Lectures Notes

On

Engineering Material

(Subject Code-Th-3)

3rd Semester in Mechanical Engg

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Module # 1

Engg Material classifications and their properties

Contents

1) Historic perspective and Materials Science
2) Why study properties of materials, Classification of materials
3) Advanced materials, Future materials and Modern materials' needs

Historic perspective

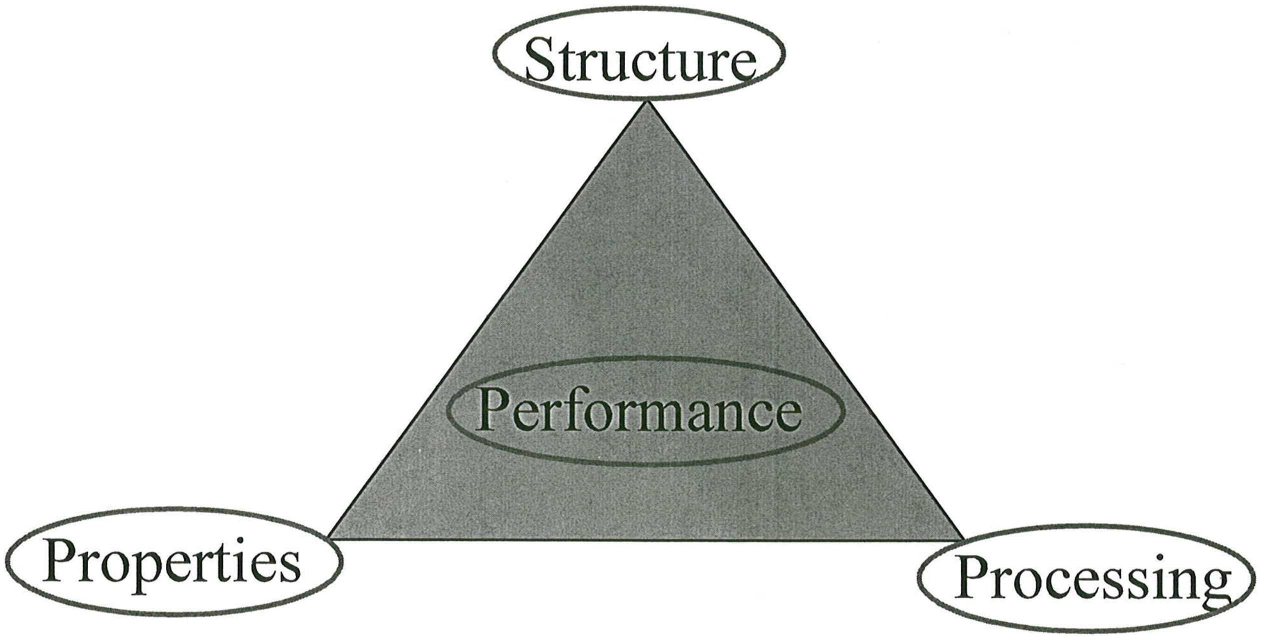
- Materials are very important in development of human civilization. In respect, their names are associated in history, e.g. stone age, Bronze age, Iron age, etc.

- With time humans discovered new materials and also techniques to produce known materials. This is an ongoing process for coming centuries, i.e. no end in sight!

Materials Science

- It can be defined as science dealing the relationships that exist between the structures and properties of materials, which are useful in practice of engineer's profession.

- Basic components and their interrelationship:



Properties of Materials

- All solid engineering materials are characterized for their properties.

- Engineering use of a material is reflection of its properties under conditions of use.

- All important properties can be grouped into six categories: Mechanical, Electrical, Thermal, Magnetic, Optical, and Deteriorative.

- Each material possess a structure, relevant properties, which dependent on processing and determines the performance.

Why Study Properties of Materials?

- Since there are thousands of materials available it is almost impossible to select a material for a specific task unless otherwise its properties are known.
- There are several criteria on which the final decision is based on.
- There are less chances of material possessing optimal or idle combination of properties.
- A need to trade off between number of factors!

