Hardness testing

Hardness has already been defined as the resistance of a material to indentation or abrasion by another hard body (good hardness generally means that the material is resistant to scratching and wear) . It is by indentation that most hardness tests are performed. A hard indenter is pressed into the specimen by a standard load, and the magnitude of the indentation (either area or depth) is taken as a measure of hardness.
Hardness tests are commonly used for assessing material properties because they are quick and convenient. However, a variety of testing methods is appropriate due to differences in hardness among different materials. The most well known hardness tests are Brinell and Rockwell.

Hardness is a measure of the material's resistance to localized plastic deformation (e.g. dent or scratch)

A qualitative Moh's scale, determined by the ability of a material to scratch another material: from 1 (softest = talc) to 10 (hardest = diamond).

Diamond	10
Corundum	9
Topaz	8
Quartz	7
Orthoclase (Feldspar)	6
Apatite	5
Fluorite	4
Calcite	3
Gypsum	2
Talc	1

Different types of quantitative hardness test have been designed (Rockwell, Brinell, Vickers, etc.).

Usually a small indenter (sphere, cone, or pyramid) is forced into the surface of a material under conditions of controlled magnitude and rate of loading. The depth or size of indentation is measured.
The tests somewhat approximate, but popular because they are easy and non-destructive (except for the small dent).

Some limitation for hardness test as follows :-

- Type of material
- Specimen thickness
- Test location
- Scale limitations

1. *The Brinell hardness test*

J.A. Brinell introduced the first standardized indentation-hardness test in 1900.
The Brinell hardness test consists in indenting the metal surface with a 10-mm diameter steel or tungsten carbide ball at a load range of 500-3000 kg, depending of hardness of particular materials.
The load is applied for a standard time (between 10 - 30 s), and the diameter of the indentation is measured. Giving an average value of two readings of the diameter of the indentation at right angle.

• The Brinell hardness number (BHN or HB) is expressed as the load P divided by surface area of the indentation .٢

In this test, hardness is measured by pressing a hard steel ball into the surface of the test piece, using a known load. It is important to choose the combination of load and ball size carefully so that the indentation is free from distortion and suitable for measurement.

The relationship of the Brinell hardness [HB] which is between load ***P*** (kg), the diameter ***D*** (mm) of the hardened ball indenter and the diameter d (mm) of the indentation on the surface is given by the expression:

$$HB = \frac{2P}{\pi D\ (D - \sqrt{D^2 - d^2}}$$

Where:
P: applied load (kg)
D: diameter of ball (indenter) (mm)
d: diameter of indentation (mm)

The Brinell hardness number followed by the symbol HB

For different materials, the ratio (p / $\mathbf{D}^2$) has been standardized in order to obtain accurate and comparative results such as :

$\boldsymbol{K}$ = p / $\mathbf{D}^2$
Where ***K*** is. a constant; typical values of ***K*** are:

Ferrous metals	K = 30
Copper and copper alloys	K = 10
Aluminum and aluminum alloys	K = 5
Lead, tin and white-bearing metals	K = 1

Figure 22 shows how the Brinell hardness value is determined. The diameter of the indentation is measured in two directions at right angles and the average taken. The diameter is measured either by using a microscope scale, or by a projection screen with micrometer adjustment.

