

Plastic deformation

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Plastic deformation

- If the solid body is loaded beyond the elastic limit, the body will experience a permanent change in shape and size, even if the load is removed .
- Plastic deformation of metals and alloys is generally studied under two categories namely,
 - i. Plastic deformation of single crystals.
 - ii. Plastic deformation of polycrystalline materials

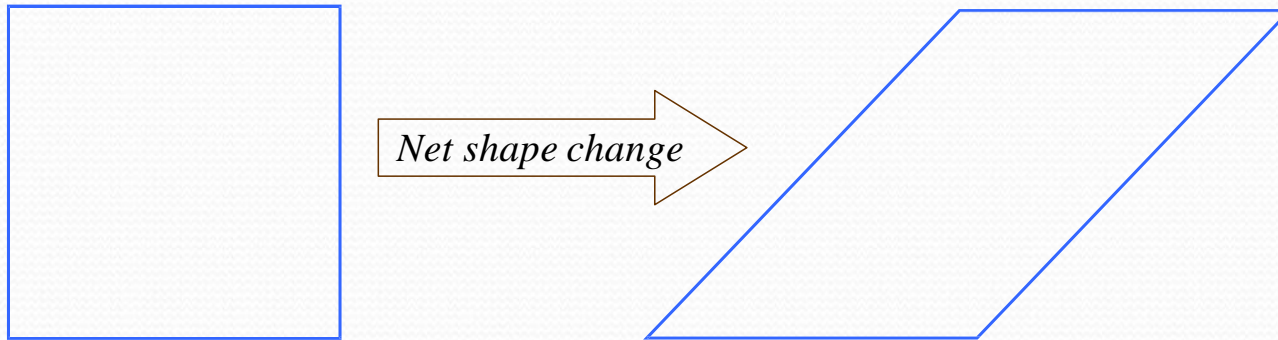
Plastic deformation of single crystals

- Plastic deformation of single crystals involve the study of one single crystal and observing how it behaves under stress.
- A single crystal is nothing but a single grain and has no grain boundaries.
- Plastic deformation in single crystals may take place by
 - i. Slip
 - ii. Twinning or
 - iii. a combination of both.

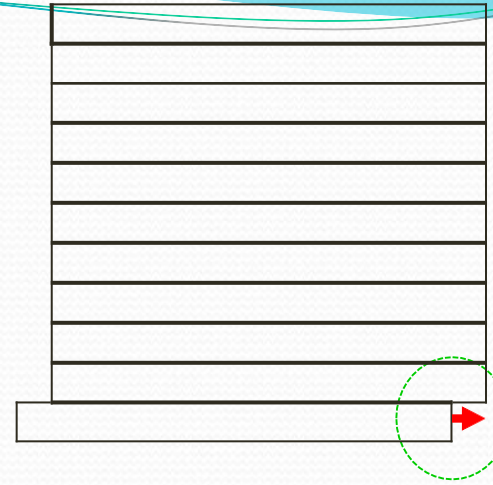
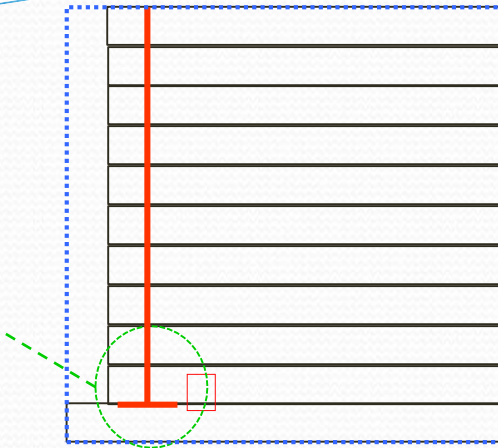
Plastic deformation by slip

- Slip is the most common mode of plastic deformation among crystals.
- When a single crystal in tension is stressed beyond its elastic limit, a step appears such that the single crystal divides into two blocks .
- When the tensile load is further increased, the blocks become again divided and relative displacement takes place.
- Slip occurs due to the movement of dislocations through the crystal as shown in below figure.

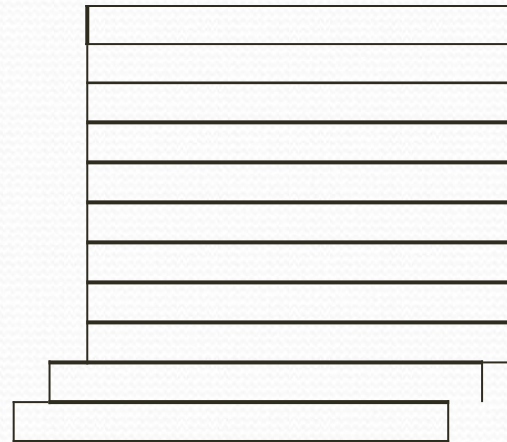
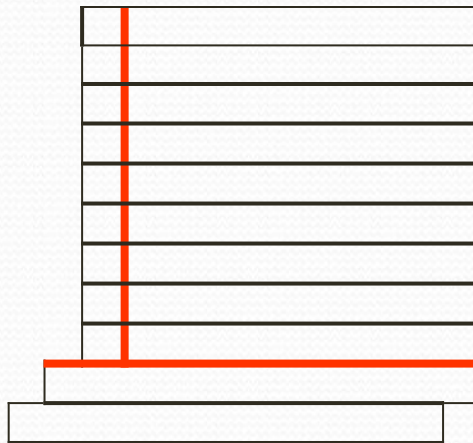
To understand 'how slip can lead to shape change?'; we consider a square crystal deformed to a rhombus (as Below).

