Dislocation strengthening mechanism

Mechanisms of plastic deformation in metals

Slip

- Slip is the prominent mechanism of plastic deformation in metals. It involves sliding of blocks of crystal over one other along definite crystallographic planes, called slip planes.

- In physical words it is analogous to a deck of cards when it is pushed from one end. Slip occurs when shear stress applied exceeds a critical value.

- During slip each atom usually moves same integral number of atomic distances along the slip plane producing a step, but the orientation of the crystal remains the same. Steps observable under microscope as straight lines are called slip lines.

- Slip occurs most readily in specific directions (slip directions) on certain crystallographic planes. This is due to limitations imposed by the fact that single crystal remains homogeneous after deformation.

- In a single crystal, plastic deformation is accomplished by the process called slip, and sometimes by twinning.

- In a polycrystalline aggregate, individual grains provide a mutual geometrical constraint on one other, and this precludes plastic deformation at low applied stresses. That is to initiate plastic deformation, polycrystalline metals require higher stresses than for equivalent single crystals, where stress depends on orientation of the crystal.

- Slip in polycrystalline material involves generation, movement and re-arrangement of dislocations. Because of dislocation motion on different planes in various directions, they may interact as well. This interaction can cause dislocation immobile or mobile at higher stresses.

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 possesses a different orientation from the untwined region. This is in contrast with slip, where slip lines can be removed by polishing the specimen.

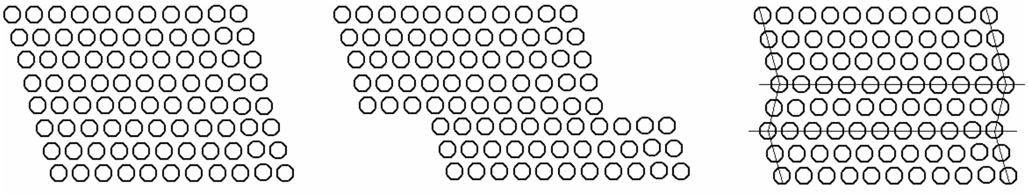
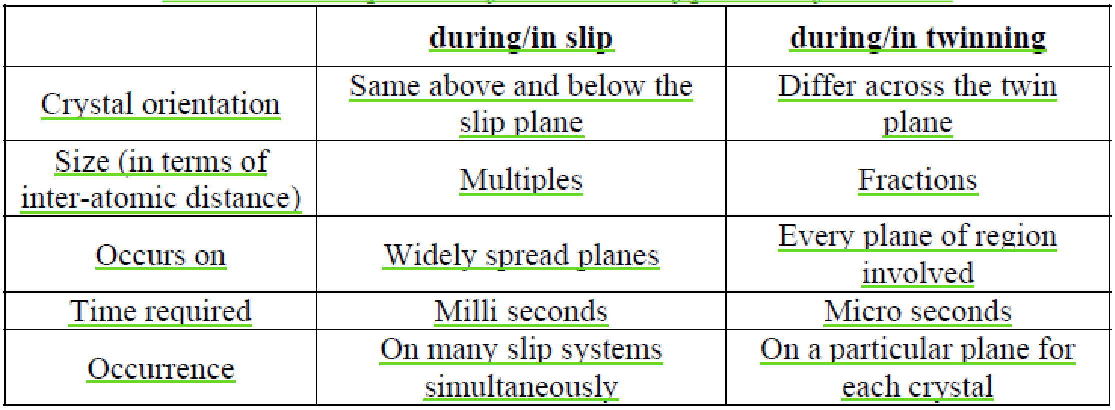

Undeformed Crystal After Slip After Twinning

Table-6.3: *Comparison of mechanism of plastic deformation.*



	during/in slip	**during/in twinning**
Crystal orientation	Same above and below the slip plane	Differ across the twin plane
Size (in terms of inter-atomic distance)	Multiples	Fractions
Occurs on	Widely spread planes	Every plane of region involved
Time required	Milli seconds	Micro seconds
Occurrence	On many slip systems simultaneously	On a particular plane for each crystal

Strengthening mechanisms in Metals

- Strengthening of a metal consist hindering dislocation motion.
- Dislocation motion can be hindered in many ways, thus are strengthening mechanisms in metals. Strengthening by methods of grain-size reduction, solid-solution alloying and strain hardening applies for single-phase metals.
- Precipitation hardening, dispersion hardening, fibre strengthening and Martensite strengthening are applicable to multi-phase metallic materials.

