Mechanical behavior of crystalline materials- Comprehensive Behaviour

In the previous lecture we have considered the behavior of engineering materials under uniaxial tensile loading. In this lecture we will discuss material behavior during compression and shear. The main focus is with reference to metal forming processes. Further, material properties such as hardness and toughness are dealt with.

4.1 Compressive behavior:

Many bulk forming operations involve compressive stress. Therefore, it is important to study the material behavior under compression. Moreover, the simple compression test is utilized for determination of material flow stress.

4.1.1 Simple axial compression:

In simple compression test, a cylindrical billet held between two platens, is subjected to compressive stress. Friction at interface causes non-uniform flow along the height of the billet, causing barreling. Compression test can be used for determination of ductility and fracture limit. Large strains can be induced in compression test without necking.

The simple homogeneous compression test can be used for determination of flow stress of a material. A cylindrical piece of initial height to diameter ratio Ho/Do is subjected to compression between two platens, applying the load incrementally. True strain is calculated from the formula:

$\varepsilon = \ln(H_o/H)$, where H is deformed height. True stress can be calculated from:

$\sigma = F/\pi R^2$ R is instantaneous radius of billet, F is the force applied axially on billet

The height to diameter ratio of the billet should not exceed 2 in order to avoid bucking. Also a very low value of H_o/D_o will make the deformation more difficult and higher loads are required due to the presence of un-deformed zones.

Strain in compression test is given as:

$e = [h_o - h]/h_o$, h being height of billet at any load.

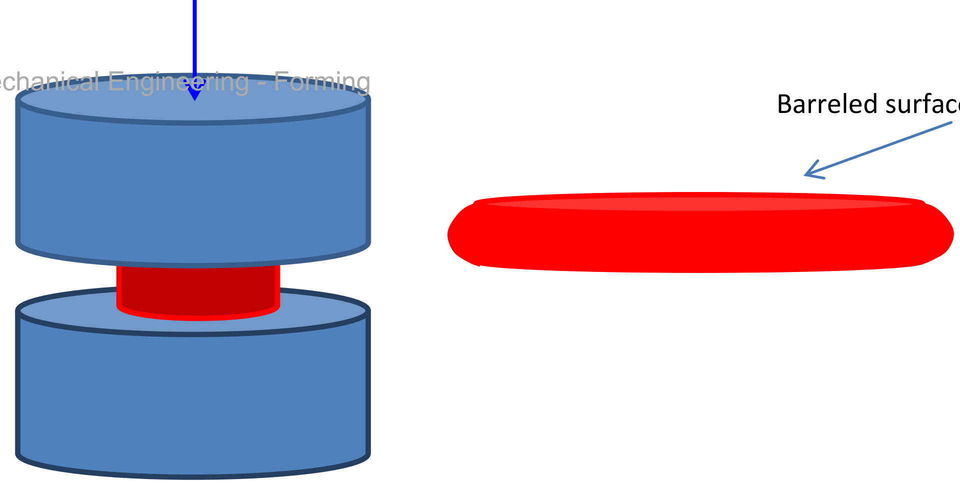
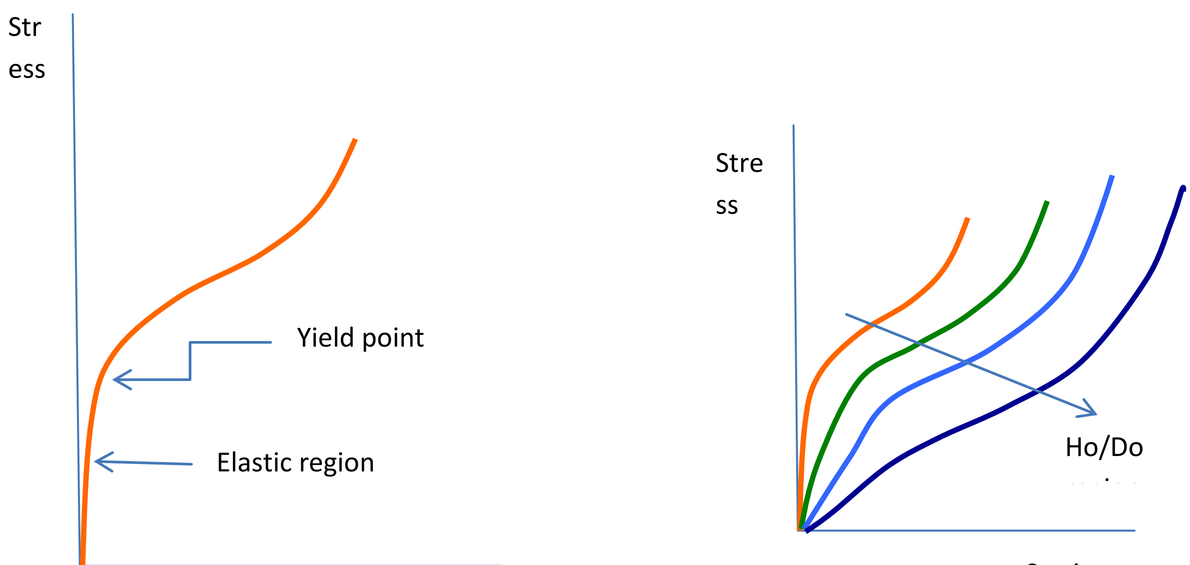