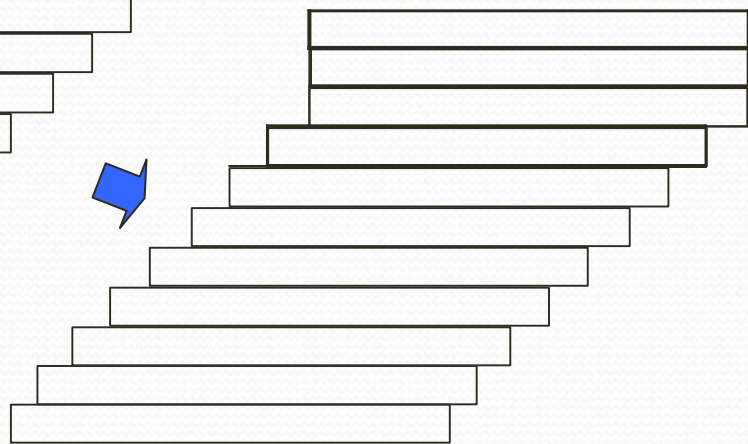
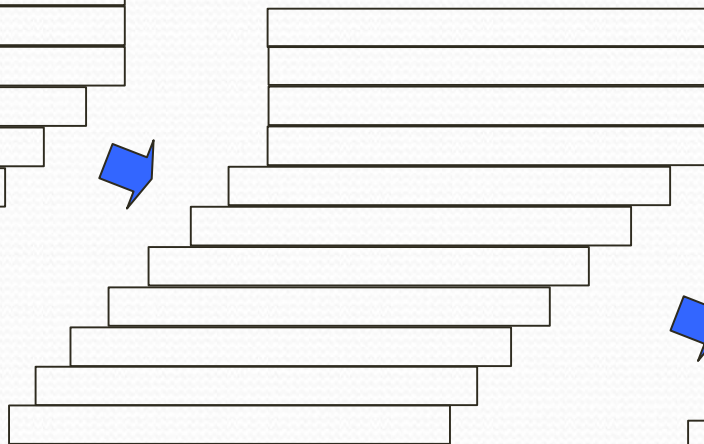
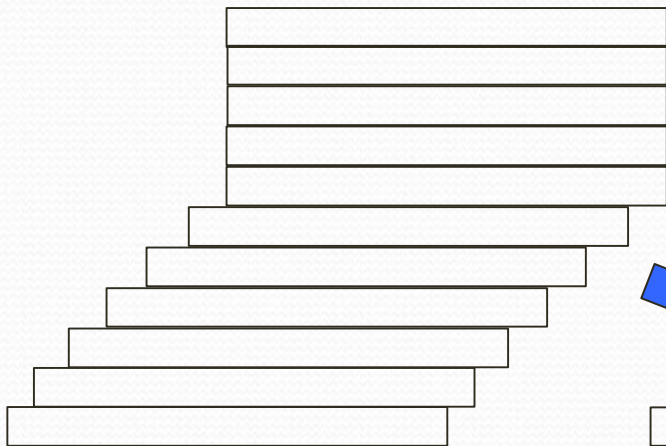
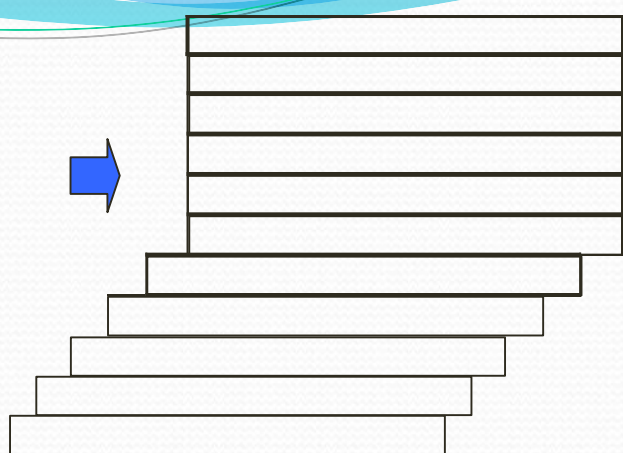
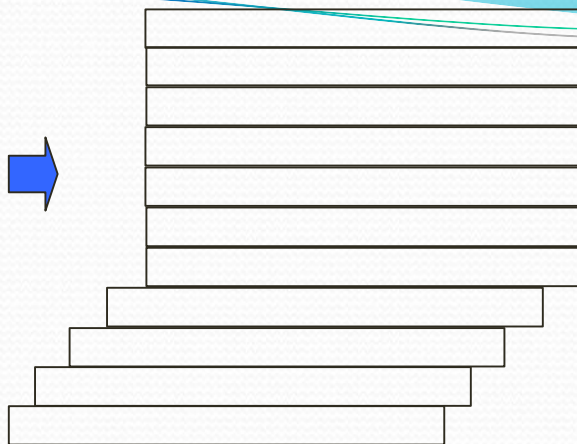
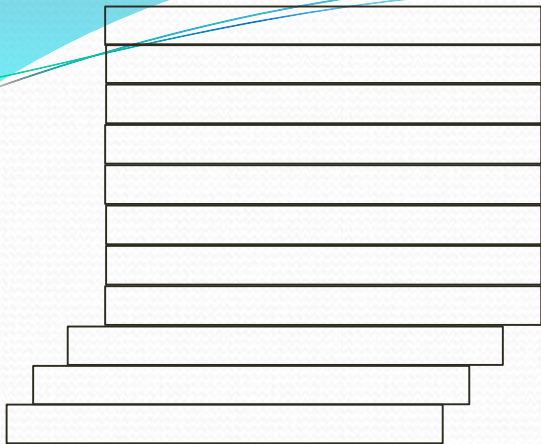