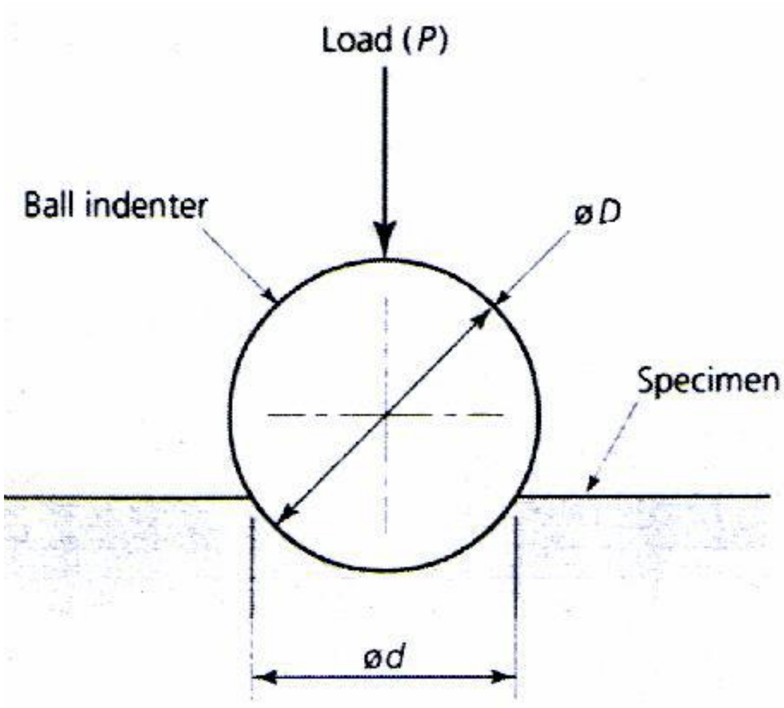
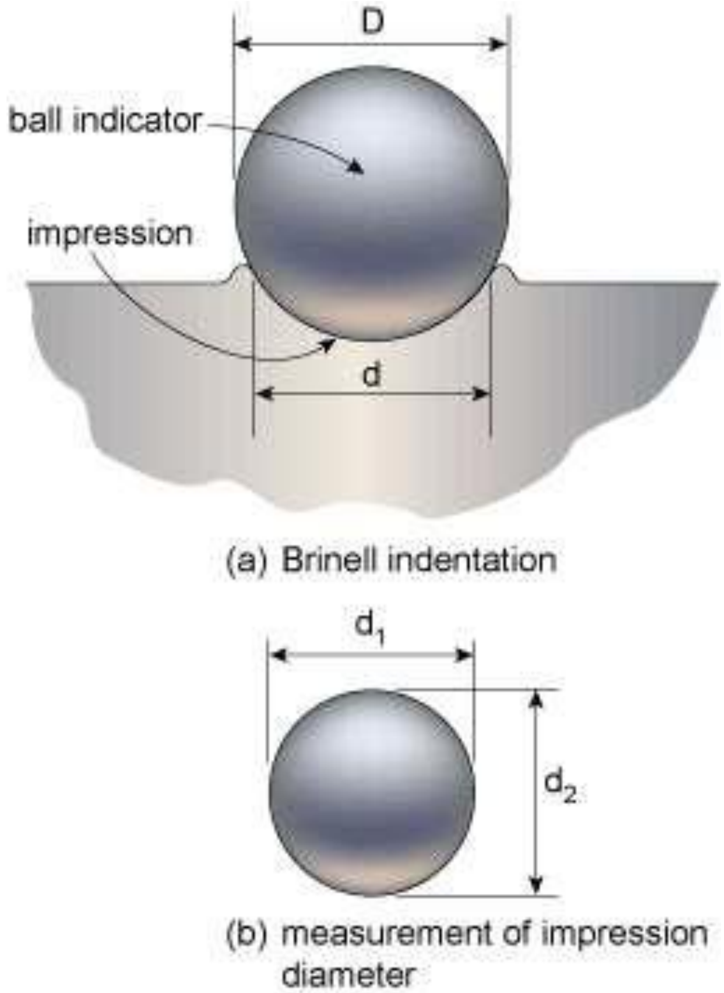


Figure 22. Principle of the Brinell hardness test.



To ensure consistent results, the following precautions should be observed.

1- The thickness of the specimen should be at least seven times the depth of the indentation to allow unrestricted plastic flow below the indenter.
2- The edge of the indentation should be at least three times the diameter of the indentation from the edge of the test piece.
3- The test is unsuitable for materials whose hardness exceeds 500 HB, as the ball indenter tends to flatten.