Fig. 4.1.1.1: Simple compression test and bulging of the billet due to non-uniform flow

Figures below show the stress-strain curve for specimen subjected to axial compressive stress



Effect of aspect ratio (Ho/Do)

Fig. 4.1.1.2: Stress-stress diagram for simple compression

Aspect ratio – the diameter of billet divided by its height can have greater effect on compressive behavior of the billet. As seen from figure above, if the billet has high aspect ratio, the compressive stress required for a certain strain is higher. This is due to the difficulty of material deformation as a result of shear zone and also due to larger area over which the force is getting applied.

4.1.2. Plane strain compression

Like simple compression test, the plane strain conpression test is another method of determination of flow stress. In this test, a thin sheet is subjected to compression using a pair of platens. The mode of material flow in this test is plane strain compression – there is no strain along width direction of the sheet.

The yield stress obtained from thie test is plane strain yield strain, $Y' = [2/\sqrt{3}]Y$

For ductile materials, true stress-true strain curves under compression and under tension can be considered identical.

In some forming operations like bending, the material is subjected to tensile stress and then to compression test. When a material is subjected to tensile loading upto yield and then compression, the yield strength of the metal in compression may be lower than that in tension. This phenomenon is called Bauschinger effect. The lowering of yield in compression [or in tension if prior compression is affected] is called strain softening. Usually in metal forming analysis, this effect is neglected.