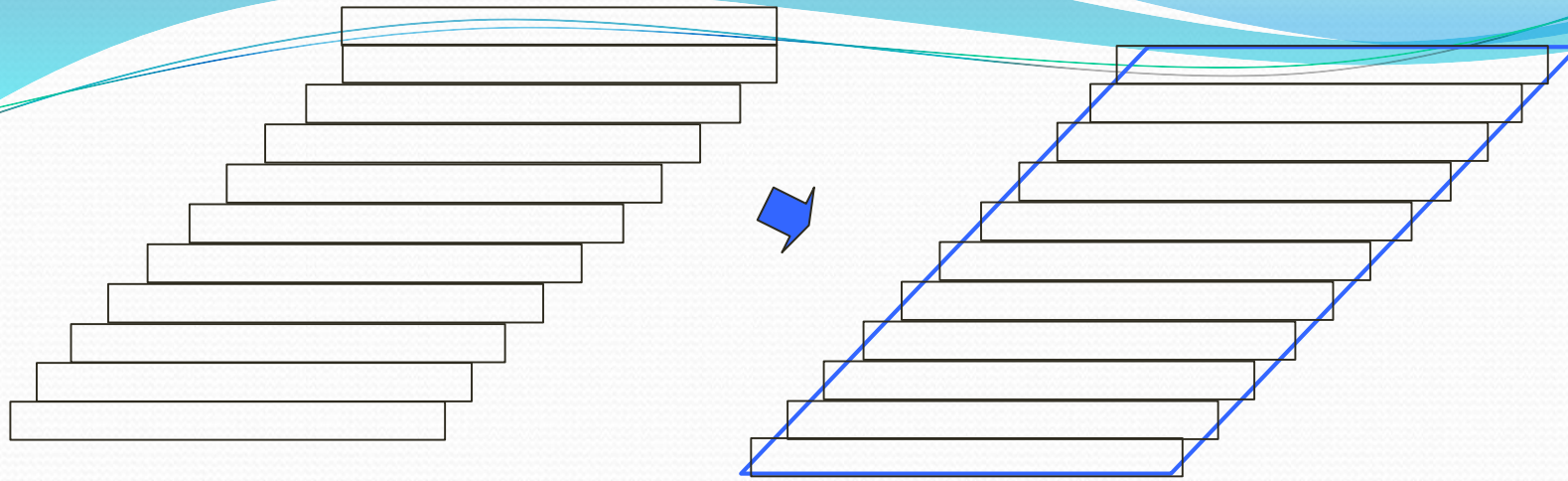
Dislocation formed by pushing in a plane



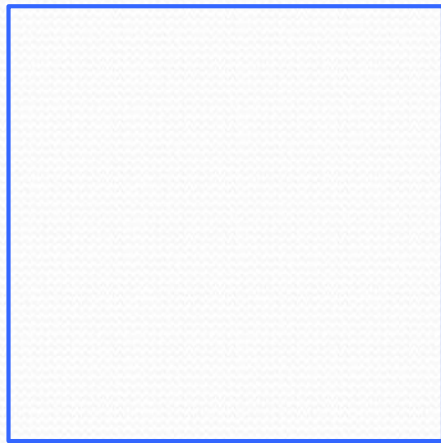
Step formed when dislocation leaves the crystal



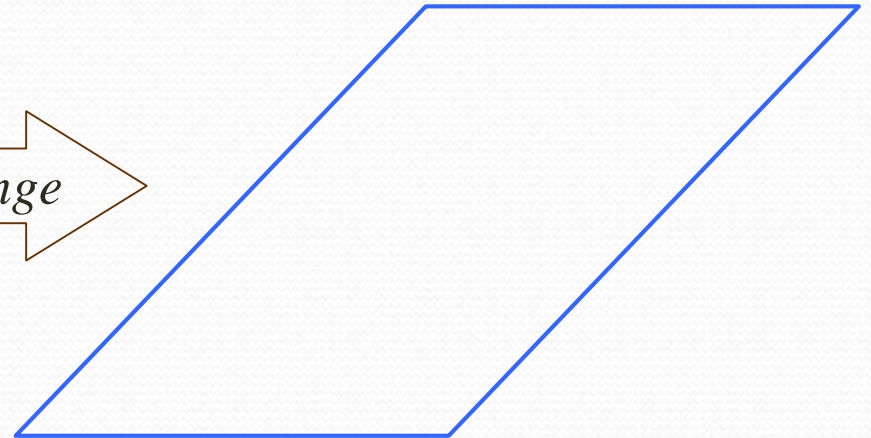




This sequence of events finally leads to deformed shape which can be approximated to a rhombus

