is being measured. Newer test machines have digital time, force, and elongation measurement systems consisting of electronic sensors connected to a data collection device (often a computer) and software to manipulate and output the data.


Universal testing machine

- Process:-

The test process involves placing the test specimen in the testing machine and slowly extending it until it fractures. During this process, the elongation of the gauge section is recorded against the applied force. The elongation measurement is used to calculate the engineering strain, *ε.*

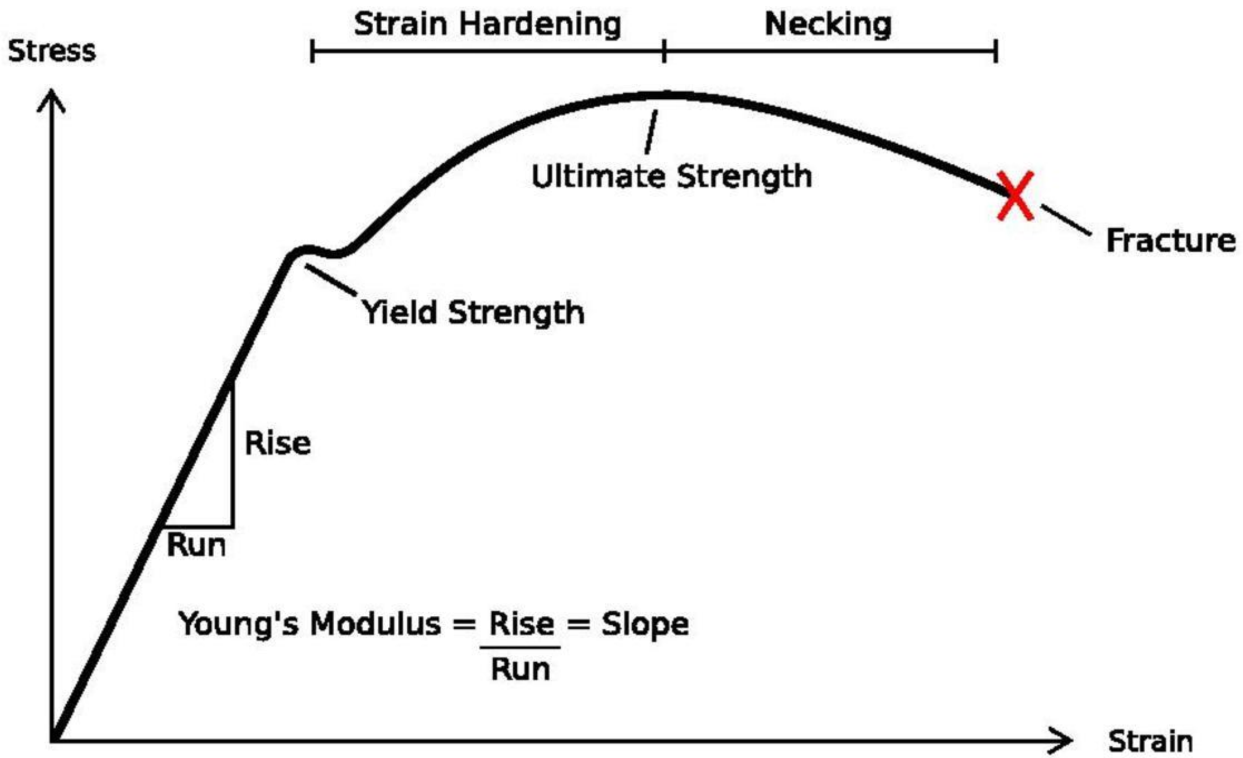
$$\textit{Strain}=\frac{change\ in\ length}{original\ length}$$

$$\text{Stress}=\frac{Resisting\ force}{cross\ sectional\ area}$$

The machine does these calculations as the force increases, so that the data points can be graphed into a *stress–strain curve*.

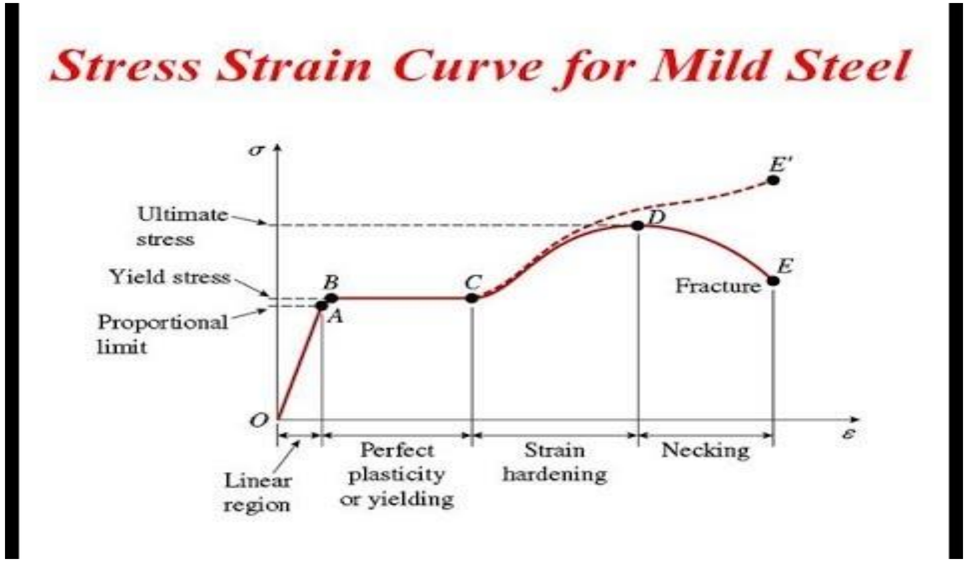
- A **stress–strain curve** for a material gives the relationship between stress and strain.

These curves reveal many of the properties of a material such as the Young's modulus, the yield strength and the ultimate tensile strength.




Stress-strain curve typical of a low carbon steel

- Stages:-
- A schematic diagram for the stress-strain curve of low carbon steel at room temperature is shown in previous slide. There are several stages showing different behaviors, which suggests different mechanical properties.
- The first stage is the linear elastic region. The stress is proportional to the strain, that is, obeys the general Hooke's law, and the slope is Young's modulus. In this region, the material undergoes only elastic deformation. The end of the stage is the initiation point of plastic deformation. The stress component of this point is defined as yield strength (or upper yield point, UYP for short).
- The second stage is the strain hardening region. This region starts as the strain goes beyond the yielding point, reaching a maximum at the ultimate strength point, which is the maximal stress that can be sustained and is called the ultimate tensile strength (UTS).
- In this region, the stress mainly increases as the material elongates, except that for some materials such as steel, there is a nearly flat region at the beginning. The stress of the flat region is defined as the lower yield point (LYP). (Shown in next slides).




