Module #19b

Upper Yield Points Caused by Solutes (i.e., Strain Aging)

READING LIST

►DIETER: Ch. 6, Pages 201-203

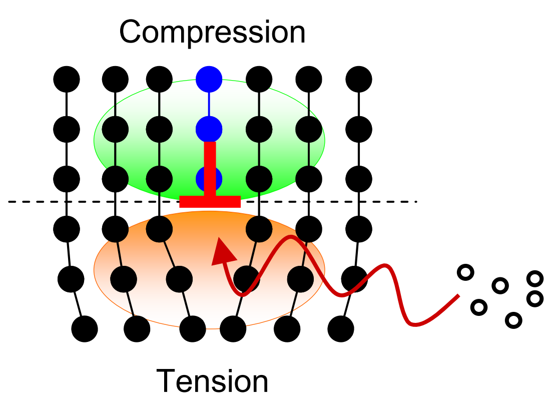
- Reed-Hill and Abbaschian, 3rd Edition, pp. 288-298.

Upper Yield Point Formation Due to Solutes

Cottrell-Bilby Model for Yield Point Formation
(i.e., solute diffusion)

- *Solute atoms will preferentially segregate to the distorted regions near the dislocations* such that the total elastic strain can be minimized (i.e., solutes will move to locations that minimize the distortion of the lattice caused by their presence).

- This segregation of solutes *results in the formation of solute atmospheres* wherein solute atoms will tend to accumulate in the stress field of the dislocation.

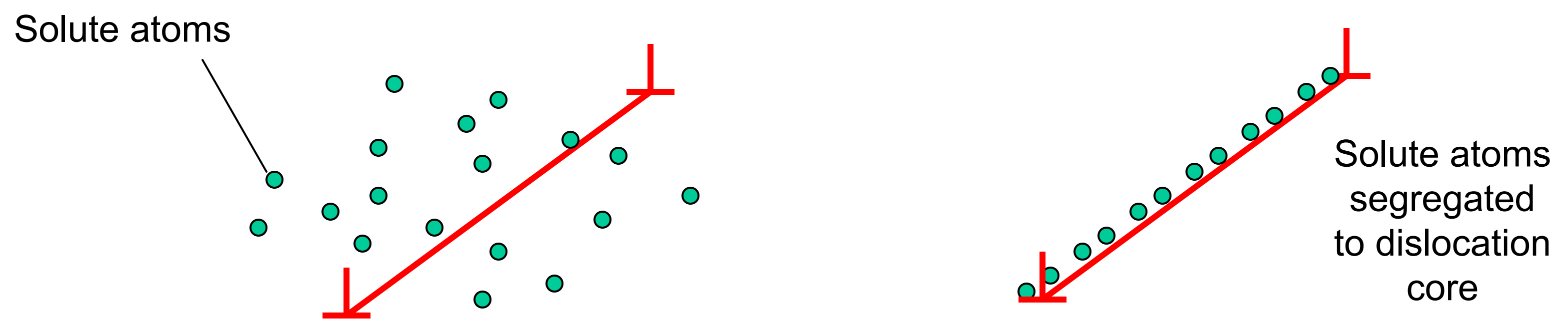


- At elevated temperatures, diffusion processes can become more significant, which results in increased mobility for the solute atoms.

- Under these conditions, *solute atmospheres can move along with the dislocation line in order to maintain a minimum energy state*. Recall: “You studied this in Physical Metallurgy.”

- Diffusion of solutes, within a specific temperature-strain rate range, restricts dislocation motion because the dislocations must “drag” the solute atmospheres along with them.

- The drag stress is directly related to the dislocation velocity in that solute atmospheres will tend to lag behind the dislocations, thus slowing them down.



- Dislocation motion will be restricted until the applied stress is becomes large enough to "break the dislocations free" from the solute atmospheres.

