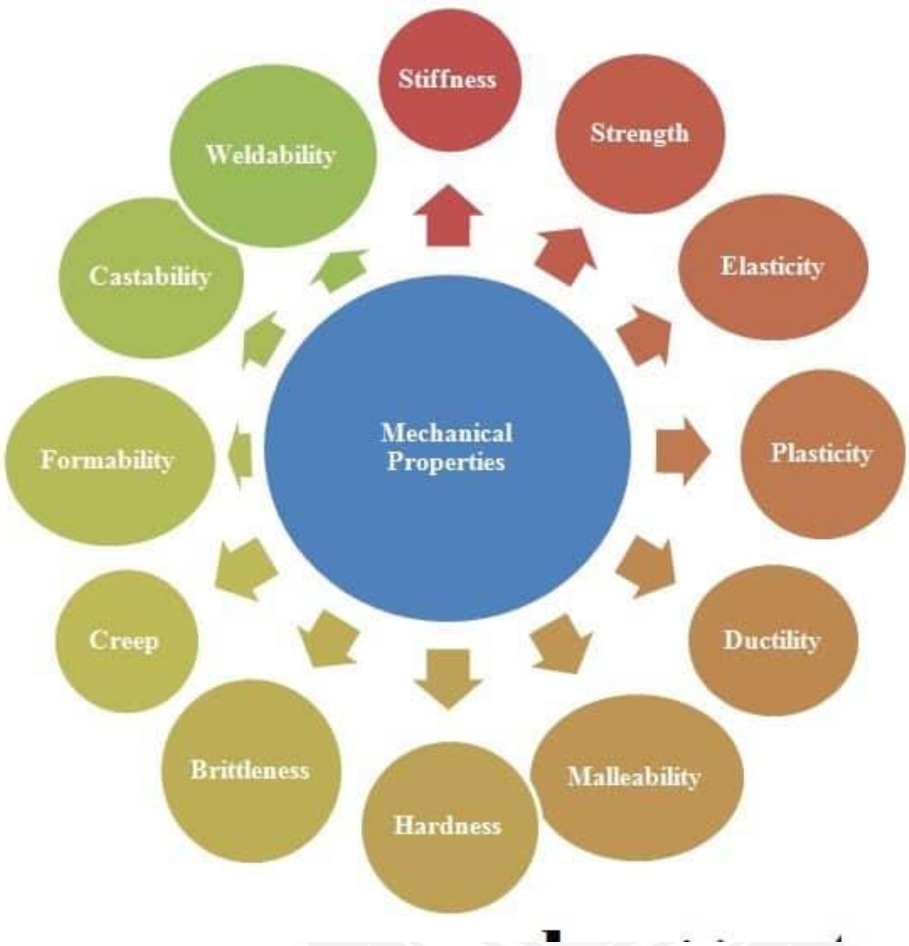
UNIT II

MECHANICAL TESTING

2.1 INTRODUCTION TO MECHANICAL TESTING

The **mechanical properties of a material** are those which affect the mechanical strength and ability of a material to be molded in suitable shape. Some of the typical mechanical properties of a material include:

- Strength
- Toughness
- Hardness
- Hardenability
- Brittleness
- Malleability
- Ductility
- Creep and Slip
- Resilience
- Fatigue