- The classic example involves strength and ductility:

  - Normally material possessing strength have limited ductility.In such cases a reasonable comprise between two or more properties are important.

  - A second selection consideration is any deterioration of material properties during service operations.

  - Finally the overriding consideration is economics.

Classification of Materials

- Three basic groups of solid engineering materials based on atomic bonds and structures:

  Metals

  Ceramics

  Polymers

- Classification can also be done based on either properties (*mechanical, electrical, optical*), areas of applications (*structures, machines, devices*). Further we can subdivide these groups.

- According to the present engineering needs:

  Composites, Semiconductors, Biomatrials

Metals

- Characteristics are owed to non-localized electrons (metallic bond between atoms) i.e. electrons are not bound to a particular atom.
- They are characterized by their high thermal and electrical conductivities.
- They are opaque, can be polished to high luster. The opacity and reflectivity of a metal arise from the response of the unbound electrons to electromagnetic vibrations at light frequencies.
- Relatively heavier, strong, yet deformable.

E.g.: Steel, Aluminium, Brass, Bronze, Lead, Titanium, etc.

Ceramics

- They contain both metallic and nonmetallic elements.
- Characterized by their higher resistance to high temperatures and harsh environments than metals and polymers.
- Typically good insulators to passage of both heat and electricity.
- Less dense than most metals and alloys.
- They are harder and stiffer, but brittle in nature.
- They are mostly oxides, nitrides, and carbides of metals.
- Wide range: traditional (*clay, silicate glass, cement*) to advanced (*carbides, pure oxides, non-silicate glasses*).

E.g.: Glass, Porcelain, Minerals, etc.

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Polymers

- Commercially called *plastics*; noted for their low density, flexibility and use as insulators.
- Mostly are of organic compounds i.e. based on carbon, oxygen and other nonmetallic elements.
- Consists large molecular structures bonded by covalent and van der Waals forces.
- They decompose at relatively moderate temperatures (100-400 C).
- Application: packaging, textiles, biomedical devices, optical devices, ceramics household items, toys, etc.

E.g.: Nylon, Teflon, Rubber, Polyester, etc.

Module # 2

Crystal Imperfections

(Point defects, line defects, interfacial defects, Volume defects)