There are a definite relationship between strength and hardness so it is possible to measure the tensile strength from the hardness test.

Advantage and disadvantages of Brinell hardness test

• Different loads are used to cover a wide range of hardness of commercial metals.
• Brinell hardness test is less influenced by surface scratches and roughness than other hardness tests.
• The test has limitations on small specimens or in critically stressed parts where indentation could be a possible site of failure

2- The Vickers hardness test

Vickers hardness test uses a square-base diamond pyramid as the indenter with the included angle between opposite faces of the pyramid of 136^o.
The Vickers hardness number (VHN) is defined as the load divided by the surface area of the indentation.

This test is preferable to the Brinell test where hard materials are concerned, as it uses a diamond indenter. (Diamond is the hardest material known - approximately 6000 HB.)

Standard loads are 5, 10, 20. 30, 50 and 1 00 kg. It is necessary to state the load when specifying a Vickers hardness number.
For example, if the hardness number is found to be 200 when using a 50 kg load, then the hardness number is written as
HV (50) = 200.
Figure 23 shows the measuring screen for determining the distance across the corners of the indentation. The screen can be rotated so that two readings at right angles can be taken and the average is used to determine the hardness number (HD). This is calculated by dividing the load by the projected area of the indentation:

$$VHN = \frac{2Psin(\frac{\theta}{2})}{d^2} = \frac{1.854\,P}{d^2}$$

where P is the load in Kg and d (mm) is the diagonal of the impression made by the indenter made by the diamond.

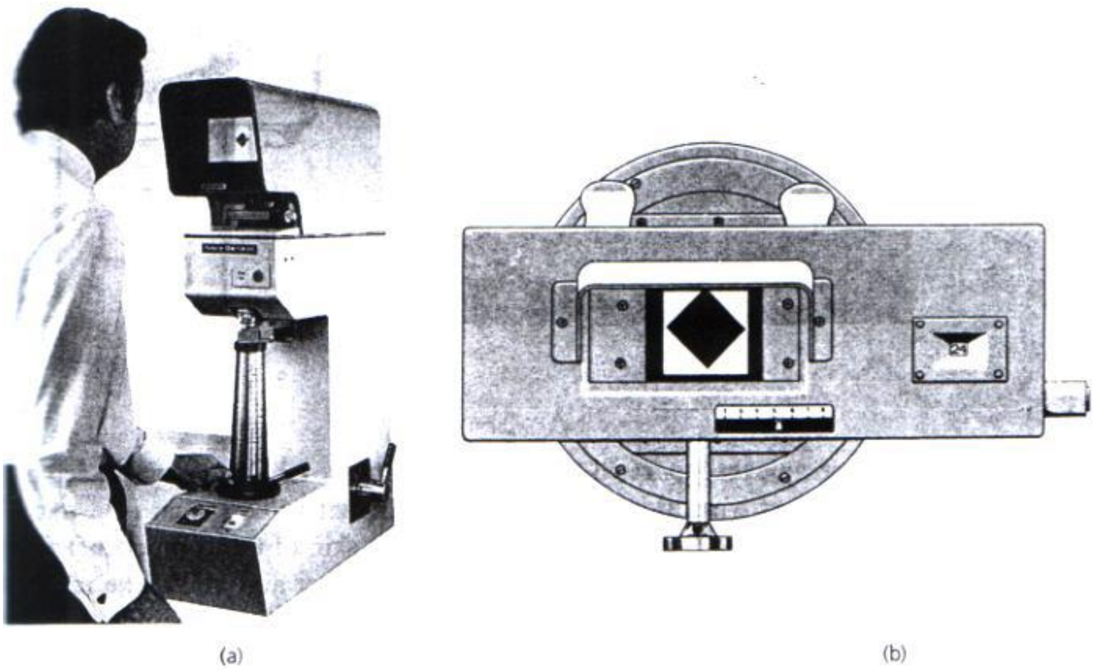
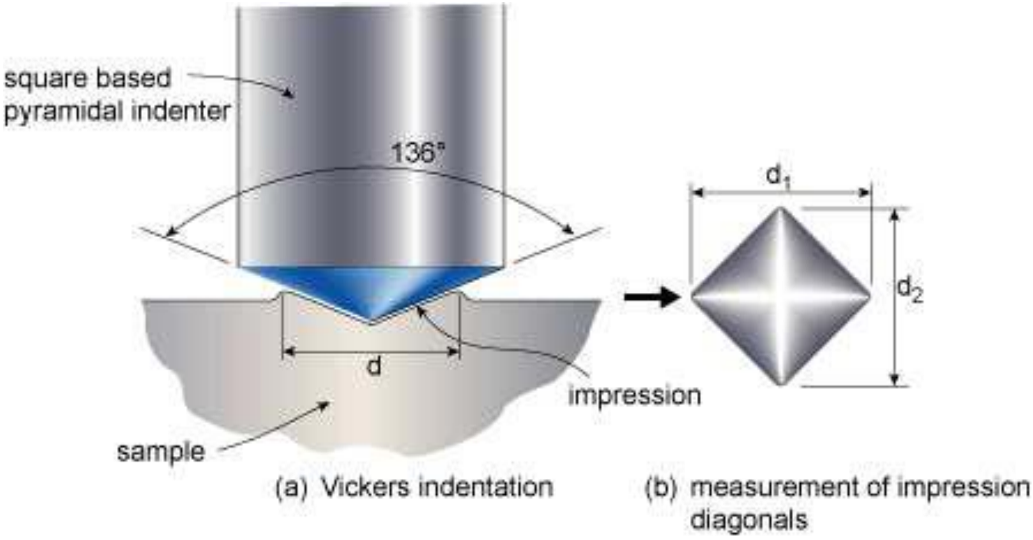