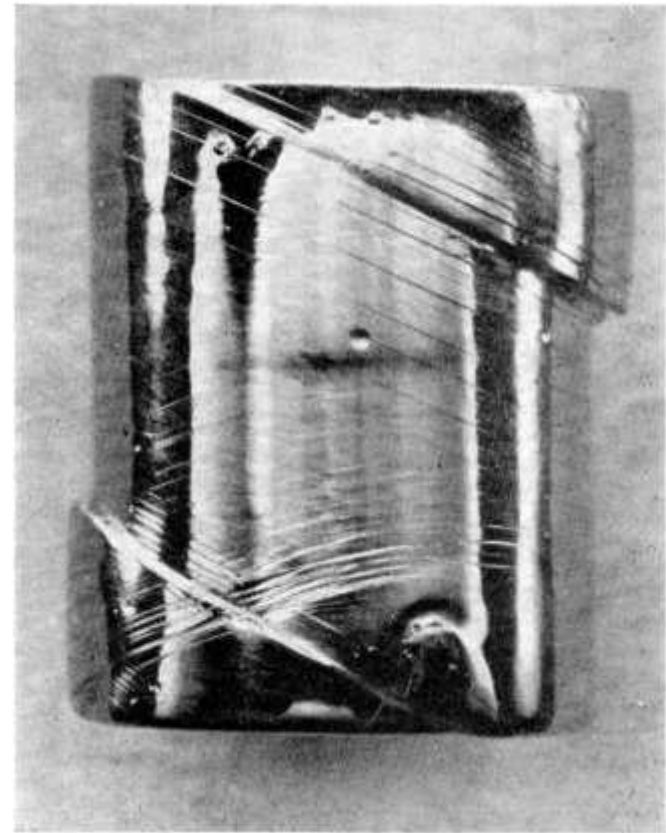
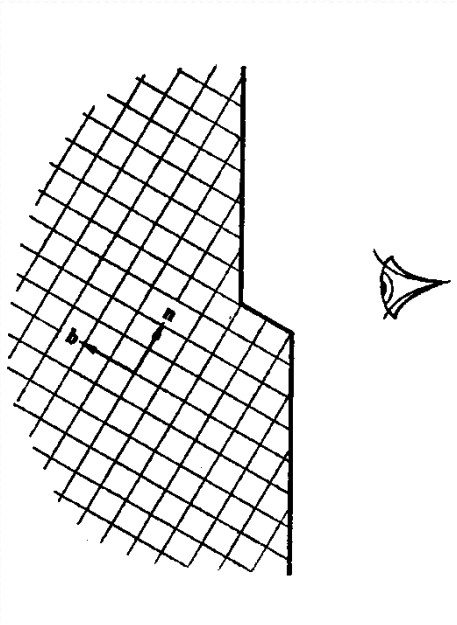


Net shape change



Slip steps

- Slip steps (where dislocations exit from the crystal) on the surface of compressed single crystal .



- The movement of dislocations can be compared to the movement of an caterpillar as its arches its back in order to move forward.

