3.2 **Plastic Deformation**

Permanent deformation of materials, on application of a load is called plastic deformation. If such a deformation takes place at elevated temperature (more than 40% of absolute melting point of the metal, $0.4T_m$), then it is call creep. Plastic deformation can occur under tensile, compressive or torsional stresses. Here engineering stress and strain are given by

$$\text{Stress, } \sigma = \frac{P}{A_o} \quad \text{Strain } \varepsilon = \frac{\Delta l}{l}$$

Where P is the applied stress

A_o is the initial cross-sectional area

Δl is the fractional change in the gauge length of the sample

l is the original length of the sample

Plastic deformation corresponds to the motion of a large numbers of dislocations. There are two types of fundamental dislocations, vis., edge dislocation (slip) and screw dislocation (twin). Slip deformation is the result of lattice distortion, which moves along dislocation line in a direction perpendicular to applied stress. Deformation due to twinning is a result of a shear distortion at the dislocation line passes through the center of a spiral plane.

Mechanism of plastic deformation by slipping

Slip mode of deformation is a shear deformation that moves atoms by many inter-atomic distances from initial position. The orientation of the all parts of the crystal remains the same before and after slip. Thus, even though imperfections are introduced during plastic deformation, X-ray diffraction pattern shows that the crystal structure remains same.

The slipping take place along the plane called ***slip plane***. The slip planes are closely packed atomic planes within the crystal with greatest atomic density (higher number of atoms per unit area). The direction along which slip occurs called slip directions are the closest packed planes in the crystal.

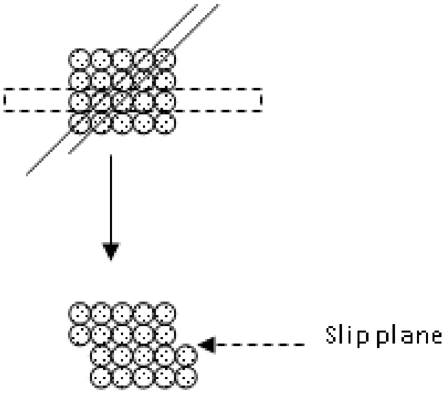

Fig.3.2.1 slip

In the case of ionic crystals, the slip planes and slip directions are such that the ions of the same polarity do not become juxtaposed as nearest neighbors during shear, since, this will increase potential energy of the crystal to a great extent.

Slip system

A slip plane and a slip direction that lies on to it together constitute a slip system. For example, in FCC system, a combination of (111) and [110] form a slip system, but not (111) and [110], as the direction [110] does not line on (111) plane. There are 12 slip systems in FCC and BCC crystals, while in HCP there are only 3 slip systems.

Critically resolved shear stress (CRSS)

CRSS is a parameter which decides whether the applied stress can cause slip or not in a particular plane.

Deformation by slip mode in the crystal takes place on application of shear stress through slip plane in slip direction. When the tensile or compressive stress is applied, the shear component exists in all directions. The shear component existing in a direction parallel and perpendicular to the applied stress, is called resolved shear stress. Their magnitude not only depends on the applied stress, but also on the orientation of both slip plane and slip direction within that plane.

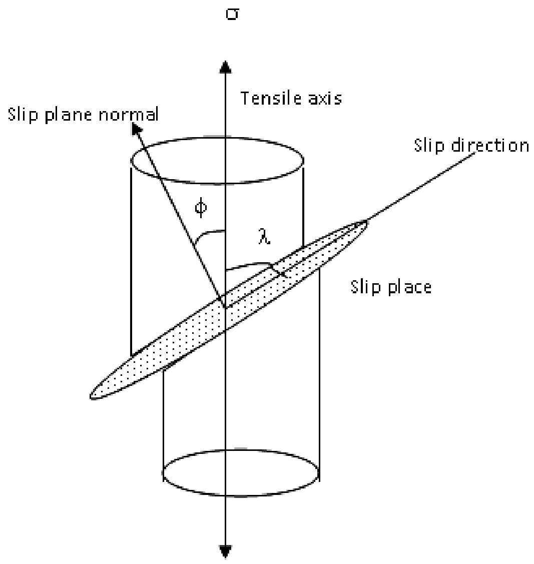

Fig 3.2.2 slip direction

Let ϕ represent the angle between normal to the slip plane and the applied direction, and λ be the angle between slip plane and stress direction, then the resolved shear stress, τ_R is

$$\tau_R = \sigma \cos\phi \ \text{cost}\ \lambda$$

Where σ is the applied stress.

In the case of a metal single crystal, there are a number of slip systems that can lead to slip deformation. But they differ in a way that, the direction of applied stress, which may not be the same. Hence, the slip system, which is favourably oriented will have largest resolved shear stress ($\tau_{R(max)}$) which is written as

$$\tau_{R(max)} = \sigma\,(\cos\phi \ \text{cost}\ \lambda)_{max}$$

Thus, when the resolved shear stress in the most favoured slip system reaches a critical value, then only the slip deformation takes place. This is called ***Critical resolved shear stress***, $\tau_{crss.}$ It is represents the minimum shear stress required to initiate the slip, i.e., when $\boldsymbol{\tau_{R(max)} = \tau_{crss}}$**,** then deformation takes place, and this point is the yield strength σ_y and is given as:

$$\sigma_y = \frac{\tau_{crss}}{(\cos\phi \cos\lambda)_{max}}$$

Mechanism of deformation by twinning

The second important mechanism of plastic deformation is twinning. It results when a portion of crystal takes up an orientation that is related to the orientation of the rest of the untwined lattice in a definite, symmetrical way. The twinned portion of the crystal is a mirror image of the parent crystal. The plane of symmetry is called twinning plane. Each atom in the twinned region moves by a homogeneous shear a distance proportional to its distance from the twin plane. The lattice strains involved in twinning are small, usually in order of fraction of inter-atomic distance, thus resulting in very small gross plastic deformation. The important role of twinning in plastic deformation is that it causes changes in plane orientation so that further slip can occur. If the surface is polished, the twin would be still visible after etching because it possess a different orientation from the untwined region. This is in contrast with slip, where slip lines can be removed by polishing the specimen.

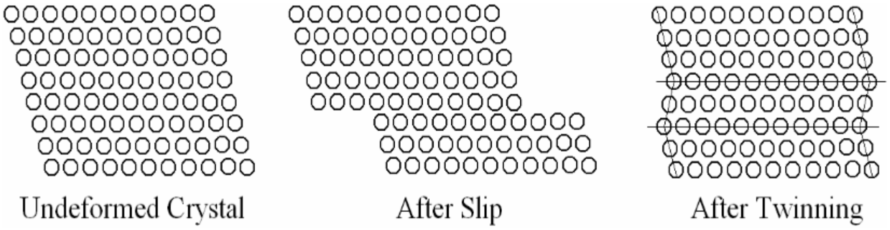

Fig 3.2.3 Twinning