Stress versus Strain

- **Mechanical Properties**
  - Deal directly with behavior of materials under applied forces.
  - Properties are described by applied stress and resulting strain,
  - or applied strain and resulting stress.
  - **Strength**: ability of material to resist application of load without break.
  - **Stiffness**: resistance of material to deform under load while in elastic state.
Testing Procedures

• Mechanical Testing
  – Properties that deal with elastic or inelastic behavior of a material under load
  – Primary measurements involved are load applied and effects of load application
  – Two classification of tests:
    – 1- method of loading
    – 2- the condition of the specimen during the test

• Primary types of tests
  – Tensile
  – Compression
  – Shear
  – Torsion
  – Flexure
Mechanical Test Considerations

- Principle factors are in three main
  - manner in which the load is applied
  - condition of material specimen at time of test
  - surrounding conditions (environment) during testing

- Tests classification - load application
  - kind of stress induced. Single load or Multiple loads
  - speed at which stress is developed: static versus dynamic
  - number of cycles of load application: single versus fatigue

- Primary types of loading

  - tension
  - compression
  - torsion
  - shear
  - flexure
Standardized Testing Conditions

- **wetness**
  - 100F, 100% R.H.
  - 1 Day, 7 Days, 14 Days

- **Temperature**
  - Room Temperature: Most common
  - high Temperature: Rocket engines
  - Low Temperature: Automotive crash

- **Salt spray for corrosion**
  - Rocker Arms on cars subject to immersion in NaCl solution for 1 Day and 7 Days at Room Temperature and 140 F.

- **Acid environments**
  - Tensile tests on samples after interest in acid/alkaline baths.
Stress

• Stress: Intensity of the internal distribute forces or component of forces that resist a change in the form of a body.
  – Tension, Compression, Shear, Torsion, Flexure

• Stress calculated: by force per unit area. OR

• Applied force divided by the cross sectional area of the specimen.

  \[ \sigma = \frac{F}{A} \]

• Stress units
  – Pascals = Pa = Newtons/m²
  – Pounds per square inch = Psi
Strain

- **Strain**: Physical change in the dimensions of a specimen that results from applying a load to the test specimen.
- Strain calculated by the ratio of the change in length and the original length. (Deformation)

\[ \varepsilon = \frac{\Delta l}{l_0} \]

- Strain units (Dimensionless)
  - When units are given they usually are in/in or mm/mm. (Change in dimension divided by original length)
- % Elongation = strain x 100%
Stress-Strain Diagrams

• tools
  – Strainometers: measures dimensional changes that occur during testing
    • extensometers, deflectometers, and compressometers measure changes in linear dimensions.
    • load cells measure load
    • data is recorded at several readings and the results averaged, e.g., 10 samples per ONE second during the test.
Stress-Strain Diagrams

- Stress-strain diagrams is a plot of stress with the corresponding strain produced.
- Stress is the y-axis
- Strain is the x-axis

![Stress-Strain Diagram]

- Linear (Hookean)
- Non-Linear (non-Hookean)
Stiffness

- **Stiffness** is a measure of the materials ability to resist deformation under load as measured in stress.
  - Stiffness is measures as the **slope** of the stress-strain curve
  - Hookean solid: (like a spring) linear slope
    - steel
    - aluminum
    - iron
    - copper
  - All solids (Hookean and viscoelastic)
    - metals
    - plastics
    - composites
    - ceramics

\[ F = kx \]
\[ \sigma = E \varepsilon \]
1. **Modulus of Elasticity (E) or Young’s Modulus**: is the ratio of stress to corresponding strain (within specified limits).

2. **Modulus**: Slope of the stress-strain curve

3. **Initial Modulus**: slope of the curve drawn at the origin.

4. **Departure Modulus**: slope of the curve drawn at the tangent of the curve at some point.

5. **Secant Modulus**: Ratio of stress to strain at any point on curve in a stress-strain diagram. It is the slope of a line from the origin to any point on a stress-strain curve.
Compression Testing

• Principles
  – Compression results from forces that push toward each other.
  – Specimens are short and large diameter.
  – Circular cross section is recommended.
  – Length to diameter ratio is important consideration

• Universal test machine (UTM)
  – Size and load of compression machine are specially build.
  – Load and compression amount are measured.
Expected Results

- Similar Stress-strain curve as tensile testing
Shear Testing

• Principles
  – Direct shear occurs when parallel forces are applied in the opposite direction.
  – Single shear occurs on a single plane.
  – Double shear occurs on two planes at the same time
Torsional shearing

• Principles
  – Torsional shearing forces occur when the forces applied lie in parallel but opposite directions. Twisting motion.
    • Torsional forces developed in a material are the result of an applied torque.
    • Torque is Forces x distance.