The third stage is the necking region. Beyond tensile strength, a neck forms where the local cross-sectional area becomes significantly smaller than the average. The necking deformation is heterogeneous and will reinforce itself as the stress concentrates more at small section. Such positive feedback leads to quick development of necking and leads to fracture.

Note that though the pulling force is decreasing, the work strengthening is still progressing, that is, the true stress keeps growing but the engineering stress decreases because the shrinking section area is not considered. This region ends up with the fracture. After fracture, percent elongation and reduction in section area can be calculated.

# Engineering stress and strain

- Consider a bar of original cross sectional area $A_0$ being subjected to equal and opposite forces F pulling at the ends so the bar is under tension. The material is experiencing a stress defined to be the ratio of the force to the cross sectional area of the bar, as well as an axial elongation:

$$\text{STRESS} = \frac{F}{A_0}$$

$$\text{STRAIN} = \frac{L-L_0}{L_0} = \frac{\Delta L}{L_0}$$

Subscript 0 denotes the original dimensions of the sample. The SI unit for stress is newton per square metre, or pascal (1 pascal = 1 Pa = 1 $N/m^2$), and for strain is "1". Stress-strain curve for this material is plotted by elongating the sample and recording the stress variation with strain until the sample fractures.

Note that for engineering purposes we often assume the cross-section area of the material does not change during the whole deformation process. This is not true since the actual area will decrease while deforming due to elastic and plastic deformation. The curve based on the original cross-section and gauge length is called the engineering stress-strain curve.

# True stress and strain

- Due to the shrinking of section area and the ignored effect of developed elongation to further elongation, true stress and strain are different from engineering stress and strain.

True Stress = $\frac{F}{A}$

A= Instantaneous area

True Strain,

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

L = Final Length

= $L_0 + \Delta L$ OR $L_0 - \Delta L$

Here the dimensions are instantaneous values. Assuming volume of the sample conserves and deformation happens uniformly,

AL= $A_0 \, L_0$

The curve based on the instantaneous cross-section area and length is called the true stress-strain curve.

- The true stress and strain can be expressed by engineering stress and strain.

**Engineering Stress/Strain vs. True Stress/Strain**

- **True Stress & Engineering Stress (Up to necking)**

$$\sigma = \frac{P}{A} = \frac{P}{\left(\frac{A_0 l_0}{l}\right)} = \frac{P}{A_0} \bullet \frac{l}{l_0}$$

$$= \sigma_0 \left(\frac{l_0 + \Delta l}{l_0}\right) = \sigma_0 \left(1 + \frac{\Delta l}{l_0}\right) = \sigma_0 (1 + e)$$

- **True Strain & Engineering Strain (Up to necking)**

$$\varepsilon = \ln \frac{l}{l_0} = \ln \left(\frac{l_0 + \Delta l}{l_0}\right) = \ln(1 + e)$$

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So in a tension test, true stress is larger than engineering stress and true strain is less than engineering strain. Thus, a point defining true stress-strain curve is displaced upwards and to the left to define the equivalent engineering stress-strain curve. The difference between the true and engineering stresses and strains will increase with plastic deformation. At low strains (such as elastic deformation), the differences between the two is negligible.

# Classification

It is possible to distinguish some common characteristics among the stress–strain curves of various groups of materials and, on this basis, to divide materials into two broad categories; namely, the ductile materials and the brittle materials.

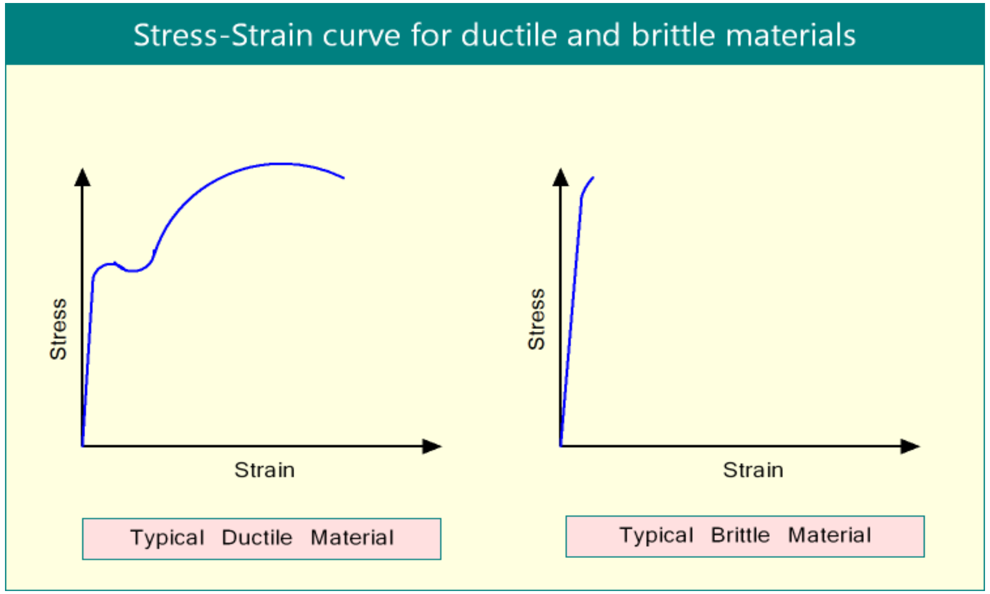
1. **Ductile materials**

Ductile materials are those which could show plastic deformation. Such materials can be actually drawn or bent or rolled before it reaches its fracture point.

**2.Brittle materials**

Brittle material are those which breaks into pieces upon application of tensile force without any elongation or plastic deformation.

Brittle materials such as concrete or carbon fiber do not have a well-defined yield point, and do not strain-harden. Therefore, the ultimate strength and breaking strength are the same. A typical stress–strain curve for a brittle material will be linear.