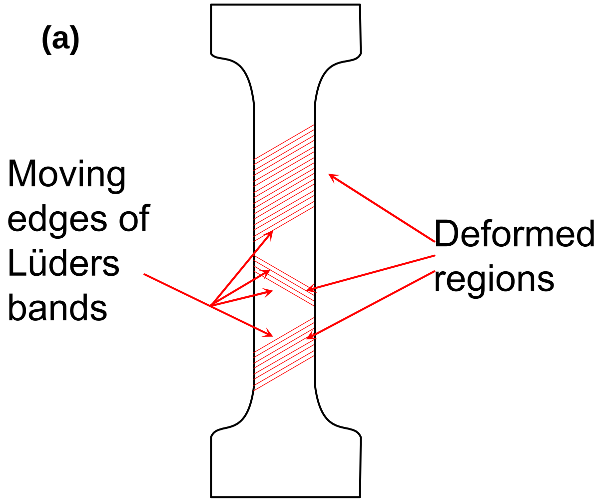
- At this point, slip can occur at a lower stress.

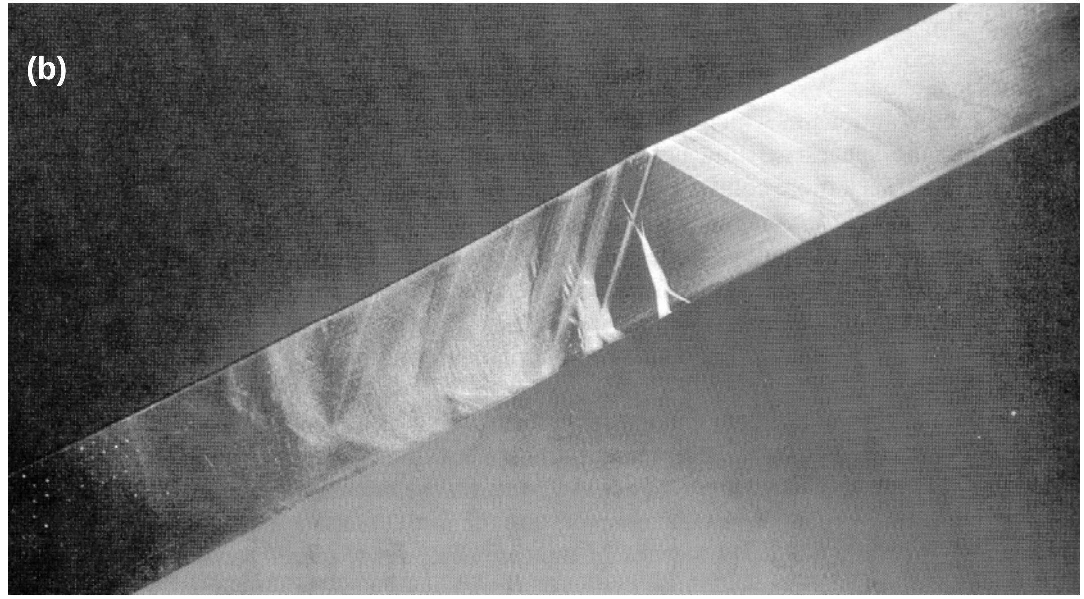
- The breakaway of dislocations from solute atmospheres is in effect analogous to an increase in the density of mobile dislocations (ρ_m).

- The number of mobile dislocations suddenly increases at breakaway.

- Those (now mobile) dislocations can move freely without a significant increase in stress until the dislocation density is high enough for regular work hardening to occur.

- In that region where σ remains relatively constant with increasing ε, we often see *Lüders bands*.





[J.A. Schey, Introduction to Manufacturing Processes, 3rd Edition, (McGraw-Hill, 2000) p. 258]

- Lüders bands represents regions of non-homogeneous deformation where localized slip has occurred.
- Once formed, they will propagate through the test sample.
- The figures show: (a) Lüders band development in a tensile specimen. (b) Actual Lüders bands in a mild steel strip after tensile deformation.