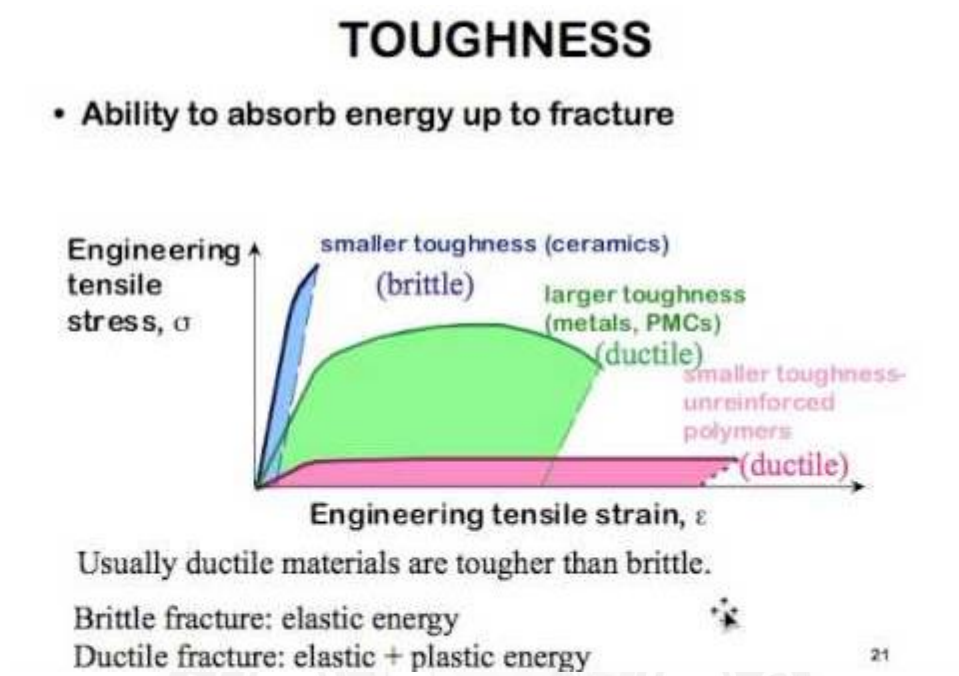
Strength

It is the property of a material which opposes the deformation or breakdown of material in presence of external forces or load. Materials which we finalize for our engineering products, must have suitable mechanical strength to be capable to work under different mechanical forces or loads.

Toughness

It is the ability of a material to absorb the energy and gets plastically deformed without fracturing. Its numerical value is determined by the amount of energy per unit volume. Its unit is Joule/ m^3. Value of toughness of a material can be determined by stress-strain characteristics of a material. For good toughness, materials should have good strength as well as ductility.

For example: brittle materials, having good strength but limited ductility are not tough enough. Conversely, materials having good ductility but low strength are also not tough enough. Therefore, to be tough, a material should be capable to withstand both high stress and strain.



Hardness

It is the ability of a material to resist to permanent shape change due to external stress. There are various measure of hardness – Scratch Hardness, Indentation Hardness and Rebound Hardness.

1. Scratch Hardness
   Scratch Hardness is the ability of materials to the oppose the scratches to outer surface layer due to external force.
2. Indentation Hardness
   It is the ability of materials to oppose the dent due to punch of external hard and sharp objects.
3. Rebound Hardness
   Rebound hardness is also called as dynamic hardness. It is determined by the height of "bounce" of a diamond tipped hammer dropped from a fixed height on the material.

Hardenability

It is the ability of a material to attain the hardness by heat treatment processing. It is determined by the depth up to which the material becomes hard. The SI unit of hardenability is meter (similar to length). Hardenability of material is inversely proportional to the weld-ability of material.

Brittleness

Brittleness of a material indicates that how easily it gets fractured when it is subjected to a force or load. When a brittle material is subjected to a stress it observes very less energy and gets fractures without significant strain. Brittleness is converse to ductility of material. Brittleness of material is temperature dependent. Some metals which are ductile at normal temperature become brittle at low temperature.

Malleability

Malleability is a property of solid materials which indicates that how easily a material gets deformed under compressive stress. Malleability is often categorized by the ability of material to be formed in the form of a thin sheet by hammering or rolling. This mechanical property is an aspect of plasticity of material. Malleability of material is temperature dependent. With rise in temperature, the malleability of material increases.

Ductility

Ductility is a property of a solid material which indicates that how easily a material gets deformed under tensile stress. Ductility is often categorized by the ability of material to get stretched into a wire by pulling or drawing. This mechanical property is also an aspect of plasticity of material and is temperature dependent. With rise in temperature, the ductility of material increases.

Creep and Slip

Creep is the property of a material which indicates the tendency of material to move slowly and deform permanently under the influence of external mechanical stress. It results due to long time exposure to large external mechanical stress with in limit of yielding. Creep is more severe in material that are subjected to heat for long time. Slip in material is a plane with high density of atoms.