# Differences between ductile material and brittle material

| Ductile Material | Brittle Material |
|---|---|
| Solid materials that can undergo substantial plastic deformation prior to fracture are called ductile materials. | Solid materials that exhibit negligible plastic deformation are called brittle materials. |
| Percentage elongation of the ductile materials before fracture under tensile testing is higher. | Percentage elongation of the brittle materials before fracture under tensile testing is very less. |
| Ductile materials fail gradually by neck formation under the action of external tensile loading. | Brittle materials fail by sudden fracture (without any warning such as necking). |

| | |
|---|---|
| Energy absorbed by ductile materials before fracture under tensile testing is more. | Brittle materials absorb very small energy before fracture. |
| Various metal forming operations (such as rolling, forging, drawing, bending, etc.) can be performed on ductile materials. | Forming operations cannot be easily performed on brittle materials. For example, brittle material cannot be drawn into wire. |
| Ductile materials show longer life when subjected to fatigue loading. | Brittle materials fail faster when subjected to fatigue loading. |
| Examples of ductile material:<br>•Mild steel<br>•Aluminum<br>•Copper<br>•Rubber<br>•Most plastics | Examples of brittle material:<br>•Cast iron<br>•Ceramics such as glass, cement, concrete, etc.<br>•Stone<br>•Ice |

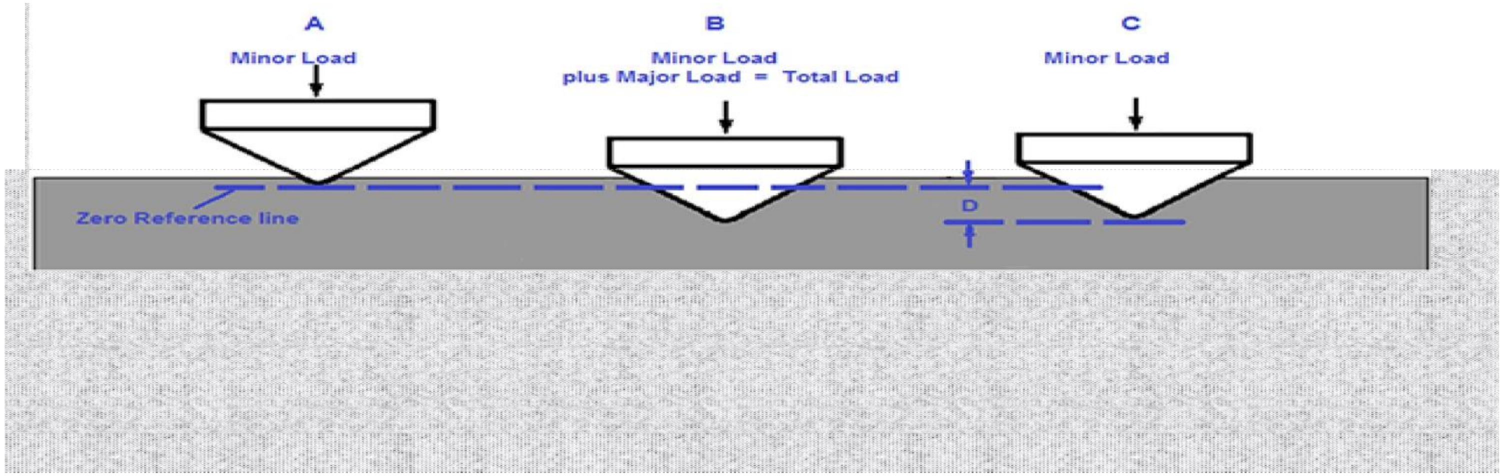
# Hardness Test

A) Rockwell method

- The Rockwell method measures the permanent depth of indentation produced by a force/load on an indenter. First, a preliminary test force (commonly referred to as preload or minor load) is applied to a sample using a diamond or ball indenter. This preload breaks through the surface to reduce the effects of surface finish. After holding the preliminary test force for a specified dwell time, the baseline depth of indentation is measured.
- After the preload, an additional load, call the major load, is added to reach the total required test load. This force is held for a predetermined amount of time (dwell time) to allow for elastic recovery. This major load is then released, returning to the preliminary load. After holding the preliminary test force for a specified dwell time, the final depth of indentation is measured. The Rockwell hardness value is derived from the difference in the baseline and final depth measurements. This distance is converted to a hardness number. The preliminary test force is removed and the indenter is removed from the test specimen.

- Preliminary test loads (preloads) range from 3 kgf (used in the "Superficial" Rockwell scale) to 10 kgf (used in the "Regular" Rockwell scale). Total test forces range from 15kgf to 150 kgf (superficial and regular) to 500 to 3000 kgf (macrohardness).
- **Test Method Illustration**

A = Depth reached by indenter after application of preload (minor load)
B = Position of indenter during Total load, Minor plus Major loads
C = Final position reached by indenter after elastic recovery of sample material
D = Distance measurement taken representing difference between preload and major load position. This distance is used to calculate the Rockwell Hardness Number.



- A variety of **indenters** may be used: conical diamond with a round tip for harder metals to ball indenters ranges with a diameter ranging from 1/16” to ½” for softer materials.

  When selecting a **Rockwell scale**, a general guide is to select the scale that specifies the largest load and the largest indenter possible without exceeding defined operation conditions and accounting for conditions that may influence the test result. These conditions include test specimens that are below the minimum thickness for the depth of indentation; a test impression that falls too close to the edge of the specimen or another impression; or testing on cylindrical specimens.

b) **Brinell hardness test method**

The Brinell hardness test method as used to determine Brinell hardness, is defined in ASTM E10. Most commonly it is used to test materials that have a structure that is too coarse or that have a surface that is too rough to be tested using another test method, e.g., castings and forgings.

Brinell testing often use a very high test load (3000 kgf) and a 10mm diameter indenter so that the resulting indentation averages out most surface and sub-surface inconsistencies.

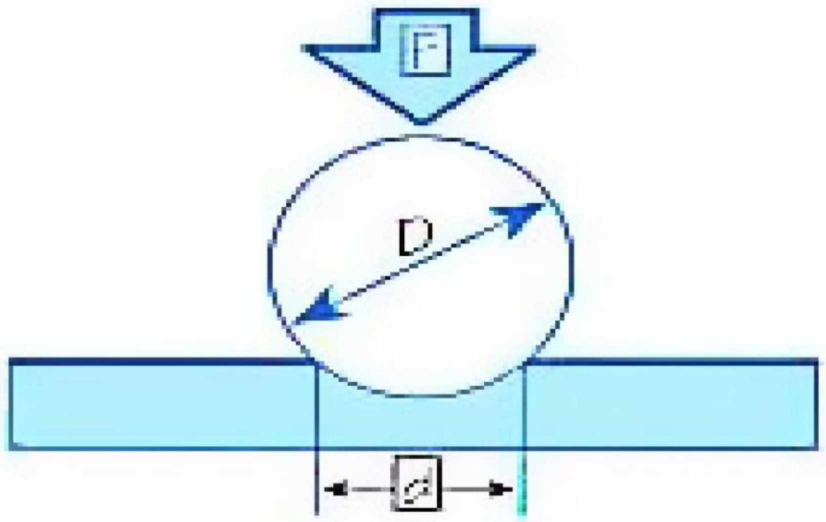
The Brinell method applies a predetermined test load (F) to a carbide ball of fixed diameter (D) which is held for a predetermined time period and then removed. The resulting impression is measured with a specially designed **Brinell microscope** or **optical system** across at least two diameters – usually at right angles to each other and these results are averaged (d).

