

Class 5: Strengthening Mechanisms



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PRIME Modules

Project-based Resources for Introduction to Materials Engineering

Memory metals are strengthened to prevent plastic deformation during use.

Self expanding stents have a large elastic strain. That is, they can undergo large changes in shape without plastic deformation.

This allows the stent to expand to fill the artery and be elastic enough to flex and change shape as the artery pulses and bends.

To increase the amount of elastic strain possible, the memory metal is strengthened to increase the yield stress and make it harder for plastic deformation to occur.



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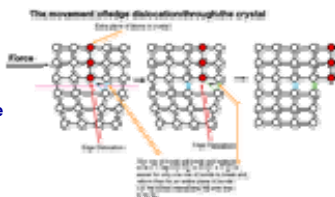
The key to limiting plastic deformation is to prevent dislocations from moving.

Dislocation motion (slip) is what causes plastic deformation.

To minimize plastic deformation, a material must be processed to make it harder for dislocations to move.

The main types of strengthening mechanisms are:

1. Strain hardening
2. Solid solution strengthening
3. Grain size reduction



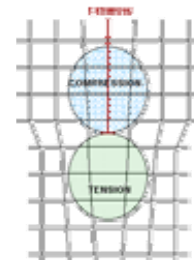
http://www.ic.arizona.edu/ic/mse257/class_note/disclocation.html

A dislocation creates strain in the surrounding lattice.

Due to the extra half plane of atoms that makes up a dislocation, the lattice around a dislocation is in compression (the extra row of atoms push the others outward).

The lattice above or below a dislocation is in tension (the atomic bonds are stretched in order to line up).

If two dislocations are moving on the same slip plane, similar strain fields would repel and opposite strain fields would attract.



<http://www.uccs.edu/~tchriste/courses/PHYS549/549lectures/defects.html>

1) In strain hardening, dislocations are created and limit the motion of other dislocations

In **strain hardening**, a material is physically deformed (strained). This process creates dislocations.

One example of a strain hardening is **cold working**. A sample is mechanically deformed at temperatures significantly below the melting temperature.

The strain fields surrounding all the dislocations interact, preventing the dislocations from moving around.

2) In solid solution strengthening, the strain fields around point defects limit dislocation motion.

Point defects also have strain fields surrounding them.

- Interstitials put the lattice around it in compression.
- Vacancies put the lattice around it in tension.
- Substitutional atoms can cause tension or compression depending on the relative size of the substitutional atom.

See Callister Figures 7.15 & 7.16

The strain fields around a point defect can cancel out the strain field around the dislocation. If this occurs, the dislocation will be pinned at the point defect (won't be able to move away).

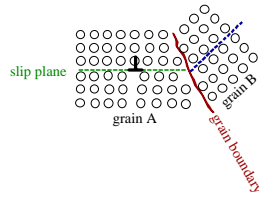
Therefore, increasing the presence of point defects limits dislocation motion (makes plastic deformation harder).

3) Grain boundaries trap dislocations.

A dislocation moves by creating a new bond with the next row of atoms in line.

In polycrystalline materials, grain boundaries exist. Across these boundaries, the line up of the atoms is disrupted.

Dislocations become trapped at the grain boundaries. They can not move across because there is not a next row of atoms that is properly lined up.

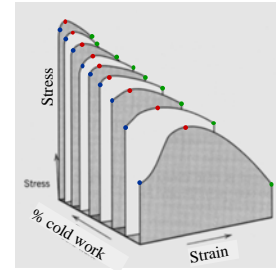


Adapted from Fig. 7.12, Callister 6e. (Fig. 7.12 is from *A Textbook of Materials Technology*, by Van Vlack, Pearson Education, Inc., Upper Saddle River, NJ.)

The strengthening mechanisms increase yield stress and tensile strength and decrease ductility.

Limiting dislocation motion causes the yield stress and tensile strength to increase. That is, it takes a greater force to get dislocations to move.

Ductility is decreased due to the fact that dislocations are not moving around. There is no plastic deformation taking place.



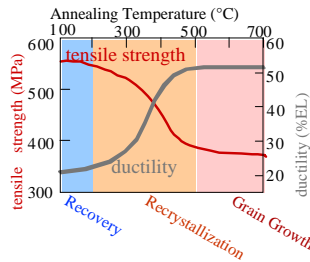
Adapted from Fig. 7.18, Callister 6e. (Fig. 7.18 is from *Metals Handbook: Properties and Selection: Iron and Steels*, Vol. 1, 9th ed., B. Bardes (Ed.), American Society for Metals, 1978, p. 221.)

The strengthening effect can be removed through annealing

In annealing, high temperatures allow atoms to move around (diffuse).

The number of defects reduce as the atoms find proper lattice sites.

- **Recovery:** Dislocation density reduces minimizing the effect of strain hardening
- **Recrystallization:** Defect free grains form within in the crystal
- **Grain growth:** Grain size increases (number of grain boundaries goes down)



Adapted from Fig. 7.20, Callister 6e. (Fig. 7.20 is adapted from G. Sachs and K.R. van Horn, *Practical Metallurgy, Applied Metallurgy, and the Industrial Processing of Ferrous and Nonferrous Metals and Alloys*, American Society for Metals, 1940, p. 139.)

In summary, materials can be processed to increase the resistance to plastic deformation.

Self expanding nitinol stents need a large range of elastic deformation to allow them to expand to fill an artery and to flex with the artery.

The stress that results onset of plastic deformation can be increased through processing.

The main strengthening mechanisms are strain hardening, solid solution strengthening, and grain size reduction.



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