• Universal test machine (UTM)
  – Special fixtures are needed to hold the specimen.
  – One end of the specimen is placed in a match that applies torsional load and the other end is connected to a tropometer, which measures the (load and deflection or twist)
Expected Results

- Similar Stress-strain curve as tensile testing

\[ \sigma \]  vs  \[ \varepsilon \]
Bend of Flexure Testing

• **Principles**
  
  – Bending forces occur when load is applied to a beam or rod that involves *compression forces* on one side of a beam and *tensile forces* on the other side.
  
  – *Deflection* of a beam is the displacement of a point on a neutral surface of a beam from its original position under action of applied loads.
  
  – *Flexure* is the bending of a material specimen under load.
  
  – Strength that material exhibits is a function of the flexural modulus of the material and the cross-sectional geometry.
  
  – Specimen is loaded in a 3-point bending test
    
    • bottom goes in tension and the top goes in compression.
Equipment

• Universal test machine (UTM)
  – Special fixtures are needed to hold the specimen.
  – Precautions
    • Specimen length should be 6 to 12 times the width to avoid shear failure or buckling.
    • Areas of contact with the material under test should be such that unduly high stress concentrations are avoided.
    • Longitudinal adjustments are necessary for the supports.
    • Lateral rotational adjustments should be provided to prevent torsional stresses.
    • The parts should be arranged to be stable under load.
Expected Results

- Similar Stress-strain curve as tensile testing
Impact Testing

• Principles
  – Materials exhibit different properties depending on the rate at which a load is applied and the resulting strain that occurs.
    • If a load is applied over a long period of time (static test) the material can withstand greater loads than if the test is applied rapidly (dynamic).
  – Properties of materials are *stain dependent*.
  – Standardized tests are used to determine the amount of energy required to break a material in impact tests.
  – Outcome of impact tests is to determine the amount of energy needed to break a sample.
Impact Testing

• Principles

– Energy absorbed in several ways
  • Elastic deformation of the members or parts of a system.
  • Plastic deformation.
  • Hysteresis effects.
  • Frictional action
  • effects of inertia on moving parts.

– Energy is defined as the ability to do work.  \( E = W = F \times D \)
  • Work is Force times distance moved.

– Energy of a dropped object striking a specimen is
  • \( E = w \times h \)  Energy is weight times height dropped.
  • \( E = m \times g \times h \) (metric)  Energy is mass times gravity acceleration times height.
• Impact strength is the resistance of a material to fracture under dynamic load.
• It is a complex characteristic which takes into account both the toughness and strength of a material.
• In S.I. units the impact strength is expressed in Mega Newton per m² (MN/m²).
• It is defined as the specific work required to fracture a test specimen with a stress concentrator in the mid when broken by a single blow of striker in pendulum type impact testing machine.
- Impact strength is the ability of the material to absorb energy during plastic deformation.
- Brittleness of a material is an inverse function of its impact strength.
- Course grain structures and precipitation of brittle layers at the grain boundaries do not appreciably change the mechanical properties in static tension, but substantially reduce the impact strength.
- Impact strength is affected by the rate of loading, temperature and presence of stress raisers in the materials.
- It is also affected by variation in heat treatment, alloy content, sulphur and phosphorus content of the material.
- Impact strength is determined by using the notch-bar impact tests on a pendulum type impact testing machine.
- This further helps to study the effect of stress concentration and high velocity load application.
• If the dimensions of the specimen are increased, the impact strength also increases.
• When the sharpness of the notch increase, the impact strength required causing failure decreases.
• The temperature of the specimen under test gives an indication about the type of fractures like ductile, brittle or ductile to brittle transition.
• The angle of the notch also improves impact-strength after certain values.
• The velocity of impact also affects impact strength to some extent.
Equipment

• Impact Testing Equipment
  – Izod and Charpy are the most common tests.
    • Both employ a swinging pendulum and conducted on small notched specimens. The notch concentrated the load at a point causing failure. Otherwise without the notch the specimen will plastically deform throughout.
    • They are different in the design of the test specimen and the velocity at which the pendulum strikes the specimen.
    • Charpy: the specimen is supported as a single beam and held horizontally. Impacted at the back face of the specimen.
    • Izod: the specimen is supported as a cantilever and help vertically. Impacted at front face of the specimen.
  • Figure 19-1
Impact Test