Although the calculation below can be used to generate the Brinell number, most often a chart is then used to convert the averaged diameter measurement to a Brinell hardness number.

Common test forces range from 500kgf often used for non-ferrous materials to 3000 kgf usually used

for steels and cast iron. There are other Brinell scales with load as low as 1kgf and 1mm diameter indenters but these are infrequently used.

D = Ball diameter
d = impression diameter
F = load
HB = Brinell result




$$HB = \frac{2F}{\pi D\left(D - \sqrt{D^2 - d^2}\right)}$$

- Typically the greatest source of error in Brinell testing is the measurement of the indentation. Due to disparities in operators making the measurements, the results will vary even under perfect conditions. Less than perfect conditions can cause the variation to increase greatly. Frequently the test surface is prepared with a grinder to remove surface conditions.

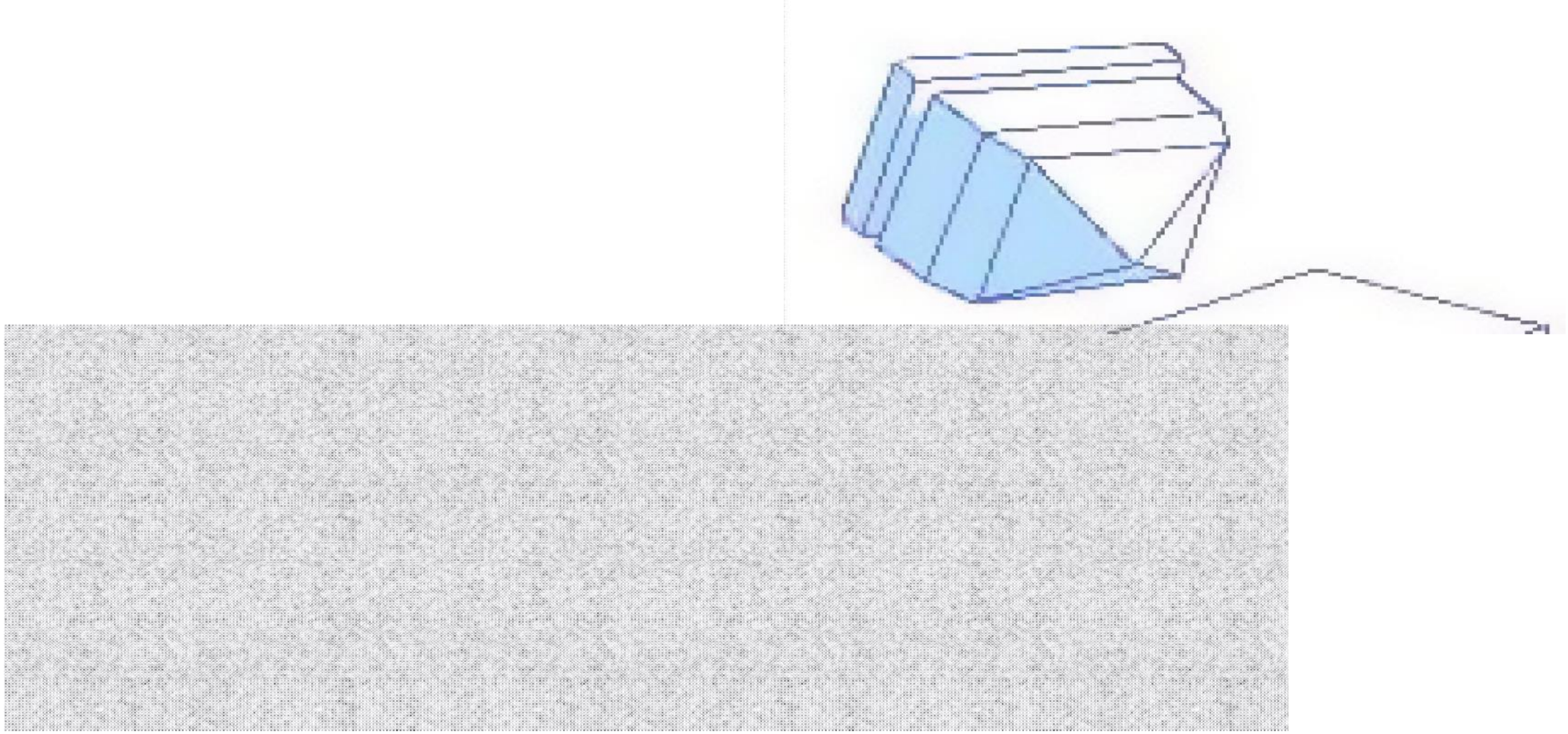
- The jagged edge makes interpretation of the indentation difficult. Furthermore, when operators know the specifications limits for rejects, they may often be influenced to see the measurements in a way that increases the percentage of “good” tests and less re-testing.

## c). Vickers hardness test method

- ✓ The Vickers hardness test method, also referred to as a micro hardness test method, is mostly used for small parts, thin sections, or case depth work.
- ✓ The Vickers method is based on an optical measurement system. The Microhardness test procedure, ASTM E-384, specifies a range of light loads using a **diamond indenter** to make an indentation which is measured and converted to a hardness value. It is very useful for testing on a wide type of materials, but test samples must be highly polished to enable measuring the size of the impressions. A square base pyramid shaped diamond is used for testing in the Vickers scale. Typically loads are very light, ranging from 10gm to 1kgf, although "Macro" Vickers loads can range up to 30 kg or more.
- ✓ The Microhardness methods are used to test on metals, ceramics, composites - almost any type of material.

Since the test indentation is very small in a Vickers test, it is useful for a variety of applications: testing very thin materials like foils or measuring the surface of a part, small parts or small areas, measuring individual microstructures, or measuring the depth of case hardening by sectioning a part and making a series of indentations to describe a profile of the change in hardness.