Line defects

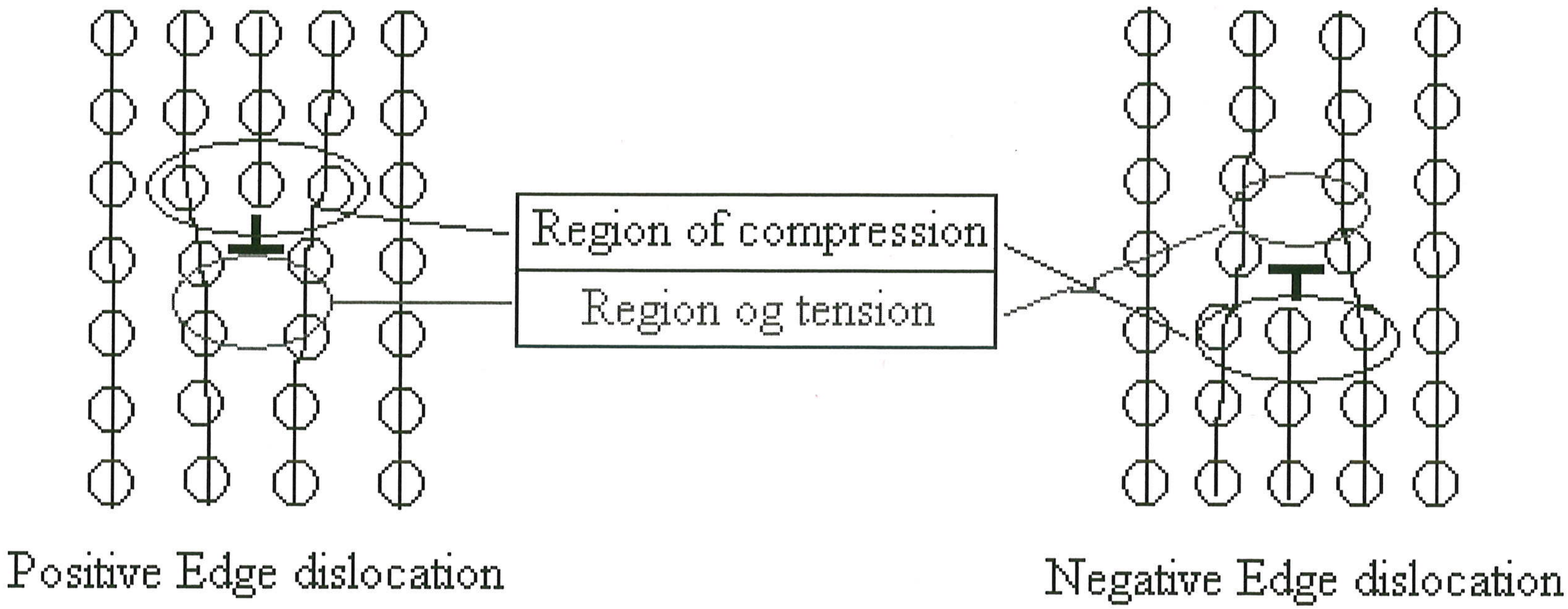
- *Line defects* or *Dislocations* are abrupt change in atomic order along a line.
- They occur if an incomplete plane inserted between perfect planes of atoms *or* when vacancies are aligned in a line.
- *A dislocation is the defect responsible for the phenomenon of slip, by which most metals deform plastically.*
- Dislocations occur in high densities (10^8-10^{10} m^{-2}), and are intimately connected to almost all mechanical properties which are in fact structure-sensitive.
- Dislocation form during plastic deformation, solidification or due to thermal stresses arising from rapid cooling.

Line defects – Burger's vector

- A dislocation in characterized by Burger's vector, ***b***.
- It is unique to a dislocation, and usually have the direction of close packed lattice direction. It is also the slip direction of a dislocation.
- *It represents the magnitude and direction of distortion associated with that particular dislocation.*
- Two limiting cases of dislocations, edge and screw, are characterized by Burger's vector perpendicular to the dislocation line (***t***) and Burger's vector parallel to the dislocation line respectively. Ordinary dislocation is of mixed character of edge and screw type.

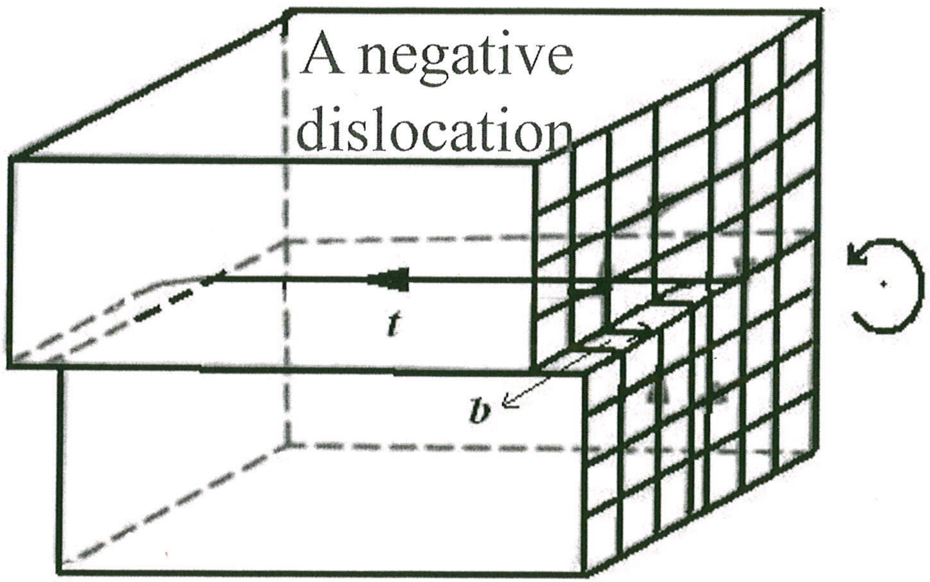
Line defects – Edge dislocation

- It is also called as *Taylor-Orowan dislocation*.
- It will have regions of compressive and tensile stresses on either side of the plane containing dislocation.



