

Why Material testing is required?

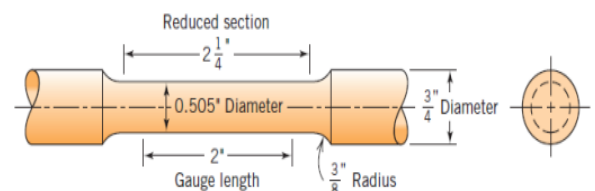
- To test mechanical properties like ultimate tensile strength, yield strength, elongation, toughness etc. which is used as a design input.
- Make informed choices in using raw materials.
- To check properties of material after heat treatment, welding, brazing and other operations.
- Ensure batch and production quality.
- As a part of maintenance and to prevent failure in usage.

Type of material testing

- Destructive testing / mechanical testing
- The material is physically tested to destruction or indentation.
- To measure the strength, hardness, toughness etc.
- Example: tensile test, impact test, hardness test etc.
- Non-destructive test (NDT)
- Samples or finished product are tested without spoiling the product.
- Radiography, dye penetration tests etc

Tensile test

- Is performed on a universal testing machine (UTM).
- Uses load cell and extensometer to measure force exerting in specimen and percentage elongation respectively.
- The load v/s elongation is then plotted and studied.
- Variables such as strain, stress, elasticity, tensile strength, ductility and shear strength are measured and computed.
- Test specimen can be round or flat.



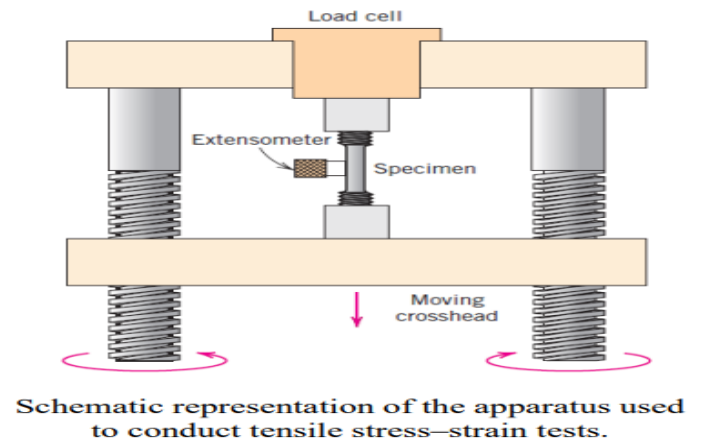
A standard tensile specimen with circular cross section

Universal Testing Machine

- Is used to test the tensile strength and compressive strength of materials.
- The "universal" part of the name reflects that it can perform many

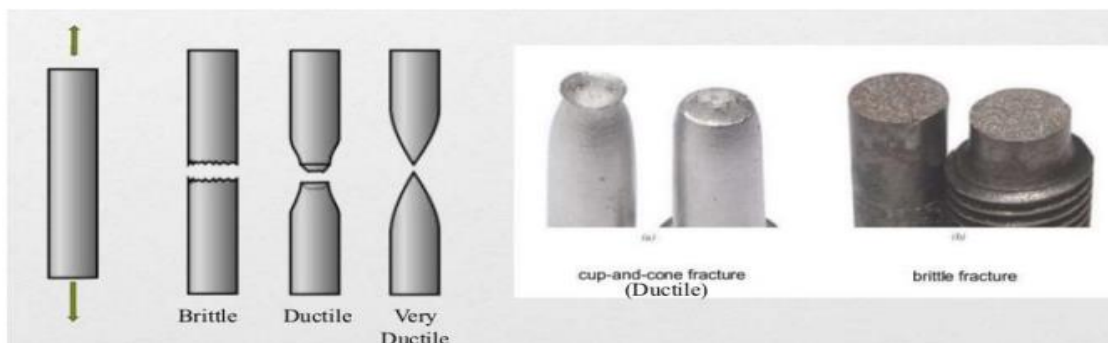
Standard tensile and compression tests on materials, components,

and structures (in other words, that it is versatile).



Fractured surface of tensile test

- Cup and cone fracture signifies a ductile material.
- A shear fracture indicates a brittle material.