- ✓ Sectioning is usually necessary with a microhardness test in order to provide a small enough specimen that can fit into the tester. Additionally, the sample preparation will need to make the specimen’s surface smooth to permit a regular indentation shape and good measurement, and to ensure the sample can be held perpendicular to the indenter.
- ✓ Often the prepared samples are mounted in a plastic medium to facilitate the preparation and testing. The indentations should be as large as possible to maximize the measurement resolution. (Error is magnified as indentation sizes decrease) The test procedure is subject to problems of operator influence on the test results.

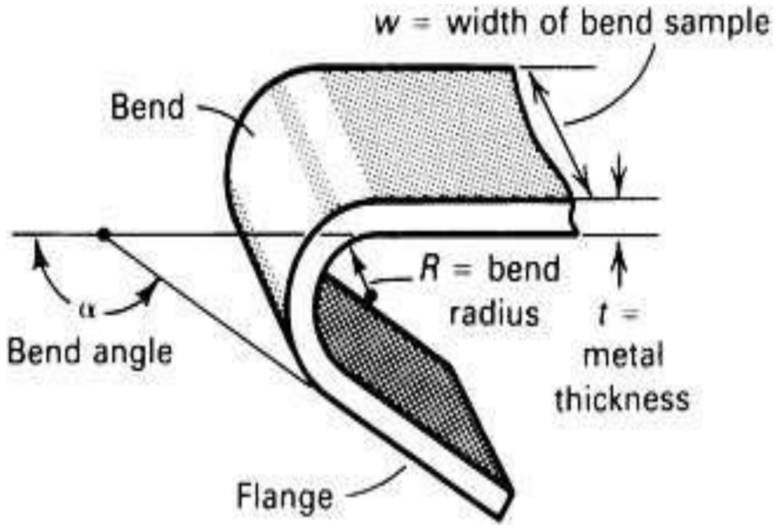


# BENDING TEST:-

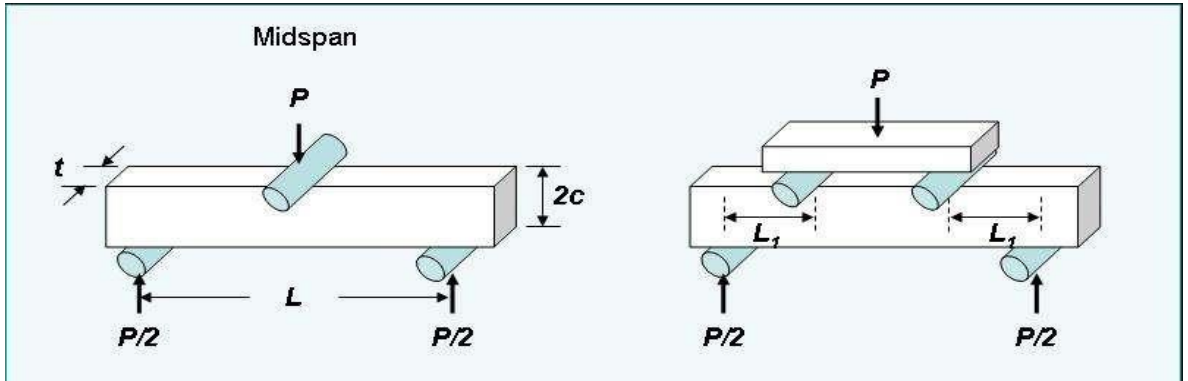
The Flexural(bending) test measures the force required to bend a beam under 3 point loading conditions. The data is often used to select materials for parts that will support loads without flexing. Flexural modulus is used as an indication of a material's stiffness when flexed. Since the physical properties of many materials (especially thermoplastics) can vary depending on ambient temperature.

- The bend test is useful for assessing the workability of thick sheet and plate. Generally, this test is most applicable to cold-working operations. Figure 9 shows a plate deformed in three-point bending. The principal stress and strains developed during bending are defined in Fig. 10. The critical parameter is width- to-thickness ratio (w/t). If w/t > 8, bending occurs under plane-strain conditions if w/t > 8, the bend ductility is independent of the exact w/t ratio. If w/t < 8, then stress state and bend ductility depend strongly on the width-to-thickness ratio.

- Bending ductility tests determine the smallest radius around which a specimen can be bent without cracks being observed in the outer fiber (tension) surface. This forming limit commonly is called the minimum bend radius and is expressed in multiples of specimen thickness, t. A material with a minimum bend radius of 3t can be bent without cracking through a radius equal to three times the specimen thickness. It thus follows that a material with a minimum bend radius of 1t has greater ductility than a material with minimum bend radius of 5t. Alternatively, the bend radius can be fixed, and the angle of bend at which fracture occurs noted. As illustrates bend radius, angle of bend, and other concepts associated with bending tests.



• Bend or flexure testing is common in springs and brittle materials whose failure behaviors are linear such as concretes, stones, woods, plastics, glasses and ceramics. Other types of brittle materials such as powder metallurgy processed metals and materials are normally tested under a transverse flexure. Bend test is therefore suitable for evaluating strength of brittle materials where interpretation of tensile test result of the same material is difficult due to breaking of specimens around specimen gripping. The evaluation of the tensile result is therefore not valid since the failed areas are not included in the specimen gauge length. Smooth rectangular specimens without notches are generally used for bend testing under three-point or four- point bend arrangements as shown in figures 1 a) and b) respectively. Figure illustrates three-point bending which is capable of 180$^{o}$ bend angle for welded materials.



a) Three-point bending

b) Four-point bending

- This test has a number of disadvantages. First, dissimilar metal corrosion and/or crevice corrosion can occur under the bolt. Secondly, once the crack has formed, the stress condition changes such that the outer layer of the specimen is not subject to a tensile stress only, but to a complex combination at tensile and bending stresses. The propagating crack will then deviate from the centerline. Thus, the three-point bend test can only be used as a qualitative test to assess the susceptibility to stress-corrosion cracking.