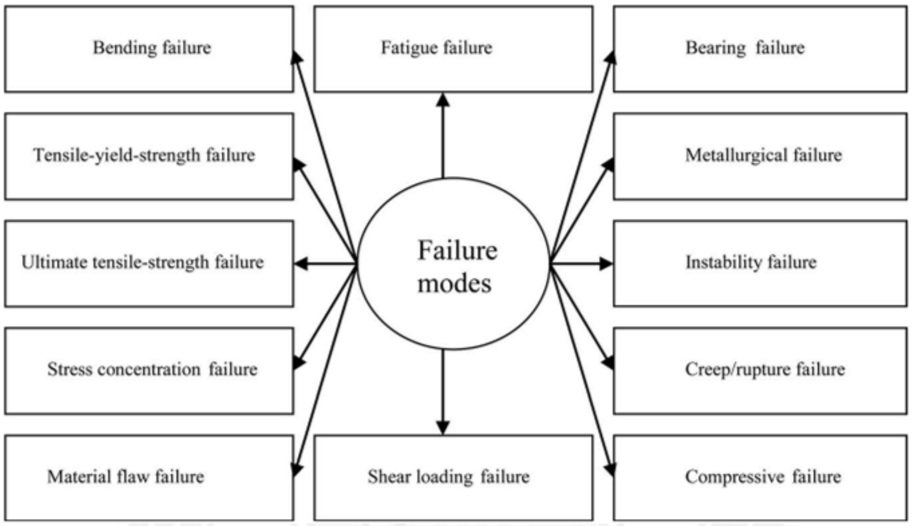
Resilience

Resilience is the ability of material to absorb the energy when it is deformed elastically by applying stress and release the energy when stress is removed. Proof resilience is defined as the maximum energy that can be absorbed without permanent deformation. The modulus of resilience is defined as the maximum energy that can be absorbed per unit volume without permanent deformation. It can be determined by integrating the stress-strain cure from zero to elastic limit. Its unit is joule/m^3.

Fatigue

Fatigue is the weakening of material caused by the repeated loading of the material. When a material is subjected to cyclic loading, and loading greater than certain threshold value but much below the strength of material (ultimate tensile strength limit or yield stress limit), microscopic cracks begin to form at grain boundaries and interfaces. Eventually the crack reaches to a critical size. This crack propagates suddenly and the structure gets fractured. The shape of structure affects the fatigue very much. Square holes and sharp corners lead to elevated stresses where the fatigue crack initiates.

Material Failure Modes:



There are two principal methods of testing the hardness of a material – scratch testing and indentation testing.

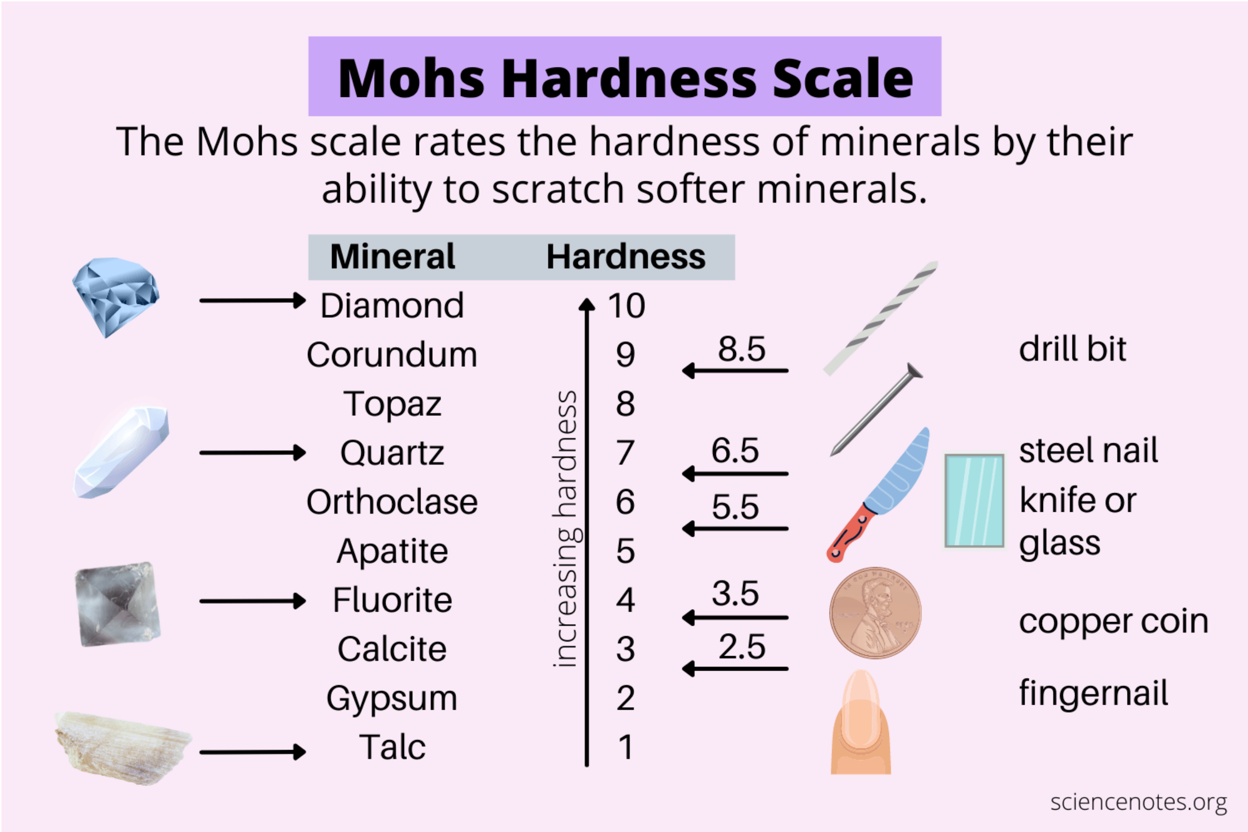
Indentation testing can only be used on materials that undergo plastic deformation such as metals and thermoplastic polymers.