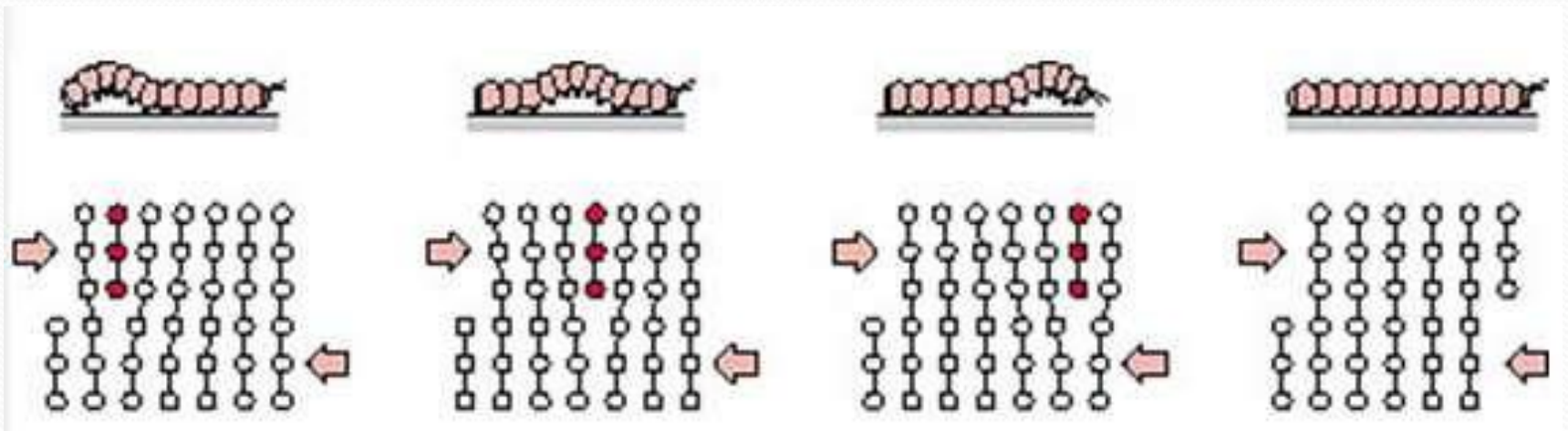
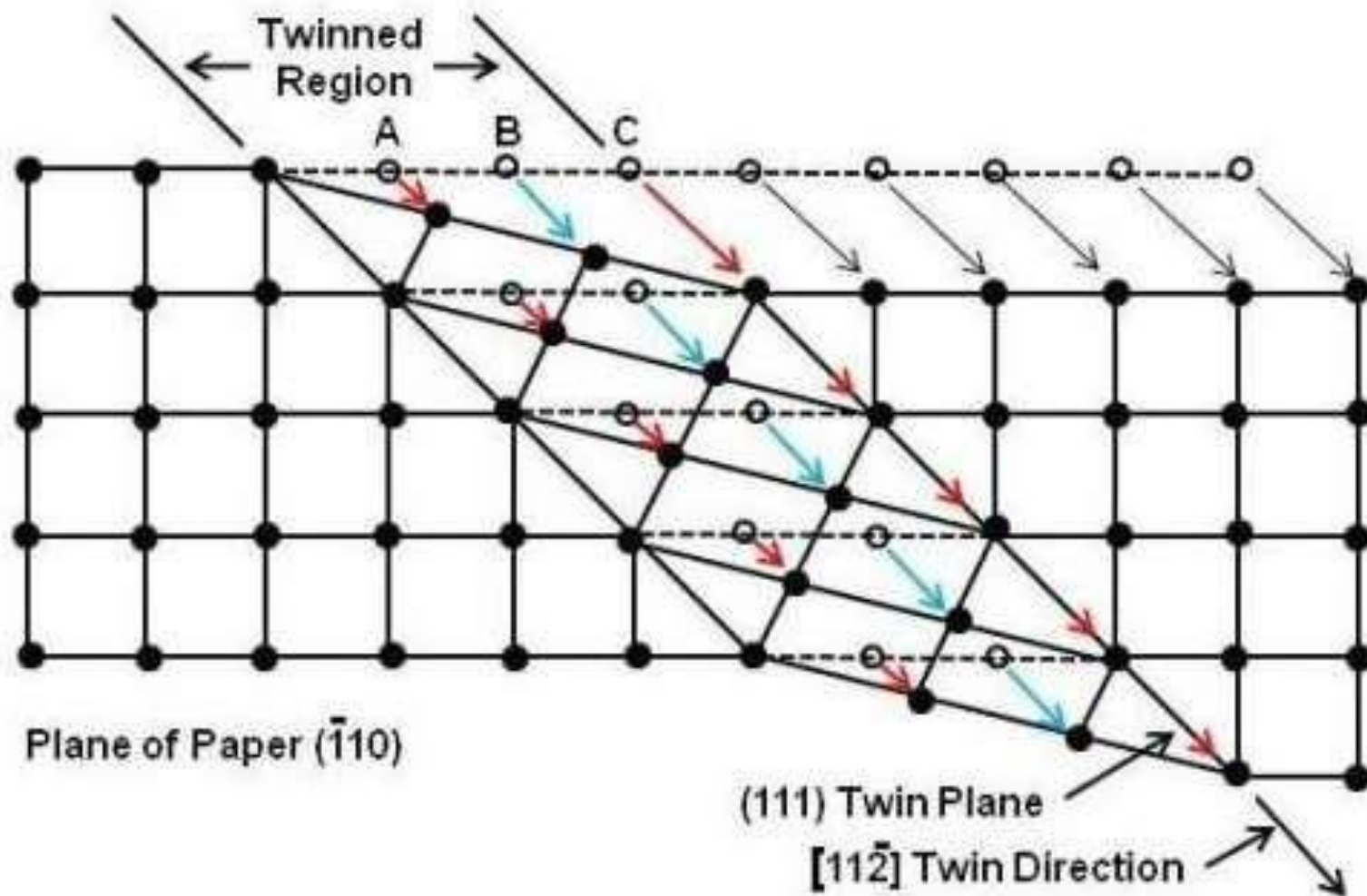