Line defects – Screw dislocation

- It is also called as *Burger's dislocation.*
- It will have regions of shear stress around the dislocation line
- For positive screw dislocation, dislocation line direction is parallel to Burger's vector, and vice versa.



Line defects – Dislocation motion

- Dislocations move under applied stresses, and thus causes plastic deformation in solids.
- Dislocations can move in three ways – glide/slip, cross-slip and climb – depending on their character. Slip is conservative in nature, while the climb is non-conservative, and is diffusion-controlled.
- *Any dislocation can slip, but in the direction of its burger's vector.*
- *Edge dislocation moves by slip and climb.*
- *Screw dislocation moves by slip / cross-slip.* Possibility for cross-slip arises as screw dislocation does not have a preferred slip plane as edge dislocation have.

Line defects – Dislocation characteristics

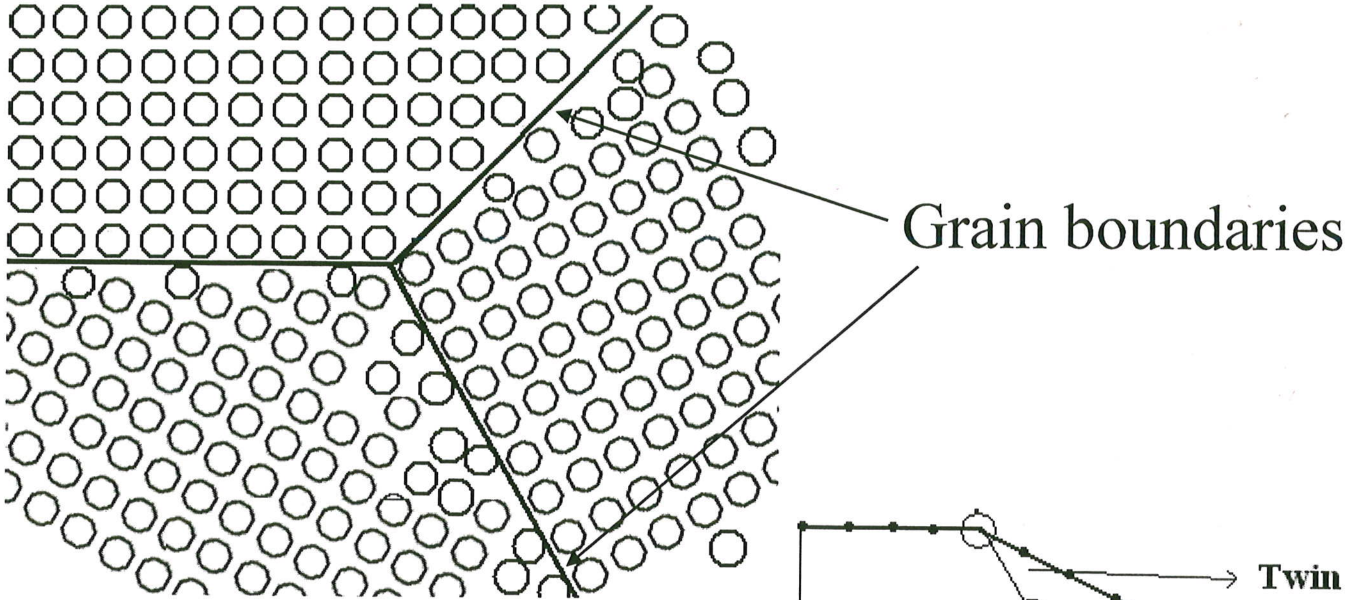
- A dislocation line cannot end at abruptly inside a crystal. It can close-on itself as a loop, either end at a node or surface.
- *Burger's vector for a dislocation line is invariant* i.e. it will have same magnitude and direction all along the dislocation line.
- Energy associated with a dislocation because of presence of stresses is proportional to square of Burger's vector length. Thus dislocations, at least of same nature, tend to stay away from each other.
- Dislocations are, thus, two types – full and partial dislocations. For *full dislocation*, Burger's vector is integral multiple of inter-atomic distance while for *partial dislocation*, it is fraction of lattice translation.