• In standard testing, such as tensile and flexural testing, the material absorbs energy slowly.
  – In real life, materials often absorb applied forces very quickly: falling objects, blows, collisions, drops, etc.
  – A product is more likely to fail when it is subjected to an impact blow, in comparison to the same force being applied more slowly.
  – The purpose of impact testing is to simulate these conditions.
Impact Test

• Impact testing is testing an object's ability to resist high-rate loading.
  – An impact test is a test for determining the energy absorbed in fracturing a test piece at high velocity.
  – Most of us think of it as one object striking another object at a relatively high speed.
  – Impact resistance is one of the most important properties for a part designer to consider, and without question the most difficult to quantify.
  – The impact resistance of a part is, in many applications, a critical measure of service life. More importantly these days, it involves the perplexing problem of product safety and liability.

• One must determine:
  – 1. the impact energies the part can be expected to see in its lifetime,
  2. the type of impact that will deliver that energy, and then
  3. select a material that will resist such assaults over the projected life span.
  – Molded-in stresses, polymer orientation, weak spots (e.g. weld lines or gate areas), and part geometry will affect impact performance.
  – Impact properties also change when additives, e.g. coloring agents, are added to plastics.
Impact Test

• Most real world impacts are biaxial rather than unidirectional.
  – Plastics, being anisotropic, cooperate by divulging the easiest route to failure.

• Complicated choice of failure modes: Ductile or brittle.
  – Brittle materials take little energy to start a crack, little more to propagate it to a shattering climax.
  – Highly ductile materials fail by puncture in drop weight testing and require a high energy load to initiate and propagate the crack.
  – Many materials are capable of either ductile or brittle failure, depending upon the type of test and rate and temperature conditions.
  – They possess a ductile/brittle transition that actually shifts according to these variables.
    • For example, some plastic food containers are fine when dropped onto the floor at room temperature but a frozen one can crack when dropped.
Expected Results

• Charpy Test
  – Capacity of 220 ft-lb for metals and 4 ft-lbs for plastics
  – Pendulum swings at 17.5 ft/sec.
  – Specimen dimensions are 10 x 10 x 55 mm, notched on one side.

• Procedure
  – Pendulum is set to angle, $\alpha$, and swings through specimen and reaches the final angle, $\beta$. If no energy given then $\alpha = \beta$. 
Expected Results

• Izod Test
  – Capacity of 120 ft-lb for metals and 4 ft-lbs for plastics
  – Impacted at the front face of the specimen.
  – Specimen dimensions are 10 x 10 x 75 mm, notched on one side.

• Procedure
  – Pendulum is set to angle, $\alpha$, and swings through specimen and reaches the final angle, $\beta$. If no energy given then $\alpha = \beta$.
  – Energy is
Fundamentals of Hardness

• Hardness is thought of as the resistance to penetration by an object or the solidity or firmness of an object
  – Resistance to permanent indentation under static or dynamic loads
  – Energy absorption under impact loads (rebound hardness)
  – Resistance toe scratching (scratch hardness)
  – Resistance to abrasion (abrasion hardness)
  – Resistance to cutting or drilling (machinability)

• Principles of hardness (resistance to indentation)
  – indenter: ball or plain or truncated cone or pyramid made of hard steel or diamond
  – Load measured that yields a given depth
  – Indentation measured that comes from a specified load
  – Rebound height measured in rebound test after a dynamic load is dropped onto a surface
Hardness Mechanical Tests

• Brinell Test Method
  – One of the oldest tests
  – Static test that involves pressing a hardened steel ball (10mm) into a test specimen while under a load of
    • 3000 kg load for hard metals,
    • 1500 kg load for intermediate hardness metals
    • 500 kg load for soft materials
  – Various types of Brinell
    • Method of load application: oil pressure, gear-driven screw, or weights with a lever
    • Method of operation: hand or electric power
    • Method of measuring load: piston with weights, bourdon gage, dynamoeter, or weights with a lever
    • Size of machine: stationary (large) or portable (hand-held)
• Hardness is the resistance of material to permanent deformation of the surface. It is the property of a metal, which gives it the ability to resist being permanently deformed (bent, broken or shape change), when a load is applied.