Scratch testing is therefore used for brittle materials such as ceramics.

Scratch testing

The hardness of a material can be determined based on Moh's scale of hardness, which ranks a material based on a list of standard materials with known hardness.

The hardness of the material is ranked on the scale between the material it just scratches and the material that it fails to scratch.



Moh's Scale of hardness

Indentation testing

There are a number of different methods of testing the hardness of a material through indentation. The three most commonly used are the Brinell test, the Vicker's Diamond test, and the Rockwell test. All three methods involve indentation of the material. The hardness is calculated by measuring the force applied and comparing this to some geometrical aspect of the indentation such as the surface area or depth.

Vickers	Brinell	Rockwell
(diamond)	(ball)	(cone)

When hardness indentation testing is done on an actual component it is often necessary to blend (grind) out the indentation to remove the stress concentration it produces

Vickers Hardness Test:

The Vickers procedure can be used to test the hardness of metals and other equally hard materials. However, it was primarily designed to focus on softer materials like plastic specifically on their ability to resist deformation from constant stress.

As with every other hardness test, the Vickers procedure uses its own unit of hardness. This is called as the Vickers Pyramid Number (HV) or the Diamond Pyramid Hardness (DPH). These units are convertible to pascals but should not, in any form, be used interchangeably with the same unit that measures pressure.

The Vickers test procedure involves the dropping of a load on to an indenter which leaves a mark on the surface of the material. However, in order for the results to be accurate, the sample itself has to have a flat surface.

This means that the material has to be polished to meet the specifications of the test. Once the material is ready, it is then going to be placed at the tester from where it would make contact with the indenter. Also, the operator can refer to Vickers Hardness test blocks to properly calibrate the tester for the procedure.

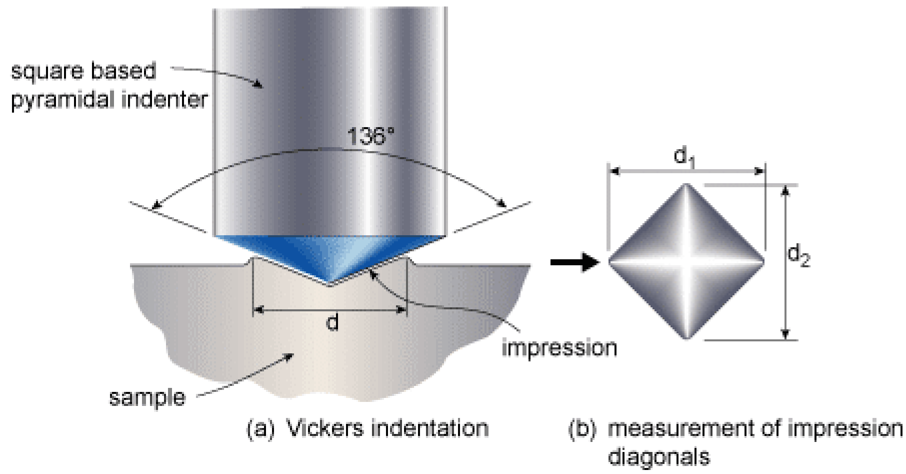
A unique feature with Vickers Indenters is that they share the same size and composition across all tests. The Vickers procedure, in fact, uses only one type of indenter: a diamond shaped in the form of an inverted pyramid (hence it being called the Vickers Pyramid).

The rationale behind this is that the impression to be left on the material should have a well-defined shape in order for the results to be measurable. Also, the indenter itself should be made of a material that is resistant to deformation itself. Diamonds fit this requirement considerably.

Once the tester has been calibrated, the load is then dropped which causes the indenter to push itself through the material's surface. It would remain there for a considerable period (also known as dwell time) as gravity continues to push the indenter deeper into the material.

Once the dwell time has elapsed, the load is removed and the indenter is released. The operator is then tasked to perform optical evaluation wherein they will examine the dimensions of the indentation left and use a specific equation to come up with the material's hardness value.