Figure 23. The Vickers hardness test method: (a) universal hardness-testing machine;
(b) measuring screen showing magnified of Vickers impression.



Vickers hardness values of materials:

Materials	Hv
Tin	5
Aluminum	25
Gold	35
Copper	40
Iron	80
Mild steel	230
Full hard steel	1000
Tungsten carbide	2500

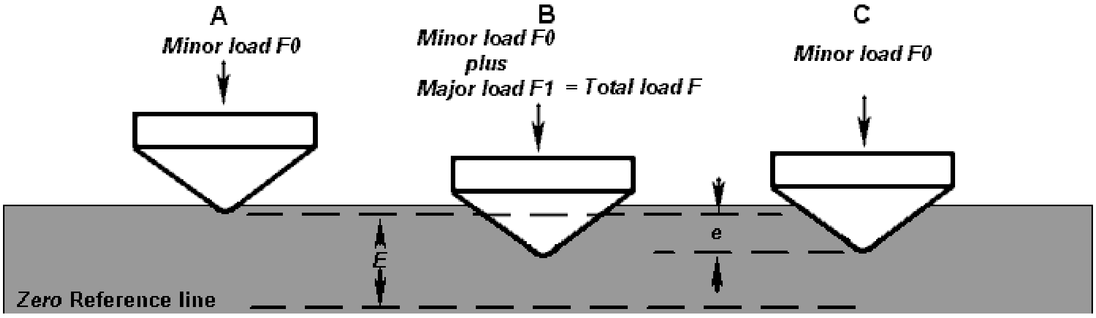
3. The Rockwell hardness test

The Rockwell tests constitute the most common method used to measure hardness and generally accepted due to

1) Its speed
2) Freedom from personal error (require no special skills).
3) Ability to distinguish small hardness difference
4) Small size of indentation.
5) They are so simple to perform.