Fig : Representation of analogy between caterpillar and dislocation motion

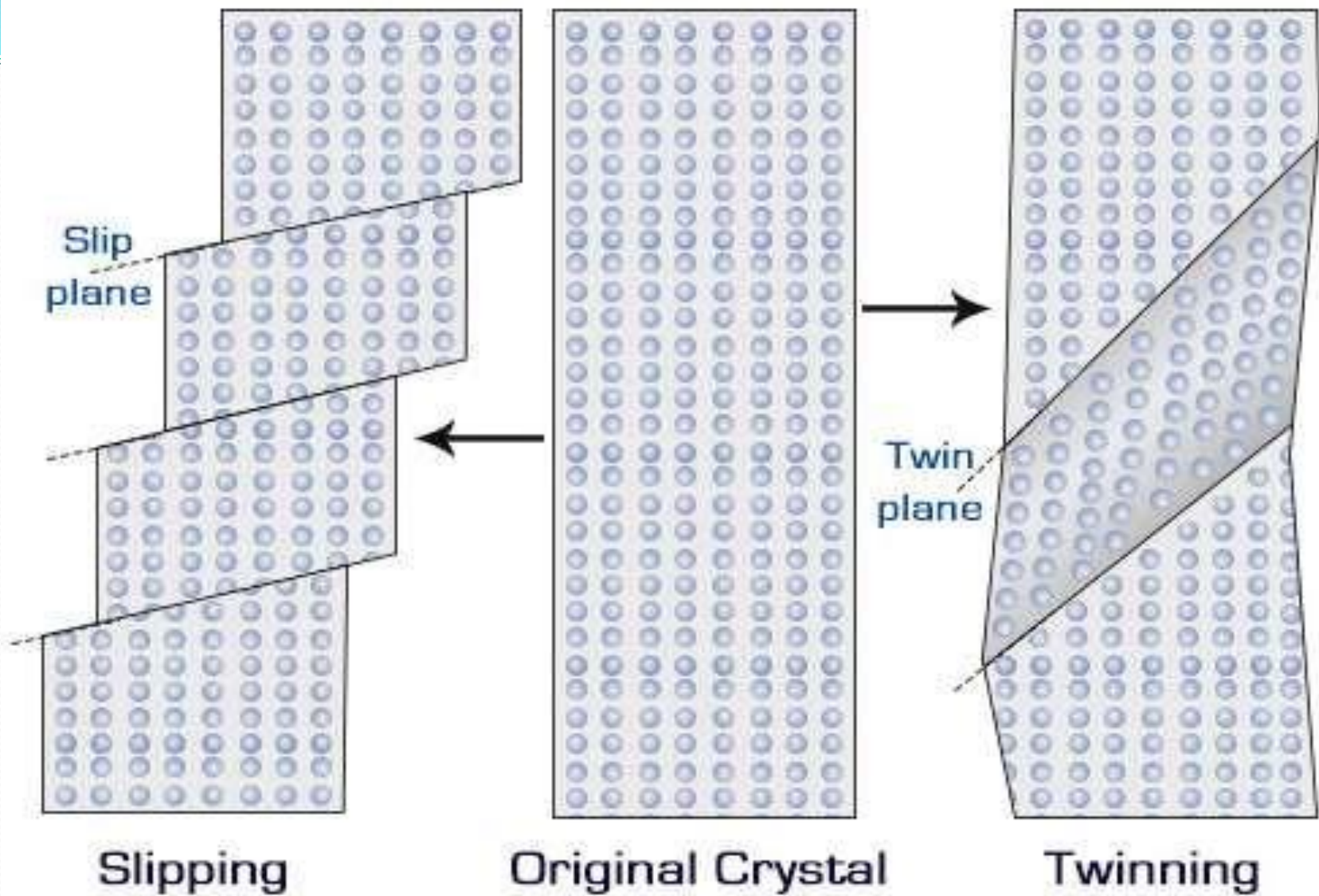
Plastic deformation

by twinning

- In twinning each plane of atoms move through a definite distance and in the same direction.
- The extent of movement of each plane is proportional to its distance from the twinning plane.
- When a shear stress is applied, the crystal will twin about the twinning plane in such a way that the region to the left of the twinning plane is not deformed whereas the region to the right is deformed.
- The atomic arrangement on either side of the twinned plane is in such a way that they are mirror reflections of each other.



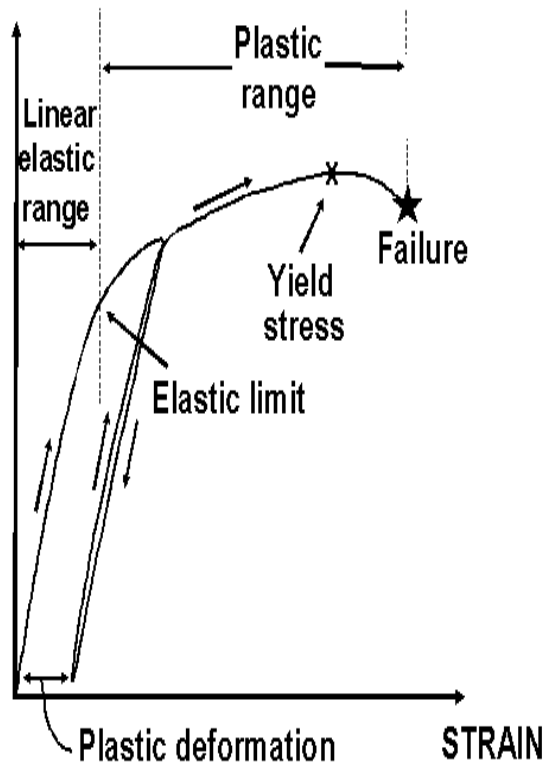
Schematic Diagram of Twinning in an f.c.c. Lattice



MECHANISMS OF PLASTIC DEFORMATION

- This type of deformation is irreversible.
- However, an object in the plastic deformation range will first have undergone elastic deformation, which is reversible.
- Thermoplastics have large plastic deformation when compared to brittle and ductile materials.
- Plastic deformation is characterized by a strain hardening region and a necking region and finally, fracture (also called rupture).
- During strain hardening the material becomes stronger through the movement of atomic dislocations. (are imperfections in crystal structure which increases as strain increases)
- There are two types of dislocations: edge and screw.
- The modes of deformation are **twinning** and **slip**.
- **Necking**, in engineering or materials science, is a mode of tensile deformation where relatively large amounts of strain localize disproportionately in a small region of the material. The resulting prominent decrease in local cross-sectional area provides the basis for the name "neck".
- This type of deformation is also irreversible. A break occurs after the material has reached the end of the elastic, and then plastic, deformation ranges. At this point forces accumulate until they are sufficient to cause a fracture. All materials will eventually fracture, if sufficient forces are applied.