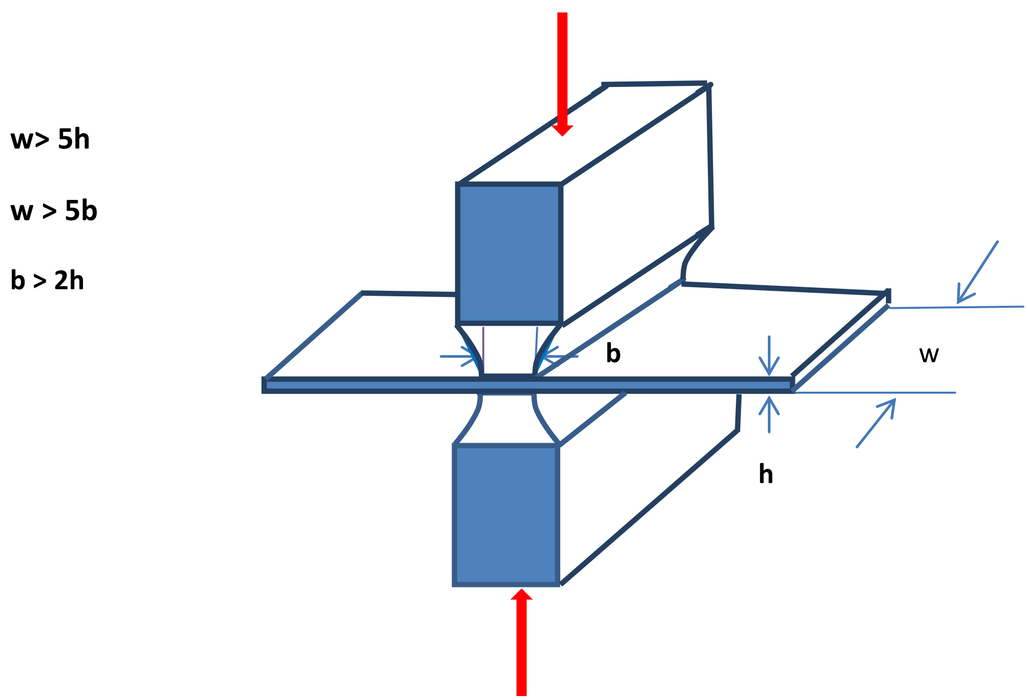


Fig. 4.1.2.1: Plane strain compression test for sheet metal

4.2Torsion and bending tests:

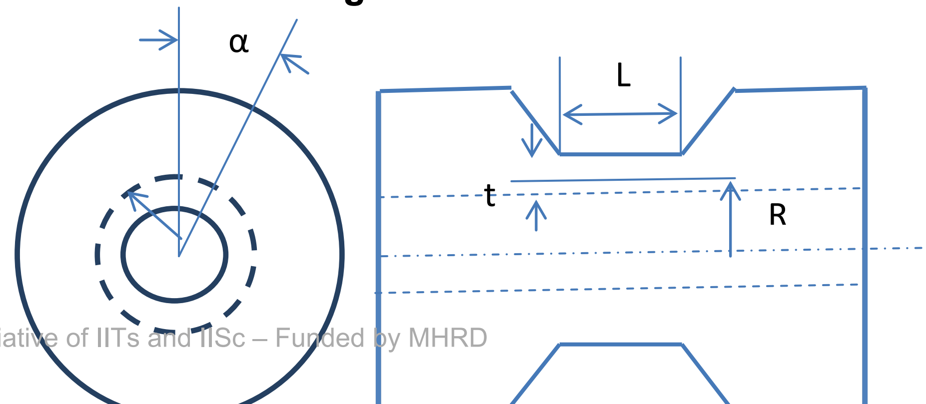


Fig. 4.2.1: Torsion test specimen

In torsion test, a hollow cylindrical specimen with a reduced crosssection midway is subjected to a torque T. The shear stress on the hollow section $\tau = T/2\pi R^2 t$, where R is radius of mean section at mid section of the tube, t is thickness of tube.

Shear strain $\gamma = R\alpha/L$ where α is angle of twist in radians and L is length of mid section.

In metal forming, the torsion test done at elevated temperatures serves as a very useful test for determination of flow stress (forgeability). Hot torsion test is very useful for determination of flow stress at high strain rates – strain rates upto 20 are involved in this test. Moreover, in hot torsion test, strain rate remains constant, as rpm remains constant, because thre is no change in area of cress-section, no necking.

Shear stress – shear strain curve from a torsion test is shown below:

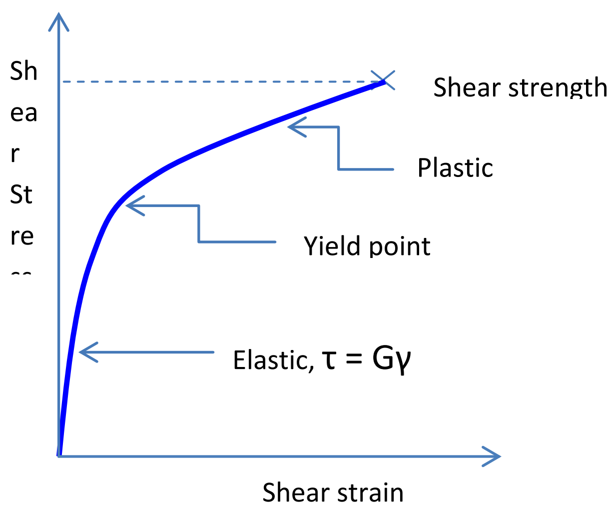


Fig. 4.2.2: Shear stress- shear strain curve

Elastic shear stress and shear strain are related by: $\tau = \gamma G$, where G is shear modulus.

Shear modulus is related to elastic modulus by the relation:

$$G = \frac{E}{2(1+\gamma)}$$

At fracture, the shear strength of the material is taken to be ¾ of tensile strength.