Although not as reliable as the Brinell and Vickers hardness tests for laboratory purposes, the Rockwell test is widely used in industry as it is quick, simple and direct reading. Universal electronic hardness testing machines are now widely used which, at the turn of a switch, can provide either Brinell,

Vickers or Rockwell tests and show the hardness number as a digital readout automatically. They also give a "hard copy' printout of the test result together with the test conditions and date.
In principle the Rockwell hardness test compares the difference in depth of penetration of the indenter when using forces of two different values. That is, a minor force is first applied (to take up the backlash and pierce the skin of the component) and the scale are set to read zero. Then a major force is applied over and above the minor force and the increased depth of penetration is shown on the scales of the machine as a direct reading of hardness without the need for calculation or conversion tables. Figure 24 shows a typical Rockwell hardness testing machine.



The standard Rockwell test can not be used for very thin sheet and foils and for these the Rockwell superficial hardness test is used.

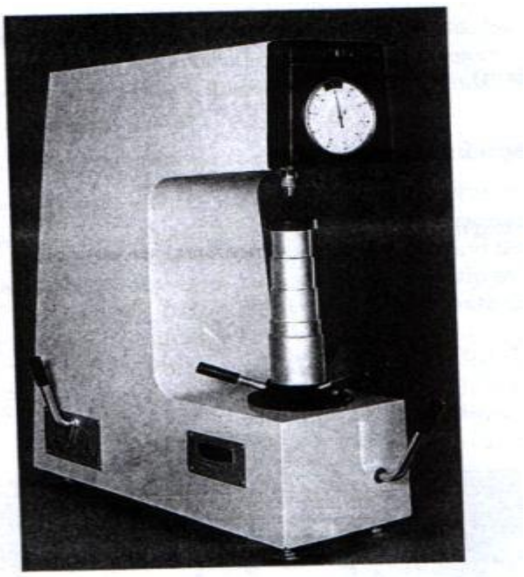


Figure 24. The Rockwell hardness test.

4. Shoe Scleroscope

The test piece must be small enough to mount in the testing machine, and hardness is measured as a function of indentation. However, the scleroscope is not like other types of hardness tests based their measure on the ratio of applied load divided by the resulting impression are [like Brinell and Vicker well] or by the depth of impression [like Rock well].

The scleroscope is an instrument that measures the rebound height of a hammer droped from a certain distance above the surface of the material to be tested. The hammer consist of a weight with diamond indenter attached to it. The scleroscope therefore measures the mechanical energy absorbed by the material when the indenters strikes the surface. The energy absorbed gives an indication of resistance to penetration, which matches our definition of hardness. As shown in figure 25.

The primary use of the sclerscope seems to be in measuring the hardness of large parts of steel, large rolls, casting and gears. And since the seclroscope can be carried to the work piece, it is useful for testing large surfaces and other components which could not easily be placed on the testing tables of any other testing machines.

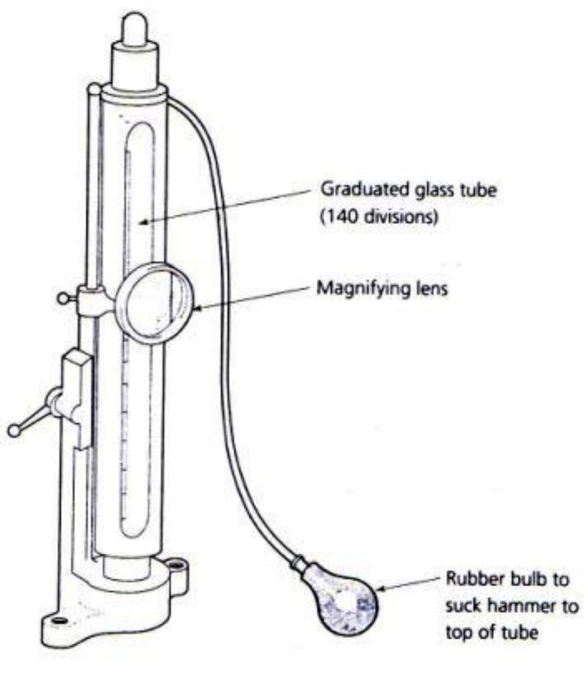


Figure 25. Shore scleroscope.