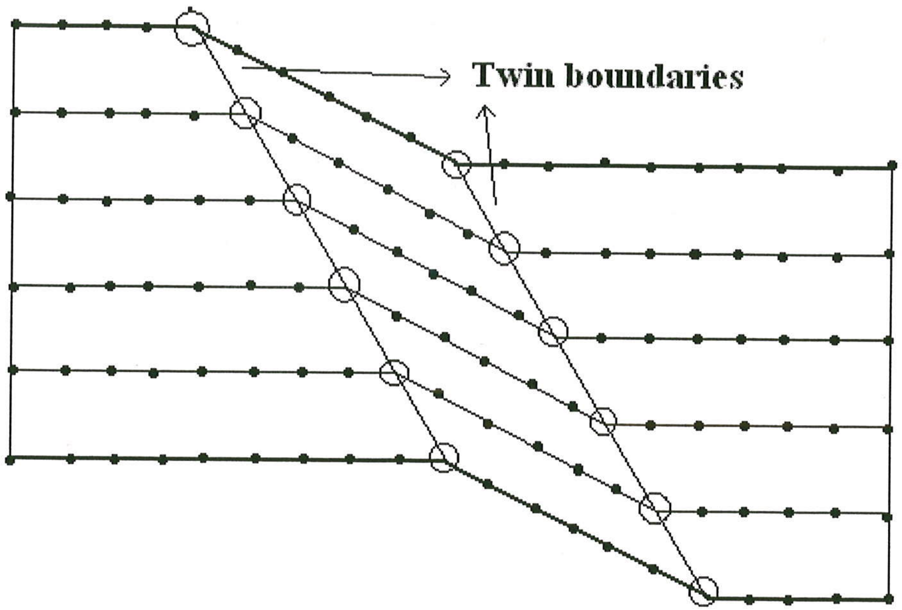
Interfacial defects

- An interfacial defect is a 2-D imperfection in crystalline solids, and have different crystallographic orientations on either side of it.
- Region of distortion is about few atomic distances.
- They usually arise from clustering of line defects into a plane.
- These imperfections are not thermodynamically stable, but meta-stable in nature.

E.g.: External surface, Grain boundaries, Stacking faults, Twin boundaries, Phase boundaries.

Interfacial defects (contd…)





Bulk *or* Volume defects

- Volume defects are three-dimensional in nature.
- These defects are introduced, usually, during processing and fabrication operations like casting, forming etc.

  E.g.: Pores, Cracks, Foreign particles

- These defects act like stress raisers, thus deleterious to mechanical properties of parent solids.
- In some instances, foreign particles are added to strengthen the solid – dispersion hardening. Particles added are hindrances to movement of dislocations which have to cut through or bypass the particles thus increasing the strength.

Atomic vibrations

- Atoms are orderly arranged, but they are expected to vibrate about their positions where the amplitude of vibration increases with the temperature.

- After reaching certain temperature, vibrations are vigorous enough to rupture the inter-atomic forces casing melting of solids.

- Average amplitude of vibration at room temperature is about 10^{-12}m i.e. thousandth of a nanometer.

- Frequency of vibrations is the range of 10^{13} Hz.

- Temperature of a solid body is actually a measure of vibrational activity of atoms and/or molecules.