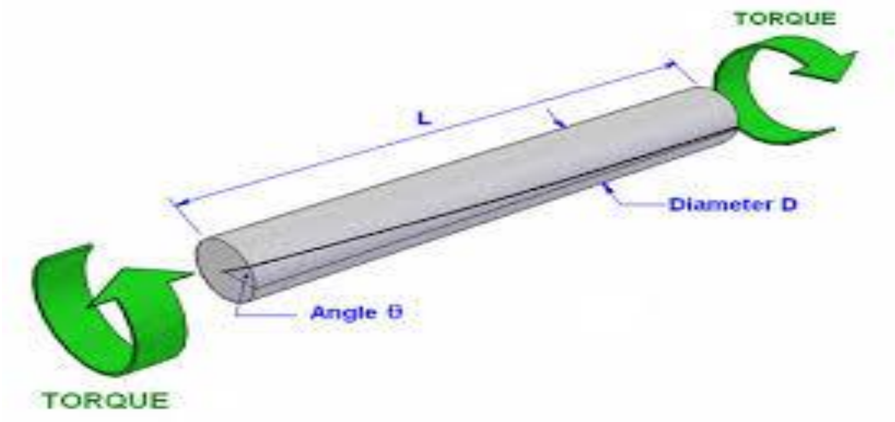
- **Three-Point Bend Specimens :-** Three-point bend tests are commonly used because of the ease of load application and the ability to use the same loading rigs for different stresses. The load is applied by turning a bolt in the rig, deflecting the specimen.
- **Procedure:-**
  - Took a steel bar specimen measured its length and mass.
  - Placed it on test machine and adjusted machine such that the difference between support is 8 time dia of bar and landle is 5 times the dia of steel bar
  - Applied load until it bended at 180 angle.

## Significance and Use

- Bend tests for ductility provide a simple way to evaluate the quality of materials by their ability to resist cracking or other surface irregularities during one continuous bend. No reversal of the bend force shall be employed when conducting these tests.
- The type of bend test used determines the location of the forces and constraints on the bent portion of the specimen, ranging from no direct contact to continuous contact.
- The test can terminate at a given angle of bend over a specified radius or continue until the specimen legs are in contact. The bend angle can be measured while the specimen is under the bending force (usually when the semi-guided bend test is employed), or after removal of the force as when performing a free-bend test. Product requirements for the material being tested determine the method used.
- Materials with an as-fabricated cross section of rectangular, round, hexagonal, or similar defined shape can be tested in full section to evaluate their bend properties by using the procedures outlined in these test methods, in which case relative width and thickness requirements do not apply.

# Torsion Test

- Torsion tests twist a material or test component to a specified degree, with a specified force, or until the material fails in torsion. The twisting force of a torsion test is applied to the test sample by anchoring one end so that it cannot move or rotate and applying a moment to the other end so that the sample is rotated about its axis. The rotating moment may also be applied to both ends of the sample but the ends must be rotated in opposite directions. The forces and mechanics found in this test are similar to those found in a piece of string that has one end held in a hand and the other end twisted by the other.

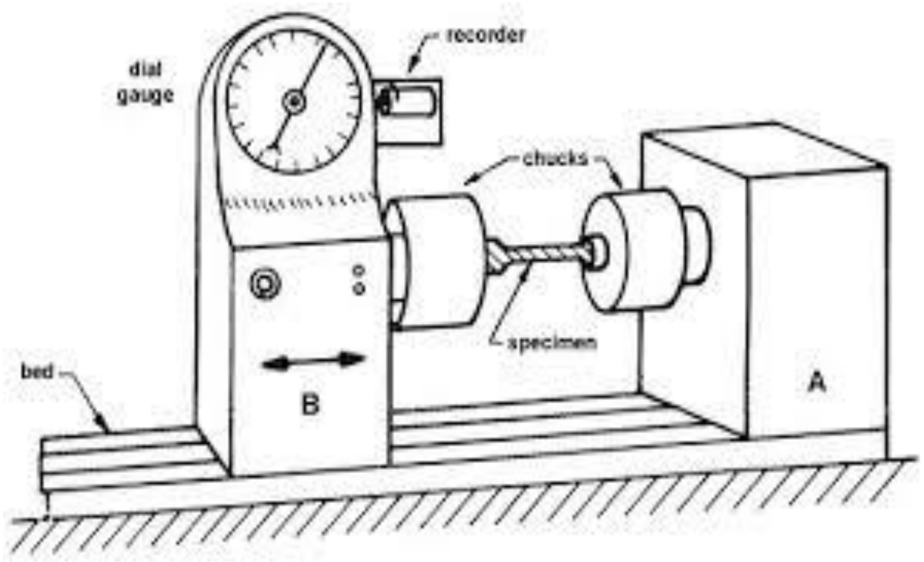



- [https://www.youtube.com/watch?v=1eBrskh1hJQ](https://www.youtube.com/watch?v=1eBrskh1hJQ)

- **Types of torsion tests:-**

The three common forms that torsion testing take include failure, proof and operational. A torsion test for failure requires that the test sample be twisted until it breaks and is designed to measure the strength of the sample. A proof test is designed to observe the material under a specified torque load over a set period of time. Finally, operational testing is measures the material's performance under the expected service conditions of its application. All of these forms of tests may be performed with either torsion only loading or a combination of torsion and axial (tension or compression) loading depending upon the characteristics to be measured.

**Procedure:-**



- Measure the specimen initial length, initial diameter and initial gauge length and put these values on the provided table shown below.
- Mark a line along the length of specimen with the help of permanent pen. This will help us to measure the rotation during twisting.
- Calibrate the torsion testing equipment as explained above
- Use the hexagonal sockets to grip specimen on torsion testing machine
- Fix one end of specimen on input and other end on torque shaft and apply small preload
- Set torque meter to zero
- Start the process and twist the specimen with the strain increment of 0.5 degree until failure of specimen
- Record all experimental data in the provided table
- Note: before taking reading make sure that it’s not fluctuating and leveled off
- Construct relationship between degree and torque
- Establish a relation between shear strain and shear stress
- Calculate the theoretical values of second polar moment of inertia and modulus of rigidity

# CREEP

- Concrete creep is defined as: deformation of structure under sustained load. Basically, long term pressure or stress on concrete can make it change shape. This deformation usually occurs in the direction the force is being applied. Like a concrete column getting more compressed, or a beam bending. Creep does not necessarily cause concrete to fail or break apart. When a load is applied to concrete, it experiences an instantaneous elastic strain which develops into creep strain if the load is sustained.
- Creep is factored in when concrete structures are designed.
- **Factors Affecting Creep:-**
- Aggregate
- Mix Proportions
- Age of concrete
- The magnitude of creep strain is one to three times the value of the instantaneous elastic strain, it is proportional to cement-paste content and, thus, inversely proportional to aggregate volumetric content.