In shear test, the crosssection of the specimen does not change, therefore necking problem does not arise.

Shear deformation in materials can happen in two ways, one is simple shear and the other is pure shear.

Simple shear can be thought as combination of pure shear and rotation

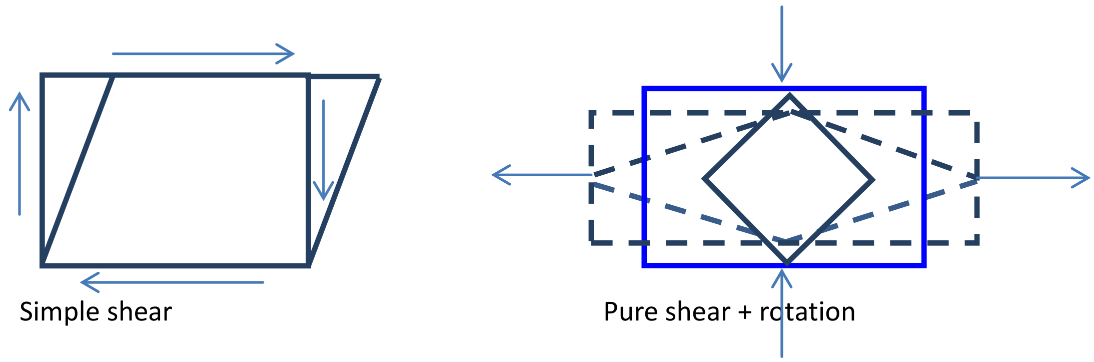


Fig. 4.2.3: Shear Deformation

4.3 Bending test:

Ceramic materials are tested for their modulus of rupture or rupture strength by bend test. Ceramics are difficult to prepare for tensile or shear tests, as they are brittle and difficult to hold. In bend test, a rectangular cross section specimen is simply supported at ends and load is applied at one point (Three point bending) or two points on top (Four point bending).

The stress at which the specimen fractures due to bending is called transverse rupture strength. It is given as $\sigma = Mc/I$, where M is bending moment, c is half of specimen thickness and I is moment of inertia.

The transfer rupture strength TRS is given as:

$TRS = 1.5\ FL/bt^2$, where F is force at rupture, L is length between supports, t is thickness of specimen, b is width of specimen.

4.4 Hardness test:

Hardness is defined as the resistance to plastic indentation, surface scratchor wear.

Hardness test is a simple but important test for assessing the mechanical properties of materials. Hardness is a very useful surface characteristic because it helps in assessing the surface quality against wear and tear. For tools and dies, hardness is considered as important as it can be measured easily and it gives significant assessment of surface resistance to wear.

It is sometimes used for correlating with tensile strength.

There are a number of ways by which hardness is determined. In general, in all these tests a hard indenter is used for making indentation on surface.

From indentation geometry, hardness values are obtained.

The indentation geometry depends on geometry of indenter as well as the force applied during indentation. Different materials may require different amounts of forces to be applied for making indentations on surface.

In Rockwell hardness test, the difference in depth of penetration produced between major and minor indentations is taken as hardness value. Depending on the range of hardness values obtained, different hardness scales are used. For example, 55HRC refers to a hardness value of 55 as measured in Rockwell hardness C scale.

In Brinell test, a steel or tungsten carbide ball 10 mm in diameter is pressed with different loads, 500, 1500, 3000kg. From the measurement of the dia of the indentation the hardness is calculated using the formula:

HB = $\frac{2P}{(\pi D)(D-\sqrt{D^2-d^2})}$ where D is diameter of indenter, d is diameter of indentation, P is load.

The impression made on surface depends on the load used.

Vicker's hardness test uses a diamond pyramid indenter with loads from 1 kg to 120 kg.

Indentations produced in this test are less than 0.5 mm in diameter.

However, the hardness values are independent of load.

Vicker's test can be applied for wide range of materials.