Properties determined by the tensile testing

- Strength (stress and strain curve after computation)
- Ductility
- Elasticity
- Stiffness
- Malleability
- Modulus of toughness

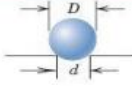
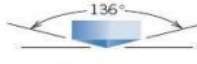
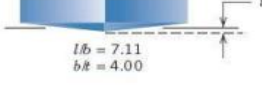
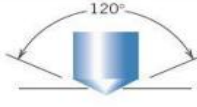
- Modulus of resilience

Hardness testing

- Hardness: is a measure of a material's resistance to localized plastic deformation (e.g., a small dent or a scratch).
- Quantitative hardness techniques have been developed over the years in which a small indenter is forced into the surface of a material to be tested, under controlled conditions of load and rate of application.
- The depth or size of the resulting indentation is measured, which in turn is related to a hardness number; the softer the material, the larger and deeper the indentation, and the lower the hardness index number.
- Measured hardness values are only relative (rather than absolute), and care should be exercised when comparing values determined by different techniques.

Types of hardness te

Table 6.5 Hardness-Testing Techniques

Test	Indenter	Shape of Indentation		Load	Formula for Hardness Number ^a
		Side View	Top View		
Brinell	10-mm sphere of steel or tungsten carbide			P	$HB = \frac{2P}{\pi D [D - \sqrt{D^2 - d^2}]}$
Vickers microhardness	Diamond pyramid			P	$HV = 1.854P/d_1^2$
Knoop microhardness	Diamond pyramid			P	$HK = 14.2P/l^2$
Rockwell and superficial Rockwell	{ Diamond cone; $\frac{1}{16}, \frac{1}{8}, \frac{1}{4}, \frac{1}{2}$ in.-diameter steel spheres }	 	 	{ 60 kg } Rockwell 100 kg } 150 kg } { 15 kg } Superficial Rockwell 30 kg } 45 kg }	

Rockwell Hardness Tests

- The Rockwell tests constitute the most common method used to measure hardness because they are so simple to perform and require no special skills.
- Several different scales may be utilized from possible combinations of various indenters and different loads, which permit the testing of virtually all metal alloys.

- Indenters include spherical and hardened steel balls having diameters Of 1/16, 1/8, 1/4 and 1/2 in. (1.588, 3.175, 6.350, and 12.70 mm), and a conical diamond (Brake) indenter, which is used for the hardest materials. (Diagrams are shown in upcoming slides)

- A hardness number is determined by the difference in depth of penetration resulting from the application of an initial minor load followed by a larger major load; utilization of a minor load enhances test accuracy.

Rockwell Hardness Tests

- Based on the magnitude of both major and minor loads, there are two types of tests: Rockwell and superficial Rockwell.

- For Rockwell, the minor load is 10 kg, whereas major loads are 60, 100, and 150 kg.

- For superficial tests, 3 kg is the minor load; 15, 30, and 45 kg are the possible major load values. These scales are identified by a 15, 30, or 45 (according to load), followed by N, T, W, X, or Y, depending on indenter.

- Superficial tests are frequently performed on thin specimens.

- When specifying Rockwell and superficial hardness's, both hardness number and scale symbol must be indicated. The scale is designated by the symbol HR followed by the appropriate scale identification.

- For example, 80 HRB represents a Rockwell hardness of 80 on the B scale, and 60 HR30W indicates a superficial hardness of 60 on the 30W scale. (Scales are shown in next slide)

Rockwell Hardness Tests

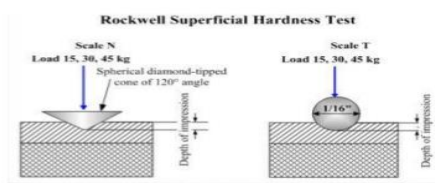
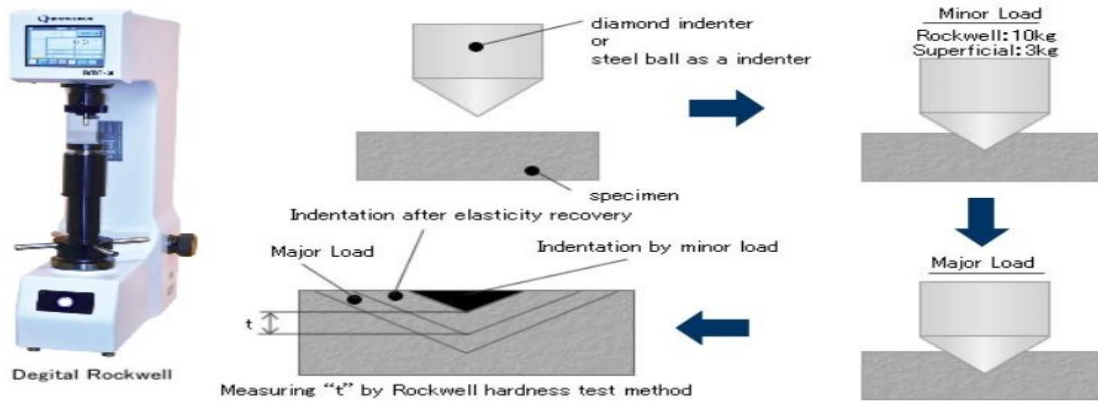