• The hardness of a surface of the material is, a direct result of interatomic forces acting on the surface of the material.

• Hardness is not a fundamental property of a material, but a combined effect of compressive, elastic and plastic properties relative to the mode of penetration, shape of penetration etc.

• The main usefulness of hardness is, it has a constant relationship to the tensile strength of a given material and so can be used as a practical non-destructive test.
• Hardness measurement can be in Macro, Micro & nano –
  scale according to the forces applied and displacements
  obtained.
• Measurement of the Macro-hardness of materials is a quick
  and simple method of obtaining mechanical property data.
• The Macro-hardness measurement will be highly variable
  and will not identify individual surface features. It is here
  that micro-hardness measurements are appropriate.
• **Micro hardness** is the hardness of a material as determined by forcing an indenter into the surface of the material under load, usually the indentations are so small that they must be measured with a microscope.

• Micro hardness measurements are capable of determining the hardness of different micro constituents within a structure.

• **Nano hardness** tests measure hardness by using an indenter, on the order of nano scale.

• These tests are based on new technology that allows precise measurement and control of the indenting forces and precise measurement of the indentation depth.
There are several methods of hardness testing, depending either on the direct thrust of some form of penetrator into the metal surface, or on the ploughing of the surface as a style is drawn across it under a controlled load, or on the measurement of elastic rebound of an impacting hammer which possessing known energy.

Measurements of hardness are the easiest to make and are widely used for industrial design and in research.

As compared to other mechanical tests, where the bulk of the material is involved in testing, all hardness tests are made on the surface or close to it.
The following are the hardness test methods

- Rockwell hardness test
- Brinell hardness
- Vickers
- Knoop hardness
- shore
• Brinell, **Rockwell and Vickers hardness tests** are used to determine hardness of metallic materials to check quality level of products, for uniformity of sample of metals, for uniformity of results of heat treatment.

• The relative **micro hardness** of a material is determined by the **knoop indentation test**.

• The shore **scleroscope** measures hardness in terms of the elasticity of the material.

• Britnell hardness number is the hardness index calculated by pressing a hardened steel ball (indenter) into test specimen under standeridies load.
• The rock well hardness is another index which widely used by engineers.
• This index number is measured by the depth of penetration by a small indenter.
• By selecting different loads and shapes of indenter, different Rockwell scales have been developed.
• The value of Brinell hardness number is related to tensile strength.
The mechanism of indentation in all indentation tests is that when the indenter is pressed into the surface under a static load, a large amount of plastic deformation takes place.

The materials thus deformed flows out in all directions.

As a result of plastic flow, sometimes the material in contact with the indenter produces a ridge around the impression.

Large amount of plastic deformation are accompanied by large amount of transient creep which vary with the material and time of testing.

Transient creep takes place rapidly at first and more slowly as it approaches its maximum.

For harder materials, the time required for reaching maximum deformation is short (few seconds) and for soft materials the time required to produce the derived indentation is unreasonably long up to a few minutes.

Hardness of materials is of importance for dies and punches, limit gauges, cutting tools bearing surfaces etc.
Brinell Test Conditions

- Brinell Test Method (continued)
  - Method
    - Specimen is placed on the anvil and raised to contact the ball
    - Load is applied by forcing the main piston down and presses the ball into the specimen
    - A Bourbon gage is used to indicate the applied load
    - When the desired load is applied, the balance weight on top of the machine is lifted to prevent an overload on the ball
    - The diameter of the ball indentation is measured with a micrometer microscope, which has a transparent engraved scale in the field of view
• Brinell Test Method (continued)

  – Units: pressure per unit area
  – Brinell Hardness Number (BHN) = applied load divided by area of the surface indenter

\[ BHN = \frac{2L}{\pi D \left( D - \sqrt{D^2 - d^2} \right)} \]

Where: 
- \( BHN \) = Brinell Hardness Number
- \( L \) = applied load (kg)
- \( D \) = diameter of the ball (10 mm)
- \( d \) = diameter of indentation (in mm)

• Example: What is the Brinell hardness for a specimen with an indentation of 5 mm is produced with a 3000 kg applied load.