Creep test

Even at constant stress, materials continue to deform for an indefinite period of time. This time – dependent deformation is called creep. At temperatures less than 40 percent of the absolute melting point, the extent of creep is negligible, but at temperatures higher than this it becomes increasingly important. It is for this reason that the creep test is commonly thought of as a high-temperature test.

The majority of creep testing is conducted in the tensile mode, and the type of test-piece used is similar to the normal tensile test-piece. Most creep testing is carried out under constant-load conditions and utilizes dead weights acting through a simple lever system. In the creep testing an extensometer readings are noted at regular time interval s until the required a mount of data has been obtained, or until the test-piece fractures, depending on whether the object of the test is to determine the creep rate or to determine the total creep strain.

One of the difficulties in creep testing is that a single test may take

A very long time to complete (10000 hours is 417 days), and there are serious difficulties in attempting to extrapolate from the results of comparatively short-term tests to assess the probable behavior of a material over a 10 or 20 year period of service.

Modern creep-testing laboratories may contain several hundred creep-testing machines in continuous use.

Also creep is sensitive to both the applied load and the testing temperature, as shown in figure 21: increasing stress raises the level of the creep curve, and increasing temperature, which accelerates recovery processes, increase the creep rate.

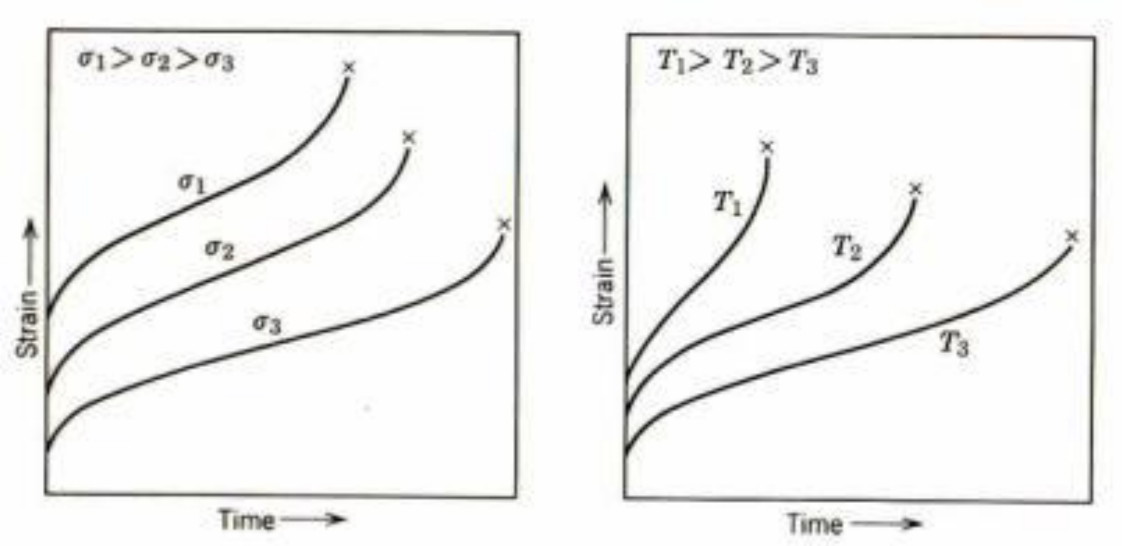


Figure 21. The effects of stress and temperature on creep behavior.

The creep test:

The creep test consists of subjecting a specimen (likes a tensile test specimen) to a constant **load** (or **stress**) and measuring its length as a function of time, at a constant temperature. The figure shows the characteristic creep curve; the ordinate shows the strain and the abscissa shows time.