Table 6.6a Rockwell Hardness Scales

Scale Symbol	Indenter	Major Load (kg)
A	Diamond	60
B	1/16-in. ball	100
C	Diamond	150
D	Diamond	100
E	1/8-in. ball	100
F	1/16-in. ball	60
G	1/16-in. ball	150
H	1/8-in. ball	60
K	1/8-in. ball	150

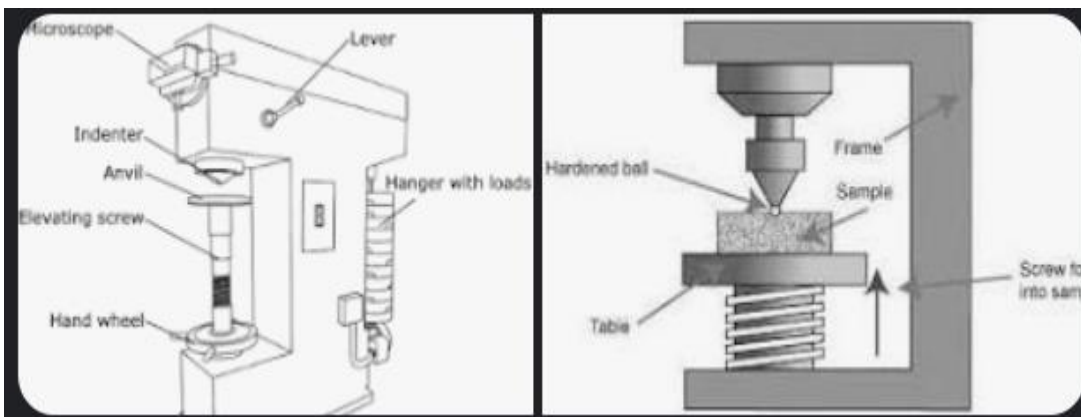
Table 6.6b Superficial Rockwell Hardness Scales

Scale Symbol	Indenter	Major Load (kg)
15N	Diamond	15
30N	Diamond	30
45N	Diamond	45
15T	1/16-in. ball	15
30T	1/16-in. ball	30
45T	1/16-in. ball	45
15W	1/8-in. ball	15
30W	1/8-in. ball	30
45W	1/8-in. ball	45



Brinell Hardness Tests

- In Brinell tests, as in Rockwell measurements, a hard, spherical indenter is forced into the surface of the metal to be tested.
- The diameter of the hardened steel (or tungsten carbide) indenter is 10.00 mm (0.394 in.).
- Standard loads range between 500 and 3000 kg in 500-kg increments; during a test, the load is maintained constant for a specified time (between 10 and 30 s).
- The Brinell hardness number, HB, is a function of both the magnitude of the load and the diameter of the resulting indentation.
- Formula for hardness number is shown in table 6.5.
- For tensile strength as a function of the HB for cast iron, steel, and brass. The same proportionality relationship does not hold for all metals.



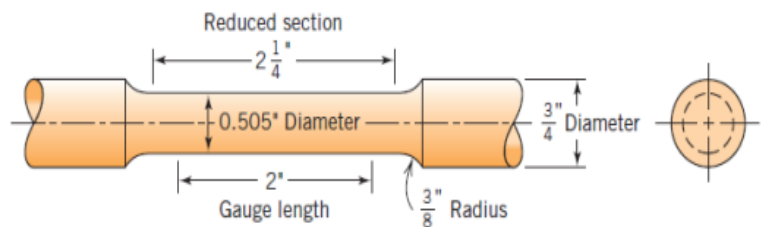
$$TS(\text{MPa}) = 3.45 \times \text{HB}$$