STRESS



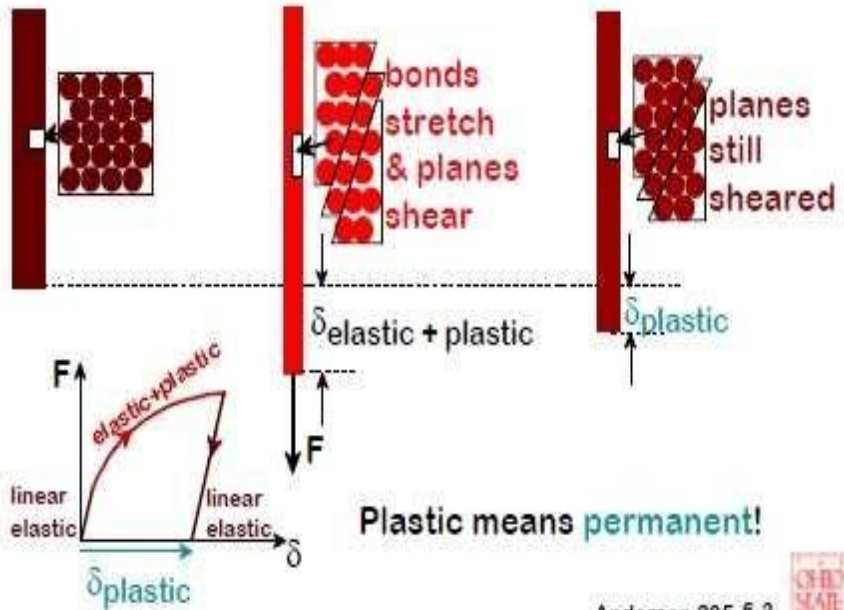
PLASTIC DEFORMATION (METALS)

(at lower temperatures: $T < T_{\text{melt}}/3$)

1. Initial

2. Large load

3. Unload



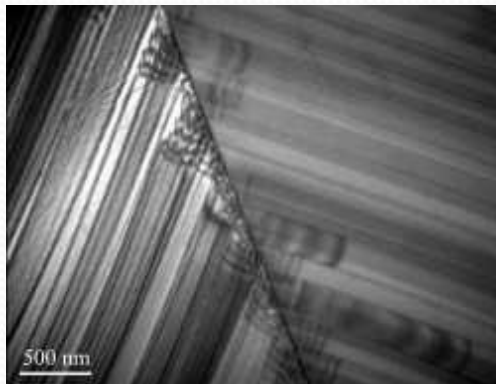
Anderson 205-6-3



Mechanism of elastic and plastic deformation

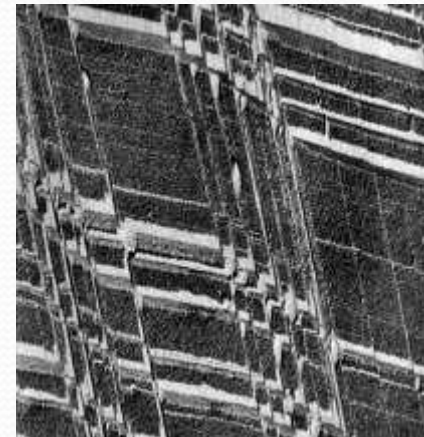
- **TWINNING**

- Common in hcp and bcc structures
- Limited deformation but help in plastic deformation in hcp and bcc crystals.
- Occurs on specific twinning planes and twinning directions