- The magnitude of creep is dependent upon the magnitude of the applied stress, the age and strength of the concrete, properties of aggregates and cementitious materials, amount of cement paste, size and shape of concrete specimen, volume to surface ratio, amount of steel reinforcement, curing conditions, and environmental conditions

- **Influence of Aggregate :-**
- Aggregate undergoes very little creep. It is really the paste which is responsible for the creep. However, the aggregate influences the creep of concrete through a restraining effect on the magnitude of creep. The paste which is creeping under load is restrained by aggregate which do not creep. The stronger the aggregate the more is the restraining effect and hence the less is the magnitude of creep. An increase from 65 to 75 % of volumetric content of the aggregate will decrease the creep by 10 %.
- The modulus of elasticity of aggregate is one of the important factors influencing creep. It can be easily imagined that the higher the modulus of elasticity the less is the creep. Light weight aggregate shows substantially higher creep than normal weight aggregate

- **Influence of Mix Proportions:**
- The amount of paste content and its quality is one of the most important factors influencing creep. A poorer paste structure undergoes higher creep. Therefore, it can be said that creep increases with increase in water/cement ratio. In other words, it can also be said that creep is inversely proportional to the strength of concrete. Broadly speaking, all other factors which are affecting the water/cement ratio are also affecting the creep.
- **Influence of Age:**
- Age at which a concrete member is loaded will have a predominant effect on the magnitude of creep. This can be easily understood from the fact that the quality of gel improves with time. Such gel creeps less, whereas a young gel under load being not so stronger creeps more. What is said above is not a very accurate statement because of the fact that the moisture content of the concrete being different at different age also influences the magnitude of creep.

- **Effects of Creep on Concrete and Reinforced Concrete**
- In reinforced concrete beams, creep increases the deflection with time and may be a critical consideration in design.
- In eccentrically loaded columns, creep increases the deflection and can load to buckling.
- In case of statically indeterminate structures and column and beam junctions creep may relieve the stress concentration induced by shrinkage, temperatures changes or movement of support. Creep property of concrete will be useful in all concrete structures to reduce the internal stresses due to non-uniform load or restrained shrinkage.
- In mass concrete structures such as dams, on account of differential temperature conditions at the interior and surface, creep is harmful and by itself may be a cause of cracking in the interior of dams. Therefore, all precautions and steps must be taken to see that increase in temperature does not take place in the interior of mass concrete structure.
- Loss of prestress due to creep of concrete in prestressed concrete structure.
- Because of rapid construction techniques, concrete members will experience loads that can be as large as the design loads at very early age; these can cause deflections due to cracking and early age low elastic modulus. So, creep has a significant effect on both the structural integrity and the economic impact that it will produce if predicted wrong.

## • Toughness

Toughness is the measurement of a material's resistance to break, fracture or rupture. It is usually measured in units of energy or work. It is the ability of a material to absorb energy and plastically deform without fracturing. One definition of material toughness is the amount of energy per unit volume that a material can absorb before rupturing.

Toughness is related to the area under the stress–strain curve. In order to be tough, a material must be both strong and ductile. For example, brittle materials (like ceramics) that are strong but with limited ductility are not tough; conversely, very ductile materials with low strengths are also not tough. To be tough, a material should withstand both high stresses and high strains. Generally speaking, toughness indicates how much energy a material can absorb before rupturing.

To calculate the toughness of a sample we have to integrate the area under stress strain curve.As the value of toughness is joule per cubic metre, so how should we convert the value of area to assign it the unit of joule per cubic metre?

# Tests for measuring toughness

There are mainly two tests which are generally used to measure toughness.

1. Charpy impact test or Charpy V-notch test
2. Izod impact strength test

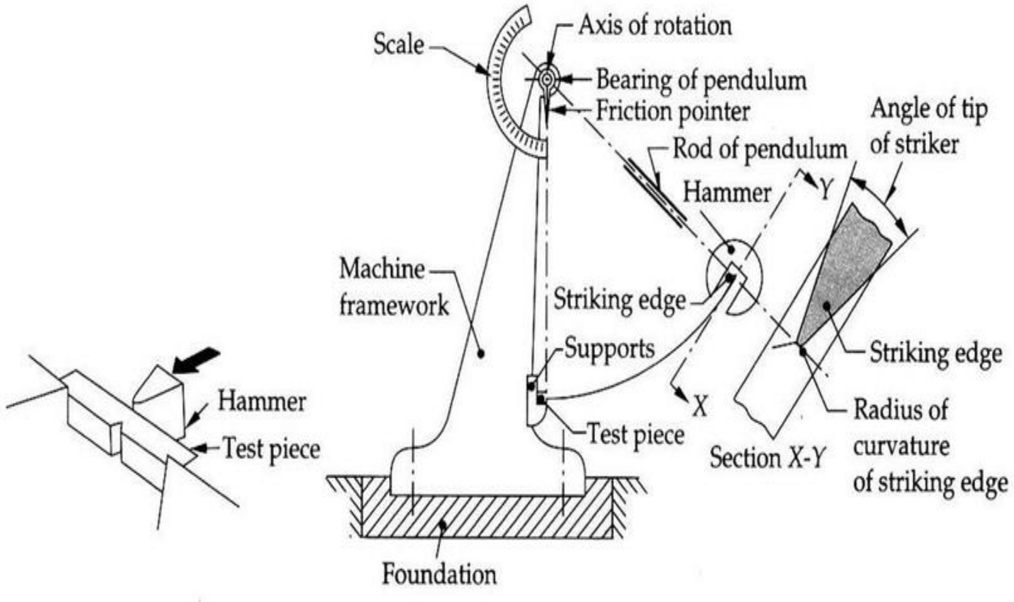
## Charpy impact test or Charpy V-notch test

The Charpy impact test, also known as the Charpy V-notch test, is a standardized high strain-rate test which determines the amount of energy absorbed by a material during fracture. Absorbed energy is a measure of the material's notch toughness.