$$TS(\text{psi}) = 500 \times \text{HB}$$

Knoop and Vickers Micro indentation Hardness Tests

- For each test, a very small diamond indenter having pyramidal geometry is forced into the surface of the specimen. Applied loads are much smaller than for Rockwell and Brinell, ranging between 1 and 1000 g.
- The resulting impression is observed under a microscope and measured; this measurement is then converted into a hardness number.
- Careful specimen surface preparation (grinding and polishing) may be necessary to ensure a well-defined indentation that may be accurately measured.
- The Knoop and Vickers hardness numbers are designated by HK and HV, respectively and hardness scales for both techniques are approximately equivalent.
- Knoop is used for testing brittle materials such as ceramics.

creep



- Time-dependent and permanent deformation of materials when subjected to a constant load or stress.
- For metals it becomes important only for temperatures greater than about $0.4 T_m$ (T_m is the absolute melting temperature).
- A typical creep test consists of subjecting a specimen to a constant load or stress while maintaining the temperature constant.
- Deformation or strain is measured and plotted as a function of elapsed time.
- For metallic materials, most creep tests are conducted in uniaxial tension using a specimen having the same geometry as for tensile tests (shown in Figure). On the other hand, uniaxial compression tests are more appropriate for brittle materials.

Creep curve

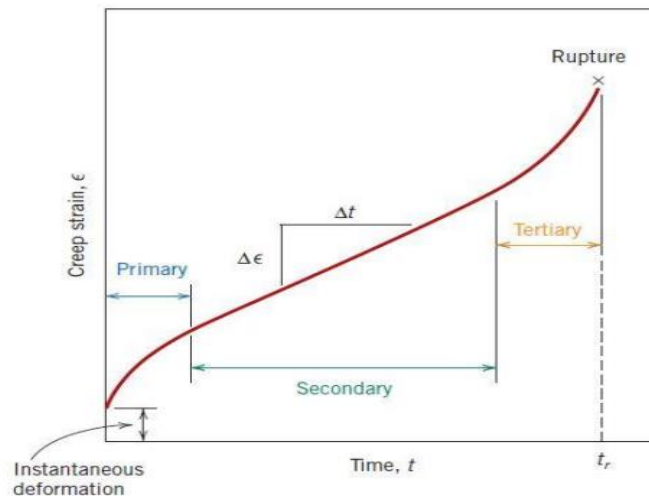


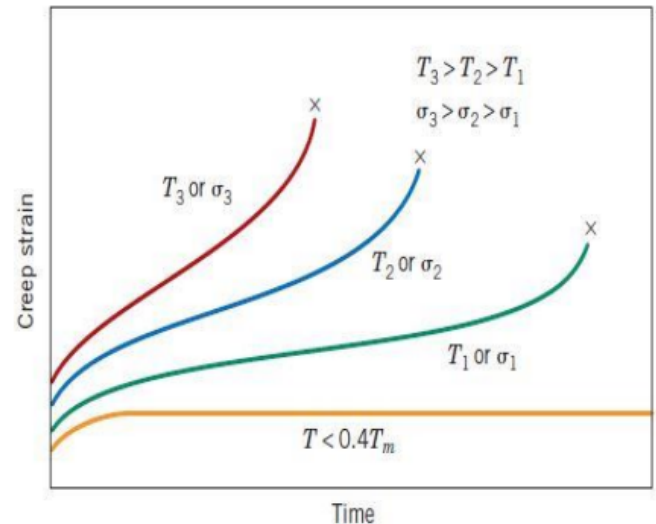
Figure 8.28 Typical creep curve of strain versus time at constant load and constant elevated temperature. The minimum creep rate $\Delta\epsilon/\Delta t$ is the slope of the linear segment in the secondary region. Rupture lifetime t_r is the total time to rupture.

- Upon application of the load there is an instantaneous deformation, as indicated in the figure, which is totally elastic.
- The resulting creep curve consists of three regions, each of which has its own distinctive strain–time feature.
- Primary or transient creep occurs first, typified by a continuously decreasing creep rate; that is, the slope of the curve diminishes with time. This suggests that the material is experiencing an increase in creep resistance or strain hardening.
- Secondary creep, sometimes termed steady-state creep, the rate is constant; that is, the plot becomes linear. This is often the stage of creep that is of the longest duration.
- The constancy of creep rate is explained based on a balance between the competing processes of strain hardening and recovery, recovery being the process whereby a material becomes softer and retains its ability to experience deformation.
- Finally, for tertiary creep, there is an acceleration of the rate and ultimate failure. This failure is frequently termed rupture and results from microstructural and/or metallurgical changes.
- Possibly the most important parameter from a creep test is the slope of the secondary portion of the creep curve, this is often called the minimum or steady-state creep rate.