HV = $1.854P/L^2$

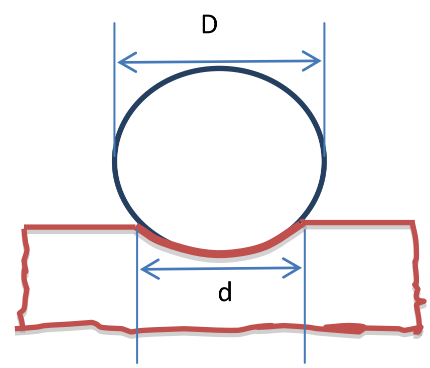


Fig. 4.4.1: Indentation in Brinell test

Knoop hardness test also called microhardness test uses an elongated

diamond indenter of size mm to 0.1 mm with loads ranging from 2.5 to 5 kg.

KH = $14.2P/L^2$. Indentations produced are very small. This test can be used for finding hardness of individual grains.

Hardness can be related to yield strength for some materials in linear form: H = C Y

Where C is a constant and Y is yield strength. Similarly, the Brinell hardness and ultimate strength are related as: UTS = 3.5 BHN.

Hardness can be conducted at elevated temperatures [hot hardness], using suitable furnace enclosure. Hot hardness is important for tool and die materials. For materials hot hardness decreases with increasing temperature. Ceramics have good hot hardness and high compressive strength.