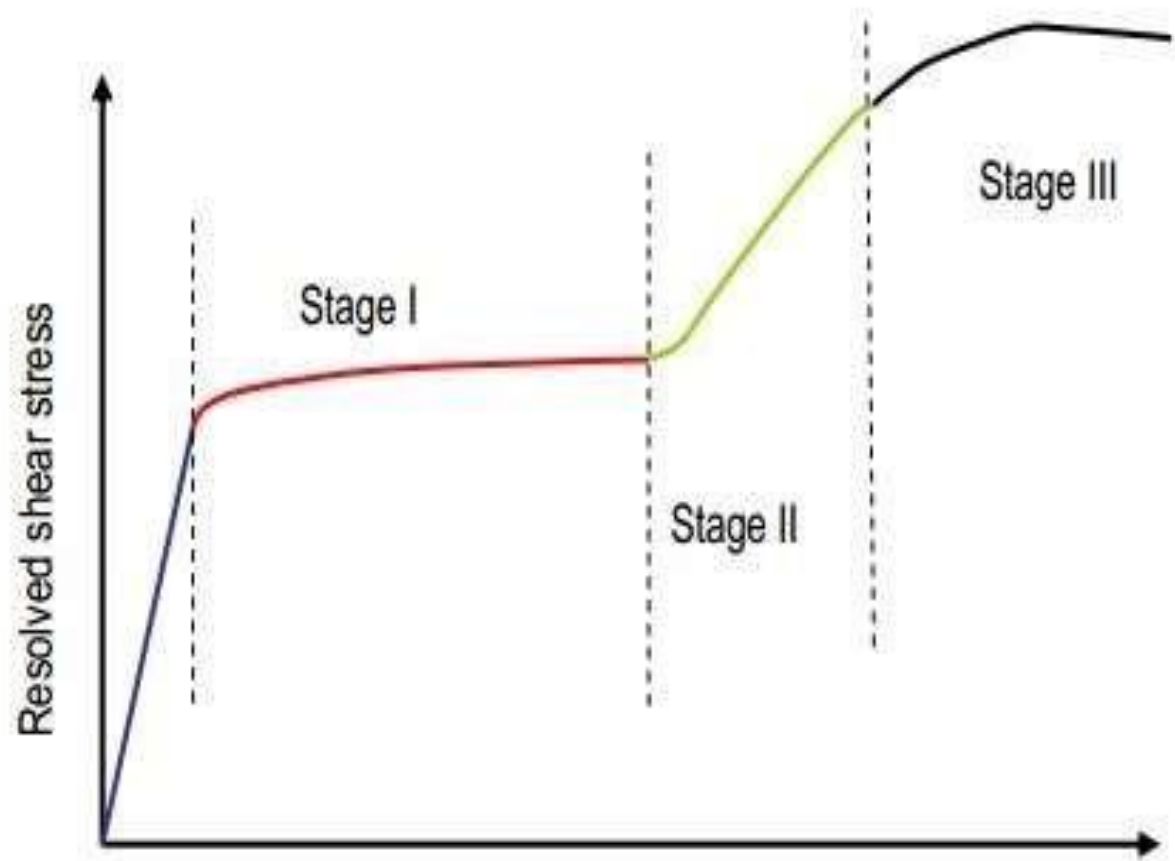
- **SLIP**

- Dislocations move on a certain crystallographic plane: slip plane
- Dislocations move in a certain crystallographic direction: slip direction
- The combination of slip direction and slip plane is called a slip system.



Yield stress for real crystals

- The stress level at which a metal or other material ceases to behave elastically. The stress divided by the strain is no longer constant. The point at which this occurs is known as the yield point.
- The *initial elastic strain* is caused by the simple stretching of bonds. Hooke's Law applies to this region.
- At the yield point, *stage I* begins. The crystal will extend considerably at almost constant stress. This is called *easy glide*, and is caused by slip on one slip system.
- The geometry of the crystal changes as slip proceeds.
- In this stage of deformation, known as *stage II*, dislocations are gliding on two slip systems, and they can interact.
- Consequently, the crystal becomes more difficult to extend. This phenomenon is called *work hardening*.
- *Stage III* corresponds to extension at high stresses, where the applied force becomes sufficient to overcome the obstacles, so the slope of the graph becomes progressively less steep. The work hardening *saturates*.
- Stage III ends with the failure of the crystal.



SHEAR STRENGTH FOR PERFECT CRYSTALS

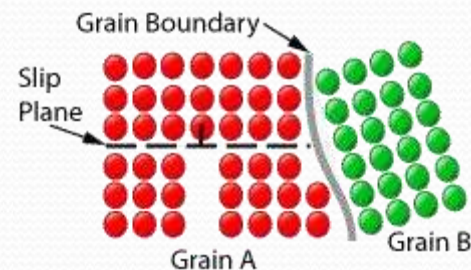
- It is a term used to describe the strength of a material against structural failure(fracture), where the material or component fails due to deforming force(shear force).
- **STRENGTH TERMS:-**
- Tensile strength or *ultimate tensile strength* is a limit state of tensile stress that leads to tensile failure in the manner of ductile failure. or brittle failure.
- Compressive strength is a limit state of compressive stress that leads to failure in the manner of ductile failure or brittle failure.
- Fatigue strength is a measure of the strength of a material or a component under cyclic loading, and is usually more difficult to assess than the static strength measures.
- Impact strength, is the capability of the material to withstand a suddenly applied load and is expressed in terms of energy.

STRENGTHENING MECHANISMS

- Methods have been devised to modify the yield strength, ductility, and toughness of both crystalline and amorphous materials.
-
- Work hardening (such as beating a red-hot piece of metal on anvil) has also been used for centuries by blacksmiths to introduce dislocations into materials, increasing their yield strengths.
-
- Q) What is strengthening?
-
- **A)** Plastic deformation occurs when large numbers of dislocations move and multiply so as to result in macroscopic deformation. In other words, it is the movement of dislocations in the material which allows for deformation. If we want to enhance a material's mechanical properties (i.e. increase the yield and tensile strength), we simply need to introduce a mechanism which prohibits the mobility of these dislocations.

WORK HARDENING

- Work hardening is the result of many contributing factors.
- The primary species responsible for work hardening are dislocations.
- Dislocations interact with each other by generating stress fields in the material.
- As a material is plastically deformed, dislocations move extensively throughout the crystal, and in addition the *dislocation density* increases.
- The effect of this is to increase the number of *entanglements* - these are points where dislocations interact in such a way that their further motion is hindered.





THANK
YOU