Lüders bands

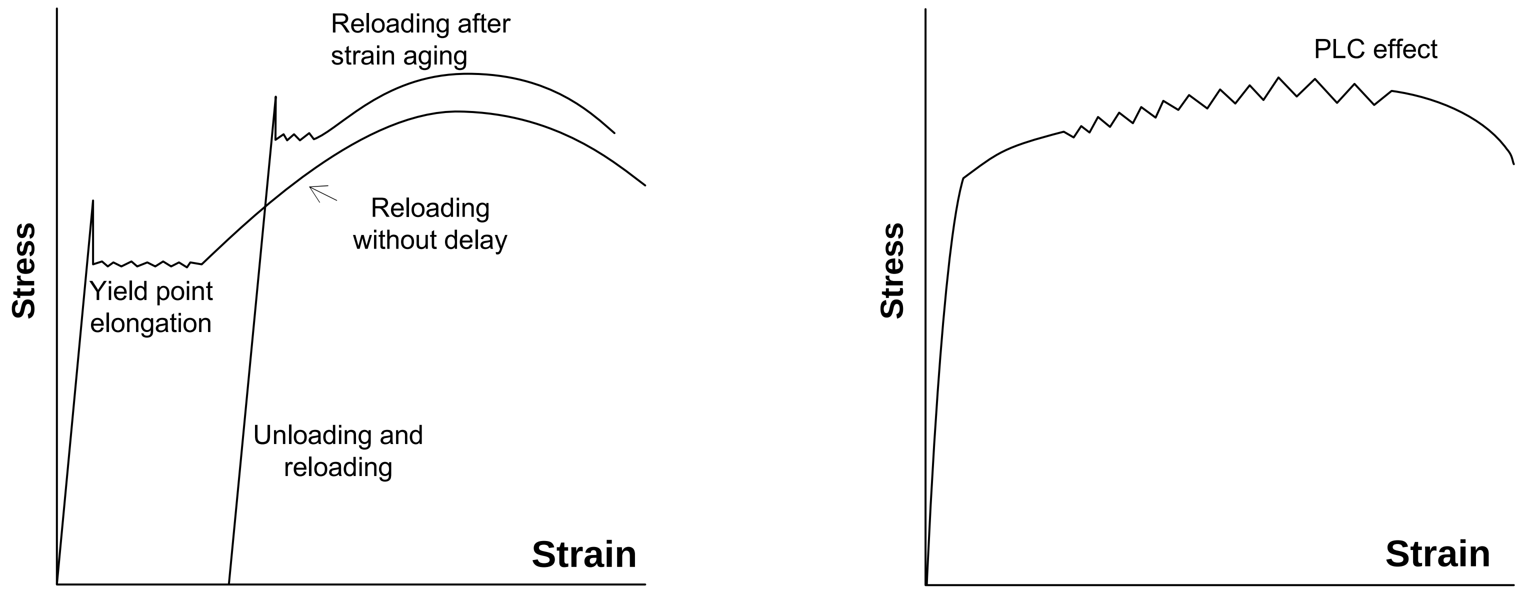
- *Lüders bands* mar the surface finishes of materials leading to surface roughness and unsightly surfaces. This phenomenon is particularly undesirable in metalworking operations.

- Discontinuous yielding in the form of sharp upper yield point formation and Lüders bands is typical of steels but has also been observed in some other materials (particularly BCC materials… I wonder why).

- The surface roughness is a result of localized plastic deformation. It is undesirable in engineering practice.

Lüders bands

- This phenomenon can be overcome by straining materials beyond the Lüders strain region prior to immediate forming.
- This essentially eliminates the upper yield point and the problems that are associated with it.
- Waiting before subsequent deformation allows the solutes to diffuse back to the dislocations, re-pinning them, leading to a reappearance of the yield point.
- You can see what I mean from figure on the next slide.



Schematic illustrations of (a) upper yield point formation characteristic of static strain aging and (b) serrated yielding characteristic of dynamic strain aging.

- In some instances, serrated stress-strain curves are observed as above illustrated in Figure (b). Serrated yielding is also known as the Portevin-LeChatelier (PLC) effect.

- PLC occurs when the solutes responsible for yield point formation are mobile enough to continuously diffuse to and pin dislocations during deformation.

- Each serration represents repeated pinning and breakaway of dislocations from solute atmospheres.

Portevin-LeChatelier (PLC) effect

- Serrated yielding has been reported in a number of engineering alloy systems including most steels ("blue brittleness"), titanium alloys, nickel base superalloys, and many commercial aluminum alloys. It has also been observed in some ceramics and ionic crystals.
- The PLC effect, which usually occurs at intermediate temperatures, has been reported to decrease the ductility of materials and to increase the work hardening rate in the regime where it occurs.
- Other manifestations of the PLC effect include a negative value of the strain rate sensitivity and a plateau or peak in the temperature dependence of the yield (or flow) stress.