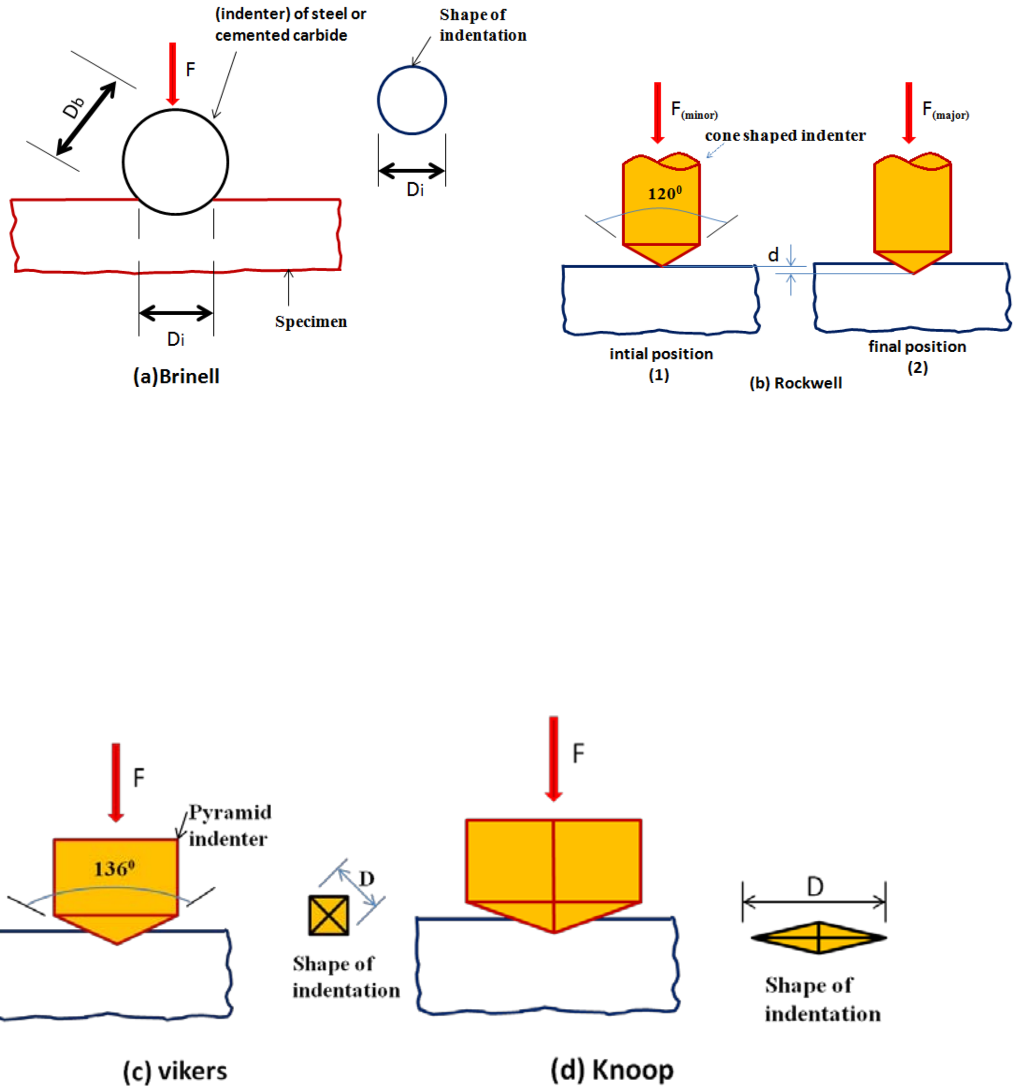


Fig. 4.4.2: Indentation and indenters in various hardness tests

Table 4.4.1: Hardness values of some alloys

Material	Rockwell hardness	Brinell hardness	Knoop hardness/Vicker's hardness
Gray cast iron		10 HRC	
Aluminium, cold worked	30 HB		
Low C steel hot rolled	200 HB	95 HRB, 15 HRC	
Austenitic stainless steel	150 HB	85 HRB	
Heat treated alloy steel	300	33 HRC	
Nylon	12 HRB		
PVC	10 HRB		
Tool steel			850 HK/800 HV
Alumina			1500 HK/2200 HV
Tungsten carbide			1900 HK/2600 HV

4.5 Impact tests:

Impact toughness refers to energy absorbed by a material during impact loading.

Impact toughness or impact strength is determined by Charpy or Izod impact test. A notched specimen supported at one end or both ends is broken using a swinging pendulum. The energy dissipated during fracture if the specimen is the impact toughness.

In Charpy test, the notched specimen of square cross-section is supported on both ends and held horizontal. In Izod test, the notched bar is held vertical, supported on one end.

Materials with high ductility have high impact toughness. Toughness is important in ductile to brittle transition of materials.

4.6 Residual stress in metal forming:

Residual stresses are the locked-in stresses which are left inside the material after working.

Residual stresses are caused due to inhomogeneous deformation in material during forming process.

Cold worked materials have greater residual stress due to locking up of dislocations.

Phase changes can also cause residual stresses. For example martensitic transformation in steel involves volume changes at microscopic levels, this induces residual stress. Temperature gradients also can cause residual stress due to restraint on material expansion during heating or contraction during cooling phase.

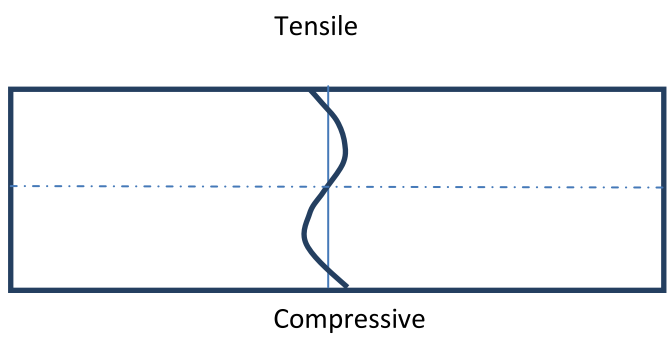


Fig. 4.6.1: Residual stress in bending

In bending there is non-uniform deformation. Outer fibers of the material are subjected to tensile stresses while section inside the neutral axis are subjected to compressive stress. Upon release of external load, residual stress remains in the material due to difference in elastic and plastic deformation within the section of the material.

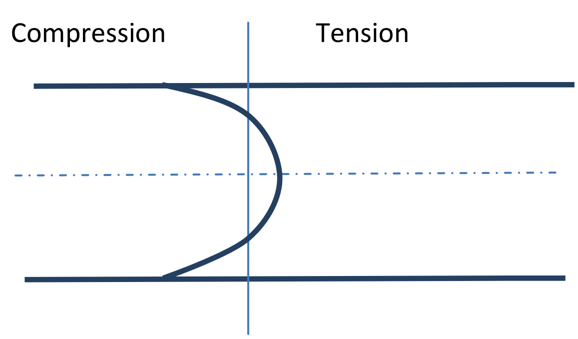


Fig. 4.6.2: Residual stress in rolling

Residual stress introduces distortion, dimensional changes after forming or machining operation. Stress relaxation may also cause dimensional and shape changes in finished products.

Source:
http://nptel.ac.in/courses/112106153/4