As with all hardness tests, however, the hardness value in the Vickers procedure is inversely proportional to the indentation left. In other words, if the indentation is smaller and less-defined, the hardness rating of the material would be higher.



Brinell Hardness Test

The Brinell Hardness Test method is the most commonly used hardness measurement technique in the industry. In the Brinell Hardness Testing, the hardness of a metal is determined by measuring the permanent indentation size produced by an indenter. Harder materials will generate shallow indentations while softer materials will produce deeper indentations. This test method was first proposed by Swedish engineer Johan August Brinell in 1900 and according to his name, the test is popular as Brinell Hardness Test.

Procedure

The Brinell Hardness test is performed in a Brinell hardness test unit. In this test method, a predetermined force (F) is applied to a tungsten carbide ball of fixed diameter (D) and held for a predetermined time period, and then removed. The spherical indenter creates an impression (permanent deformation) on the test metal piece. This indentation is measured across two or more diameters and then averaged to get the indentation diameter (d). Using this indentation size (d) Brinell Hardness Number (BHN) is found using a chart or calculated using the Brinell hardness test formula. The equipment used for Brinell Hardness Testing are:

- Brinell Hardness Testing Machine
- Indenter Sphere, and
- Brinell microscope to measure the generated impression.

Brinell Hardness Testing Machine:

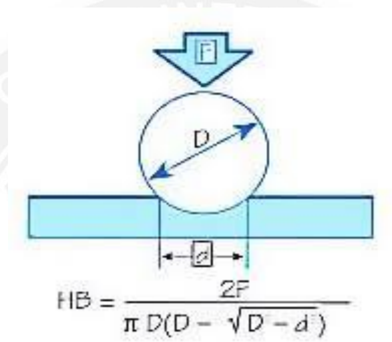
The Brinell Hardness Testing Machine consists of a loading system that includes leavers, weights, a hydraulic dashpot, and a plunger enclosed in the body of the machine. The test material is kept on the adjustable anvil. Using the lever, the spherical ball indenter descends on the material with a pre-decided force that can be read on the screen.

Brinell Hardness Testing Machine

For softer metals, the force used is less than for harder metals. The force value varies from 1 kgf to 3000 kgf. Common test forces range from 500 kgf often used for non-ferrous materials to 3000 kgf for steels and cast irons.There are four sizes of the indenter used for the Brinell hardness test. They are 1 mm, 2.5 mm, 5 mm, and 10 mm in size.To obtain the same BHN with different ball diameters, geometrically similar indentations must be produced. It is possible if F/D^2 is maintained constant.

Brinell Hardness Test Formula

Once the average indentation diameter is measured the Brinell Hardness Number (BHN or HBW) can be calculated using the following Brinell hardness test formula:



Brinell Hardness Test Equation

Note that, the term HBW stands for Hardness Brinell Wolfram carbide.
Wolfram carbide (= tungsten carbide) underlines the use of tungsten carbide balls, as opposed to the (softer) steel balls previously used (HBS).

The minimum Test Specimen thickness is at least 10 times the indentation depth as per ASTM standard and the same is at least 8 times the indentation depth as per ISO standard.

Advantages of the Brinell Hardness Test

The Brinell Test method has many advantages:

- The hardness of rough samples can be measured which is difficult with other methods.
- Application of high test load (up to 3,000 Kg) is possible.
- Wide measuring range due to availability of a range of indenter sizes and loads
- A Brinell hardness tester can determine the hardness of all types of metals.
- Provides reliable results.

However, the Brinell test method has some disadvantages as well:

- There could be measuring errors due to using of optical instruments.
- Surface imperfections can interfere with the test result if the surface is not prepared thoroughly.

- The requirement of a flat surface makes this test redundant for cylindrical surfaces.

Brinell vs Rockwell hardness Test

The main difference between Brinell and Rockwell Hardness Test is provided in the table below:

Brinell Hardness Test	**Rockwell Hardness Test**
In Brinell Hardness Test the indenter is a spherical Tungsten Carbide Ball	For Rockwell Hardness Test the Indenter is a Small Steel Ball (HRB) or a diamond cone (HRC)
Hardness greater than 650 HB can not be measured with this setup.	There is no such limitation in Rockwell hardness testing
Brinell hardness Test measures the diameter of the indentation to calculate the hardness value.	Depth of indentation is measured for calculating Rockwell hardness.
The Brinell hardness testing method is a comparatively slow method.	Rockwell hardness testing is a Quicker process.
Surface preparation is required for Brinell hardness testing.	No surface preparation is required for Rockwell hardness testing.
Comparatively costly	Cheaper option

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