• Ans: 

\[ BHN = \frac{2(3000kg)}{\pi (10mm) \left( 10mm - \sqrt{(10mm)^2 - (5mm)^2} \right)} = 142.6kg / mm^2 \]
Brinell Test Method (continued)

- **Range of Brinell Numbers**
  - 90 to 360 values with higher number indicating higher hardness
  - The deeper the penetration the higher the number
  - Brinell numbers greater than 650 should not be trusted because the diameter of the indentation is too small to be measured accurately and the ball penetrator may flatten out.
  - **Rules of thumb**
    - 3000 kg load should be used for a BHN of 150 and above
    - 1500 kg load should be used for a BHN between 75 and 300
    - 500 kg load should be used for a BHN less than 100
    - The material’s thickness should not be less than 10 times the depth of the indentation
the Brinell Hardness Test

- **Advantages**
  - Well known throughout industry with well accepted results
  - Tests are run quickly (within 2 minutes)
  - Test inexpensive to run once the machine is purchased
  - Insensitive to imperfections (hard spot or crater) in the material

- **Limitations**
  - Not well adapted for very hard materials, wherein the ball deforms excessively
  - Not well adapted for thin pieces
  - Not well adapted for case-hardened materials
  - Heavy and more expensive than other tests ($5,000)
Rockwell Test

- Hardness is a function of the degree of indentation of the test piece by action of an indenter under a given static load (similar to the Brinell test)
- Rockwell test has a choice of 3 different loads and three different indenters
- The loads are smaller and the indentation is shallower than the Brinell test
- Rockwell test is applicable to testing materials beyond the scope of the Brinell test
- Rockwell test is faster because it gives readings that do not require calculations and whose values can be compared to tables of results (ASTM E 18)
Rockwell Test Description

- Specially designed machine that applies load through a system of weights and levers
  - Indenter can be 1/16 in hardened steel ball, 1/8 in steel ball, or 120° diamond cone with a somewhat rounded point (braile)
  - Hardness number is an arbitrary value that is inversely related to the depth of indentation
  - Scale used is a function of load applied and the indenter
    - Rockwell B- 1/16in ball with a 100 kg load
    - Rockwell C- Braile is used with the 150 kg load
- Operation
  - Minor load is applied (10 kg) to set the indenter in material
  - Dial is set and the major load applied (60 to 100 kg)
  - Hardness reading is measured
  - Rockwell hardness includes the value and the scale letter
## Rockwell Values

<table>
<thead>
<tr>
<th>Scale</th>
<th>Indenter</th>
<th>Applied Load (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Braile</td>
<td>60</td>
</tr>
<tr>
<td>B</td>
<td>1/16 in</td>
<td>100</td>
</tr>
<tr>
<td>C</td>
<td>Braile</td>
<td>150</td>
</tr>
<tr>
<td>D</td>
<td>Braile</td>
<td>100</td>
</tr>
<tr>
<td>E</td>
<td>1/8 in</td>
<td>100</td>
</tr>
<tr>
<td>F</td>
<td>1/16 in</td>
<td>60</td>
</tr>
<tr>
<td>G</td>
<td>1/16 in</td>
<td>150</td>
</tr>
</tbody>
</table>

- **B Scale**: Materials of medium hardness (0 to 100HR\textsubscript{B}) Most Common
- **C Scale**: Materials of harder materials (> 100HR\textsubscript{B}) Most Common
- Rockwell scales divided into 100 divisions with each division (point of hardness) equal to 0.002mm in indentation. Thus difference between a HR\textsubscript{B}51 and HR\textsubscript{B}54 is 3 x 0.002 mm - 0.006 mm indentation
- The higher the number the harder the number
Rockwell and Brinell Conversion

- For a Rockwell C values between -20 and 40, the Brinell hardness is calculated by

\[ BHN = \frac{1.42 \times 10^6}{(100 - HR_C)} \]

- For HR_C values greater than 40, use

\[ BHN = \frac{2.5 \times 10^4}{(100 - HR_C)} \]

- For HR_B values between 35 and 100 use

\[ BHN = \frac{7.3 \times 10^3}{(130 - HR_B)} \]
Rockwell and Brinell Conversion

- For a Rockwell C values, $HRC$, values greater than 40,

$$ BHN = \frac{2.5 \times 10^4}{(100 - HRC)} $$

- Example,
  - Convert the Rockwell hardness number HRc 60 to BHN

$$ BHN = \frac{2.5 \times 10^4}{(100 - 60)} = 625 $$
Form of Polymers

- **Thermoplastic Material**: A material that is solid, that have important elasticity at room temperature and turns into a viscous liquid-like material at some higher temperature. The process is reversible.