Stress and temperature effect on creep

With either increasing stress or temperature, the following will be noted:

- (1) The instantaneous strain at the time of stress application increases,
- (2) The steady-state creep rate is increased, and
- (3) The rupture lifetime is diminished.

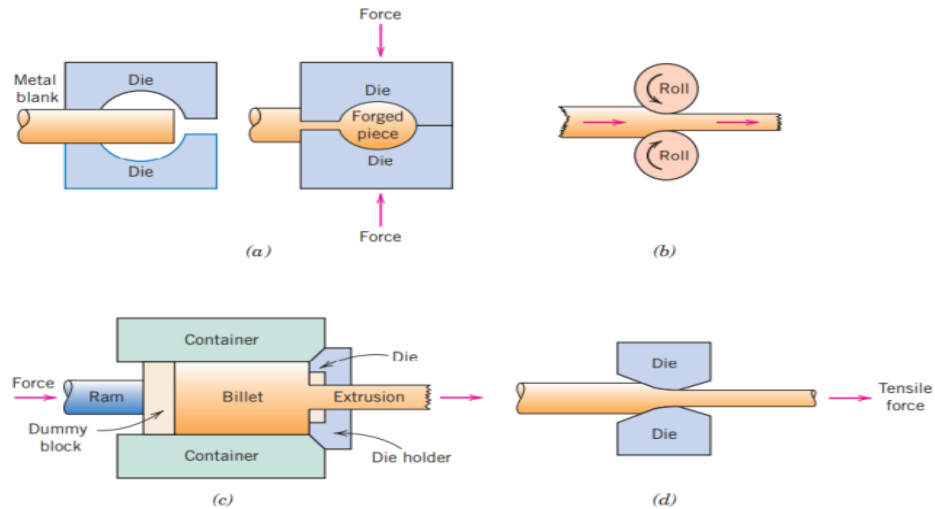


Forming (metal forming)

- Forming operations are those in which the shape of a metal piece is changed by *plastic deformation*.
- for example, forging, rolling, extrusion, and drawing are common forming techniques.
- the deformation must be induced by an external force or stress, the magnitude of which must exceed the yield strength of the material.
- Most metallic materials are especially amenable to these procedures, being at least moderately ductile and capable of some permanent deformation without cracking or fracturing.

Cold and hot working in Forming operation

- Recrystallization temperature : the minimum temperature at which the completed recrystallisation of cold worked metal occurs within a specified period of approximately one hour.
- Recrystallization temperature depends on the amount of cold work a material has already received . The higher the cold work, the lower would be the Recrystallization temperature .
- When deformation is achieved at a temperature above that at which recrystallization occurs, the process is termed *hot working* otherwise, it is *cold working*. (recrystallization temperature is important term here, above which is hot working and below is cold working).
- With most of the *forming techniques*, both *hot- and cold-working* procedures are possible.



Metal deformation during (a) Forging (b) Rolling (c) Extrusion (d) Drawing

Advantage of Cold working

- Better accuracy , close tolerances.
- Better surface finish.
- Strain hardening increases strength and hardness.
- Grain flow during deformation can cause desirable directional properties in product.
- No heating of work required

Disadvantage of Cold working

- Equipment of higher forces and power required.
- Surface of starting work piece must be free from scale and dust.
- Ductility and strain hardening limit the amount of forming that can be done.
- In some operations, metals must be annealed to allow further deformation.
- Some metals are simply not ductile enough to be cold worked.

Advantage of Hot working

- The porosity of metal is largely eliminated. (this increases the hardness and toughness)
- The grain structure of metal is refined.
- The impurities like slag are squeezed into fibres and distributed throughout the metal.
- The mechanical properties such as toughness , percentage elongation, percentage reduction in area and resistance to shock and vibration improved due to refinement of grains.

Disadvantage of hot working

- It requires expensive tools.
- It produces *poor surface finish*, due to the rapid oxidation and scale formation on the metal surface.
- Due to poor surface finish , close tolerance can't be maintained.