The test was developed around 1900 by S. B. Russell (1898, American) and Georges Charpy (1901, French). The test became known as the Charpy test in the early 1900s due to the technical contributions and standardization efforts by Charpy.

https://www.youtube.com/watch?v=tpGhqQvftAo

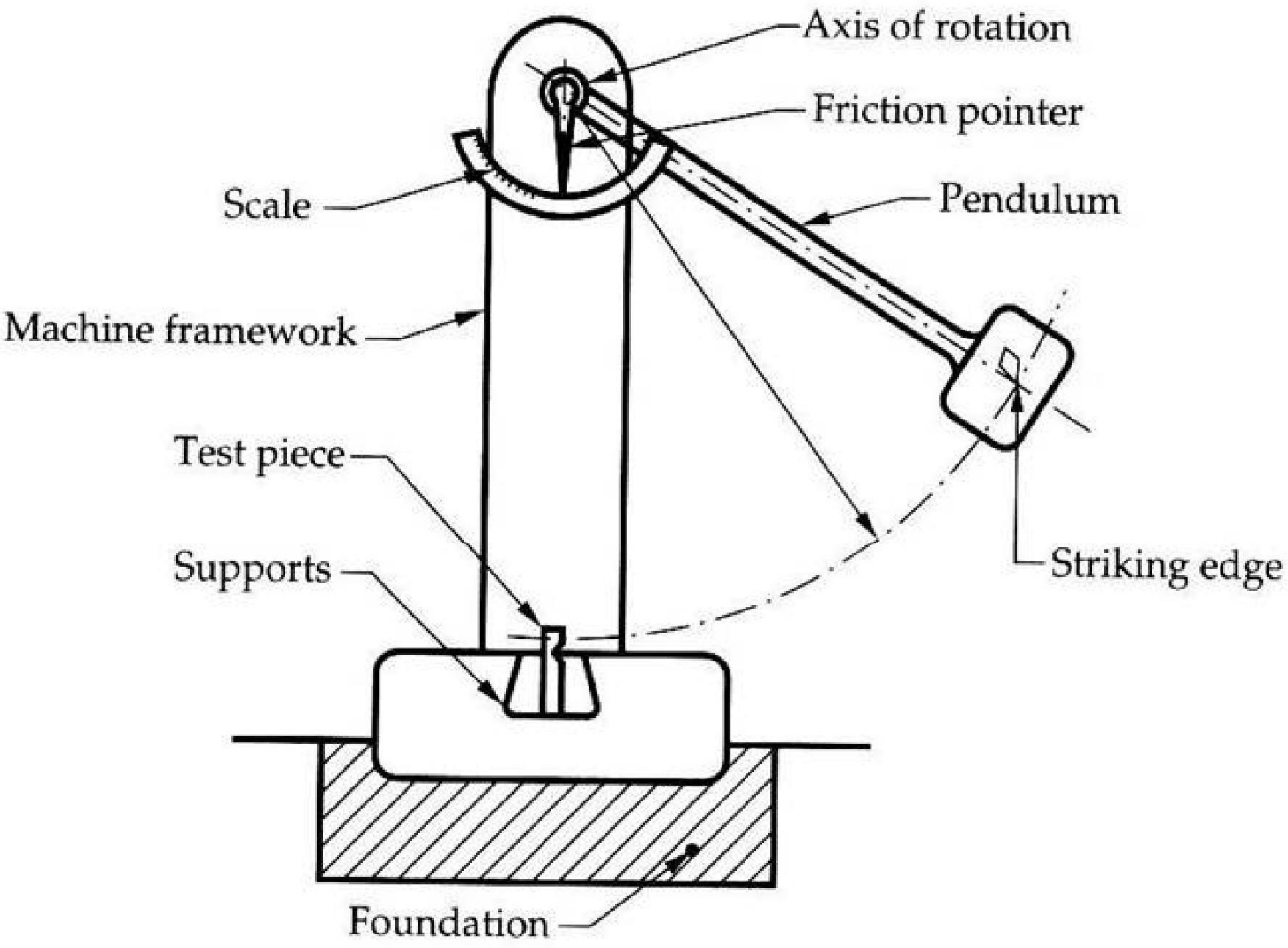
- The apparatus consists of a pendulum of known mass and length that is dropped from a known height to impact a notched specimen of material. The energy transferred to the material can be inferred by comparing the difference in the height of the hammer before and after the fracture (energy absorbed by the fracture event).
- The notch in the sample affects the results of the impact test,thus it is necessary for the notch to be of regular dimensions and geometry. The size of the sample can also affect results, since the dimensions determine whether or not the material is in plane strain.



# Izod impact strength test

- The Izod impact strength test is an ASTM standard method of determining the impact resistance of materials. A pivoting arm is raised to a specific height (constant potential energy) and then released. The arm swings down hitting a notched sample, breaking the specimen. The energy absorbed by the sample is calculated from the height the arm swings to after hitting the sample. A notched sample is generally used to determine impact energy and notch sensitivity.
- The test is similar to the Charpy impact test but uses a different arrangement of the specimen under test.The Izod impact test differs from the Charpy impact test in that the sample is held in a cantilevered beam configuration as opposed to a three-point bending configuration.
- The test is named after the English engineer Edwin Gilbert Izod (1876–1946), who described it in his 1903 address to the British Association.
- The results are expressed in energy lost per unit of thickness (such as ft·lb/in or J/cm) at the notch. Alternatively, the results may be reported as energy lost per unit cross-sectional area at the notch ($J/m^2$ or $ft \cdot lb/in^2$ )

- The Izod test involved the striker, the testing material, and the pendulum. The striker was fixed at the end of the pendulum. The test material was fastened at a vertical position at the bottom, and the notch was facing the striker. The striker swings downward, hitting the test material in the middle, at the bottom of it’s swing, and is left free at the top.
- The notch is placed to concentrate the stress, and provoke delicate failure. It lowers distortion and decreases the ductile fracture. The test was done easily and quickly to examine the quality of the materials, and test whether it meets the specific force of collision properties. It is also used to evaluate the materials for overall hardiness. It is not applicable to compound materials because of the influence of complicated and inconsistent failure modes.
- The notch is very important because it can affect the result of the test. The making of the notch has been a problem. Initially, the radius of the notch is crucial. The radius should not change. It has an essential effect on the competence of the sample to absorb the collision.
- The blades in the notch can overheat the polymers, and deteriorate the materials surrounding the notch, which could lead to an inaccurate test result. The Izod method chose a short projection, supported at one end, to produce better steel tools for cutting metal.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# FATIGUE

- Fatigue is the weakening of a material caused by cyclic loading that results in progressive and localized structural damage and the growth of cracks. Once a fatigue crack has initiated, each loading cycle will grow the crack a small amount, typically producing striations on some parts of the fracture surface.
- The crack will continue to grow until it reaches a critical size, which occurs when the stress intensity factor of the crack exceeds the fracture toughness of the material, producing rapid propagation and typically complete fracture of the structure

https://en.wikipedia.org/wiki/Fatigue_(material).

https://www.youtube.com/watch?v=-Ssi297_4Lc