- Polymer Form as a function of temperature
  - **Glassy**: Solid-like form, rigid, and hard
  - **Rubbery**: Soft solid form, flexible, and elastic
  - **Melt**: Liquid-like form, fluid, elastic
Glass Transition Temperature, $T_g$

- **Glass Transition Temperature, $T_g$:** The temperature by which:
  - Below the temperature the material is in a **still** (rigid) design
  - Above the temperature the material is in a **portable** (flexible) design.
- Transition is called “**Glass Transition**” because the properties below it are similar to ordinary glass.
- Transition range is not one temperature but a range over a relatively narrow range (10 degrees). $T_g$ is not exactly measured, but is a very important characteristic.
- $T_g$ applies to all polymers (amorphous, crystalline, rubbers, thermoses, fibers, etc.)
Glass Transition Temperature, Tg

- Glass Transition Temperature, Tg: Defined as
  - the temperature where in a large the loss of modulus (or stiffness) occurs
  - the temperature at which large loss of volume occurs

<table>
<thead>
<tr>
<th>Temperature</th>
<th>-50°C</th>
<th>50°C</th>
<th>100°C</th>
<th>150°C</th>
<th>200°C</th>
<th>250°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Modulus (Pa) or (psi)

Vol.

-50°C 50°C 100°C 150°C 200°C 250°C

Temperature

Amorphous

Crystalline
Rubbers

- Rubbers have the difference of being stretched 200% and returned to original shape. Elastic limit is 200%
- Natural rubber (isoprene) is produced from gum resin of certain leaves and plants that grow in southeast Asia, Ceylon, Liberia, and the Congo.
  - The liquid is an mix containing 40% water & 60% rubber particles
- **Vulcanization** occurs with the addition of sulfur (4%).
  - Sulfur produces cross-links to make the rubber stiffer and harder.
  - The cross-linkages reduce the slippage between chains and results in higher elasticity.
  - Some of the double covalent bonds between molecules are broken, allowing the sulfur atoms to form cross-links.
  - Soft rubber has 4% sulfur and is 10% cross-linked.
  - Hard rubber (ebonite) has 45% sulfur and is highly cross-linked.
• Viscosity- materials resistance to flow
  – Viscosity of glasses are between 50 and 500 P, whereas viscosity of water and liquid metals are 0.01p

• Viscosity of soda-lime glass from 25°C to 1500°C.
  – Melting range is between 1200 and 1500°C
  – Working range is between 700 and 900°C
  – Annealing Point
    • Internal stresses can be relieved
    – Softening point at 700°C
      • Viscosity = $10^{13.5}$ P
    – Glass transition
      • Occurs around annealing point

![Graph: Temperature vs. Log Viscosity](image-url)
Creep

• Measures the effects of long-term application of loads that are below the elastic limit if the material being tested.
  – Creep is the plastic deformation resulting from the application of a long-term load.
  – Creep is affected by temperature

• Creep process
  – Hold a specimen at a constant temperature under a fixed stress and observe the strain produced.
  – Mark the sample in two locations for a length dimension.
  – Apply a load
  – Measure the marks over a time period and record deformation.
Creep Results

- Creep versus time

![Creep Graph](image-url)
Tensile Strength

• This is the maximum straight stress that can be constant by the material.
• It is the final strength in tension and corresponds to the maximum load in a tension test.
• It is measured by the highest point on the conventional stress-strain curve. In engineering tension tests this strength provides the basic design information on the materials.
• The tensile strength of a material is the maximum sum of tensile stress that it can be subjected to before failure.
There are three typical definitions of tensile strength.

**Yield strength**

- The stress at which material strain changes from elastic deformation to plastic deformation, causing it to deform permanently is known as **yield strength**.

**Ultimate strength**

- The maximum stress a material can resist is known as **ultimate strength**.

**Breaking strength**

- The strength co-ordinate on the stress-strain curve at the point of break is known as **breaking strength**.
In elastic materials the load drops after the ultimate load.

<table>
<thead>
<tr>
<th>Material</th>
<th>Tensile Strength kg/mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alloy steel</td>
<td>60 -70</td>
</tr>
<tr>
<td>Mild Steel</td>
<td>42</td>
</tr>
<tr>
<td>Grey CI</td>
<td>19</td>
</tr>
<tr>
<td>White CI</td>
<td>47</td>
</tr>
<tr>
<td>Aluminum alloy</td>
<td>47</td>
</tr>
</tbody>
</table>