The creep curves are usually divided into three stages: I, primary or transient;
II, secondary, constant rate, or quasi viscous; and III, tertiary. This division into stages was made by Andrade, one of the pioneers in the study of creep.

The slope of this curve is the **creep rate (dε/dt).** The curve shows the instantaneous deformation (mainly elastic) that occurs as the load is applied, followed by the plastic strain which occurs over time. Three stages to the creep curve may be identified (made by Andrade, one of the pioneers in the study of creep):

- Primary or transient: in which the creep resistance increases with strain leading to a decreasing creep strain rate.

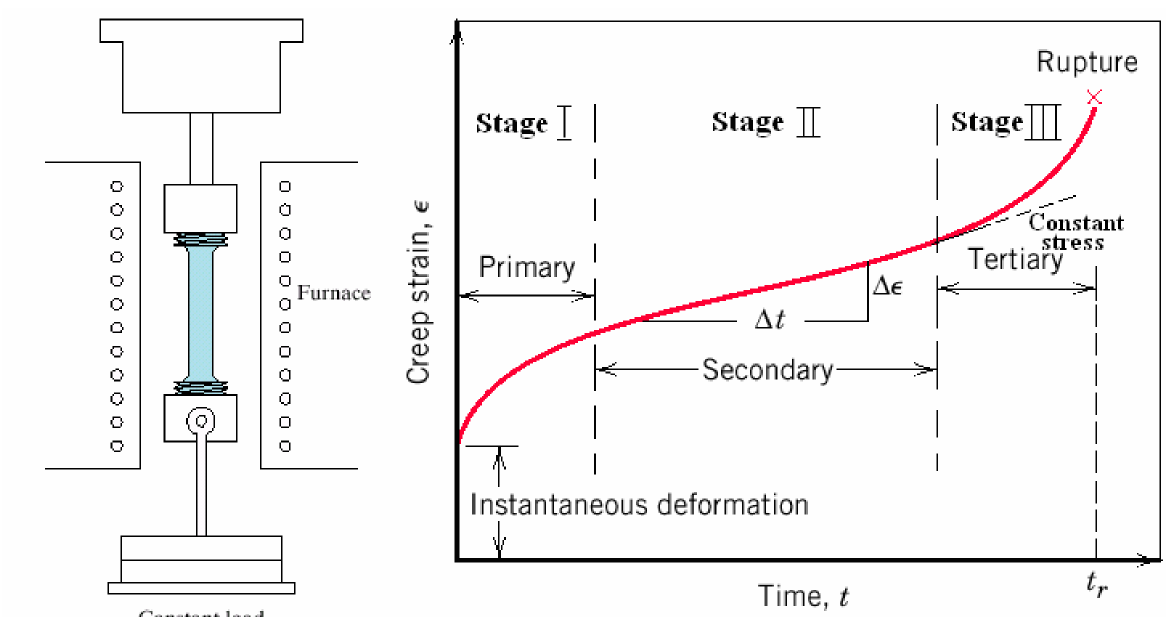
- Secondary (Steady State), or quasi viscous: in which there is a balance between work hardening and recovery processes, leading to a minimum constant creep rate.

- Tertiary creep: in which there is an accelerating creep rate due to the accumulating damage, which leads to creep rupture, and which may only be seen at high temperatures and stresses and in constant load machines.

The dashed line in the figure represents the constant stress curve. Initially they are identical, and when the specimen increases in length, the stress increases and so does the creep rate, at a constant load. The failure times under constant stress and constant load can be drastically different.

Mechanisms of Creep in metals:

There are three basic mechanisms that can contribute to creep in metals, namely:
(i) Dislocation slip and climb. (ii) Grain boundary sliding.
(iii) Diffusional flow.



Stages in a typical creep curve.