Strengthening by Grain Size Reduction

- This strengthening mechanism is based on the fact that crystallographic orientation changes abruptly in passing from one grain to the next across the grain boundary. Thus it is difficult for a dislocation moving on a common slip plane in one crystal to pass over to a similar slip plane in another grain, especially if the orientation is very misaligned.

- A grain boundary can hinder the dislocation motion in two ways: (1) by forcing the dislocation to change its direction of motion and (2) discontinuity of slip plane because of disorder.
- With decrease in grain size, the mean distance of a dislocation can travel decreases, and soon starts pile up of dislocations at grain boundaries. This leads to increase in yield strength of the material.

Solid Solution Strengthening

- Adding atoms of another element that those occupy interstitial or substitutional positions in parent lattice increases the strength of parent material. This is because stress fields generated around the solute atoms interact with the stress fields of a moving dislocation, thereby increasing the stress required for plastic deformation i.e. the impurity atoms cause lattice strain which can "anchor" dislocations. This occurs when the strain caused by the alloying element compensates that of the dislocation, thus achieving a state of low potential energy.
- |It can be said that solute atoms have more influence on the frictional resistance to dislocation motion than on the static locking of dislocations. Pure metals are almost always softer than their alloys. Solute strengthening effectiveness depends on two factors – size difference between solute and parent atoms, and concentration of solute atoms.

Strain Hardening

- Strain hardening is used for hardening/strengthening materials that are not responsive to heat treatment. The phenomenon where ductile metals become stronger and harder when they are deformed plastically is called strain hardening *or* work hardening.

- Strain hardening is used commercially to enhance the mechanical properties of metals during fabrication procedures. In addition to mechanical properties, physical properties of a material also change during cold working. There is usually a small decrease in density, an appreciable decrease in electrical conductivity, small increase in thermal coefficient of expansion and increased chemical reactivity (decrease in corrosion resistance).

Precipitation Hardening **and** *Dispersion strengthening*

- The small particles distributed in a ductile matrix can hinder the dislocation motion and thus increase the strength of a material.

- This particle either can be introduced by mixing and consolidation (dispersion strengthening) or precipitated in solid state (precipitation hardening).
- Precipitation hardening or age hardening is produced by solution treating and quenching an alloy. Term ‘Age hardening’ is used to describe the process because strength develops with time.

Fiber strengthening

- The material can also be introduced into matrix in form of fibers to strengthen it. However, mechanism of strengthening is different from either precipitation hardening or dispersion strengthening where second phase is introduced as fine particles.
- In fiber-reinforced materials, high modulus fibers carry essentially the entire load while the matrix serves to transmit the load to the fibers. Matrix also protects fibers from surface damage, serves to blunt cracks which arise from fiber breakage while it also serves to separate the fibres.

Martensite Strengthening

- This strengthening can be achieved in systems where a diffusion-controlled invariant transformation can be suppressed by rapid cooling.
- The Martensite strengthening process, thus, basically is a diffusion-less and displacive reaction.
- The martensitic phase is formed from the retained high temperature phase at temperatures lower than the equilibrium invariant transformation temperature.

Recrystallization and Grain Growth

- During recrystallization, the mechanical properties that were changes during deformation are restored to their pre-cold-work values. Thus material becomes softer, weaker and ductile.

- During this stage of annealing impurity atoms tend to segregate at grain boundaries, and retard their motion and obstruct the processes of nucleation and growth.

- During this stage newly formed strain-free grains tend to grow in size. This grain growth occurs by the migration of grain boundaries. Driving force for this process is reduction in grain boundary energy i.e. decreasing in free energy of the material. As the grains grow larger, the curvature of the boundaries becomes less. This results in a tendency for larger grains to grow at the expense of smaller grains.